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RESEARCH

Quality evaluation of land reclamation in mining area based on remote sensing

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Abstract

Several deficiencies exist in the present evaluation of land reclamation quality in mining areas. These include the absence of an established set of evaluation index systems and standard acceptance criteria, as well as the use of traditional sampling techniques, which are costly and in efficiency, and time-consuming. Compared with the traditional sampling survey methods, remote sensing has the advantages of a wide detection range, diverse information collection, multiple data-acquiring strategies, high speed, and short cycle. In this study, we used the Xinzhuang coal mining field in Yongcheng, Henan Province as an example to extract information and invert surface parameters using remote sensing techniques, based on national and local reclamation regulations and standards. Subsequently, using remote sensing, we constructed an index system for evaluating land reclamation quality in three aspects: reclaiming project quality, soil quality, and ecological benefits. Through the grading standards of evaluation indicators and quantitative remote sensing models, we determined the extracted information on the area of indicators, roads, ditches, soil moisture, organic matter, and ecological benefits after reclamation. Based on this, we established a quality evaluation model for mining land reclamation using an improved index and method. The evaluation units were divided, and the weight of the evaluation index was determined using the analytic hierarchy process and data envelopment analysis (AHP–DEA) method. The land reclamation quality in the study area was comprehensively evaluated, field accuracy was verified, and the results were analyzed. The results show that, except for the removal of roads, houses, and fishponds in the study area, all 13 evaluation units achieved a score of 60 points or higher. The quality of reclamation met the standards, and the evaluation results were consistent with the conclusions of the field investigation and project acceptance report, demonstrating the reliability and feasibility of the method developed in this study. The research results will provide technical support for the scientific evaluation of land reclamation quality.

Keywords Remote sensing · Mining area land · Reclamation quality · Evaluation · Soil

1 Introduction

Coal resources are increasingly mined annually, which inevitably collapses, pollutes, and damages land resources, due to regular excavation. Continuous exploitation of mineral resources has caused long-term and serious negative impacts on land resources and the ecological environment in and around mining areas (Fernández-Caliani 2021). Moreover, continuous mining hinders the sustainable development of these areas. Therefore, land reclamation in mining areas is important to realize economically, socially, and ecologically sustainable development. It can not only improve the utilization of land resources in the mining areas, but also protect the environment, restore the ecological balance, and promote the ecological virtuous circle of mining areas (Worlanyo et

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al. 2021; Xu 2019). Land reclamation, especially in mining areas, has always been promoted by countries worldwide. To improve the quality, technology, and efficiency of land reclamation, several countries have investigated the associated laws and regulations, technical standards, management methods, and scientific research. United States, Germany, and the former Soviet Union Countries have undertaken land reclamation work efficiently. These countries have designed long-term reclamation plans to formulate practical land reclamation laws/regulations; additionally, their research on the techniques for land reclamation are relatively advanced (Du et al. 2018; Hu et al. 2018).

Remote sensing technology, which emerged in the 1960s, rapidly developed into a comprehensive technology for Earth observations. It has significant applications in monitoring the environment, guiding ecological restoration, and managing land resources in mining areas (Avtar et al. 2020). For instance, the coal-mine ecological index (CMEI) was used to evaluate and detect the spatiotemporal changes in the ecological environment quality of the Ningwu Coalfield from 1987 to 2021 (Nie et al. 2022). By using a combination of a conventional classification method with the fuzzy logic reasoning method for decision support to classify the remote sensing images of a mining area in Heng County, Guangxi, Chen et al. (2010) considerably improved the classification accuracy. Moreover, Ma et al. (2017) used ETM, SPOT-6, and other remote sensing images of Jianshui County in Yunnan to interpret the geological disasters in Jianshui County and provided a reasonable strategy for field exploration. Şimşek et al. (2021) studied two coastal reclamation areas in Istanbul (Yenikapı, Maltepe) and used artificial neural networks (ANN) to investigate the predictability of changes in the thermal environment after landfilling. Bandyopadhyay et al. (2020) investigated the impact of reclamation on Technosol (defined as the artificial soil produced by reclaiming waste rocks of mines) as basic ecosystem development. Thakur et al. (2022) used remote sensing and GIS datasets to analyze land-use changes in the Sohagpur and Bishrampur coal mines, located in central India, over the last 20 years (2001 to 2020). Hengkai et al. (2020) used regression analysis to construct a normalized difference vegetation index (NDVI) conversion equation for HJ-1B CCD and LandsatTM/OLI data and used root mean square error to evaluate the accuracy of the conversion equation to reduce the NDVI error caused by sensor differences between different data sets. Abuzaid et al. (2021) used 29 parameters to generate and calculate four soil quality indicators (chemical properties, physical properties, fertility, and environment).

Presently, research on the evaluation of the quality of land reclamation using remote sensing is still in its preliminary stage. Most research on the evaluation of mining area reclamation is based on landscape patterns, soil quality, land remediation, and quality of farmland engineering in reclamation areas. The Pingshuo opencast coal mining area on the Loess Plateau of Shanxi Province provides a scientific basis for optimizing the landscape pattern and building ecological security patterns (Xu et al. 2021). Wang et al. (2020) took the Yimin open pit mining area as a case study. The proposed landscape key area recognition model enriched the foundations for ecological planning and ecological security pattern construction in order to support ecological protection and restoration in semi-arid steppe areas affected by coal mining. Ye et al. (2019) took a mining area in the North China Plain as its study area. The ecological environmental costs of the mine site are accounted for separately with the help of the resource depletion cost measurement model, the ecological service value method and the engineering volume method. Wang et al. (2016) used Pingyi No. 2 mining field as the research area, selected seven evaluation indicators, including ground slope, irrigation condition, soil texture, soil thickness, damage degree, the degree of soil erosion, and traffic condition, improved the Iterative Dichotomiser 3 decision tree algorithm, and established a land suitability evaluation method for evaluating mining reclamation based on the improved decision tree. Moreover, Na et al. (2021) comprehensively analyzed the criteria and evaluation factors related to arable land quality evaluation and suggested that the arable land health in mining areas could be evaluated using 12 indicators, such as soil organic matter content, soil pH, and slope.

However, evaluating the quality of land reclamation in mining areas has the following shortcomings: absence of a recognized evaluation index system and uniformly accepted criteria for standardization and feasibility (Huang 2020), and the use of traditional sampling survey methods, which have the disadvantages of high cost, low efficiency, and long duration (Chen 2017; Wang 2019). Compared with the traditional sampling survey method, remote sensing technology provides the advantages of a wide detection range, diverse information, multiple sources of information, fast speed, and a short cycle (Li et al. 2021). Moreover, it has only been applied for the dynamic monitoring of mining areas, mainly including the spectral inversion of land-use change, vegetation cover change, water body change, and soil organic matter in mining areas (Hu et al. 2019; Zhang 2020). Vorovencii (2021) used Landsat images from 1988, 1998, 2008, and 2017 to map surface mining and reclamation areas in the Nine Valleys mining area in Romania, and tracked changes over time using post-classification comparison (PCC) techniques. Considering the Xinzhuang coal mine in Yongcheng, Henan Province, as an example in the present study, we applied remote sensing technology to extract information and invert the surface parameters

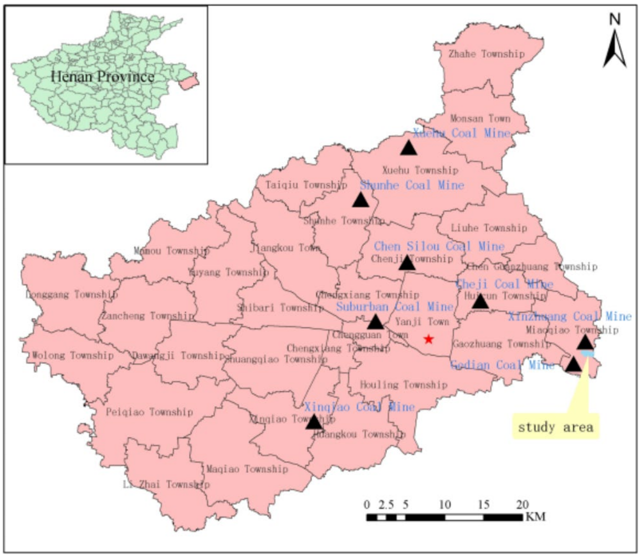

Fig. 1 Geographical location of the study area

of the selected mining area; additionally, we built a set of mining land reclamation parameters suitable for remote sensing from three aspects: reclaiming project quality, soil quality, and ecological benefits. Based on this, a quality evaluation model for the reclamation of mining land using an improved index and method was established, and land reclamation quality was comprehensively evaluated in the study area with an aim of providing strong support for the scientific evaluation of the quality of land reclamation in mining areas.

2 Materials and methods

2.1 Study area

The Xinzhuang coal mine in Yongcheng City, Henan Province (115°58–116°39 E, 33°42–34°18 N, Fig. 1), at an altitude of 33 m, was selected as the study area. It is located at the eastern and northern borders of Anhui Province and lies on the northern part of the Huaihe alluvial plain. The study area was originally the collapse site of the Xinzhuang coal mine in the Henan Shenhuo Group. The height difference across the terrain is 9 m. The highest point on the ground is 5 m from the lowest point, consequently, forming a large area of water. The mining area witnesses a warm temperate monsoon semi-humid climate with an annual average temperature of 14.2 °C and an annual average evaporation of 1807.4 mm. The total area of the region is 93.31 km^2. The soil comprises clay, sub-clay, and medium-fine silt. The farmland soil is suitable for the growth of various crops, such as wheat, corn, and cotton. After land reclamation, the land cultivation requirements were met.

Table 1 Data sources of the study

Types of data	Name of data	Date	Scale or precision	Sources
Raster data	WorldView-2 image map	December 6, 2016	0.5 m resolution	Beijing Lanyu Fangyuan Information Technology Co., Ltd.
Non-spatial data	Field soil quality sample sampling data	November 19, 2016	—	On-site sampling
	Natural and socio-economic status	2010–2016	—	Related departments of City Yongcheng
Vector data	Pre-project, design, and as-built drawings of project management in the study area	Project time is consistent	1: 2000	Shenhuo Group Co., Ltd. Henan province

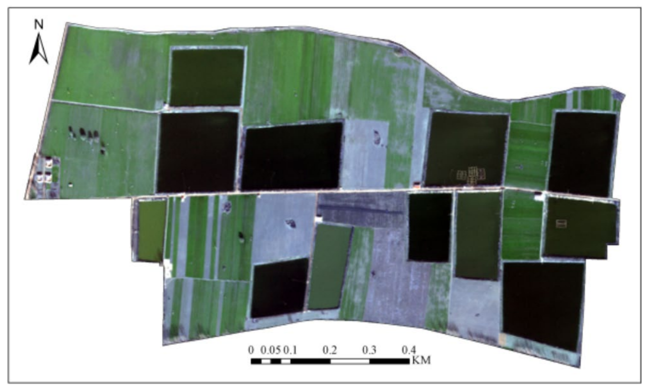

Fig. 2 Remote sensing image map of the study area

2.2 Data sources

This study mainly used WorldView-2 data and ASD (Analytica Spectra Devices., Inc) hyperspectral data. The front plan of governance, governance design drawings, as-built drawings, completion reports, final accounts, supervision reports, and other auxiliary soil sampling point data were provided by Henan Shenhuo Group Co., Ltd. that were combined the field surveys of hydrological factors, vegetation, other natural conditions, and socioeconomic statistics (Table 1).

2.3 Data processing

(1) Processing of high-resolution satellite imagery data.

We mainly used previous WorldView-2 data to extract engineering information. A remote sensing image map of the study area is shown in Fig. 2. The U.S. WorldView-2 satellite, which was launched on October 6, 2009, is a commercial satellite developed by Digitalglobe, and operates in a sun-synchronous orbit at a height of 770 km. It provides multispectral images of 1.8 m resolution other panchromatic images with a finer resolution (0.5 m) for various applications. In contrast to WorldView-1 and other satellites, WorldView-2 can not only provide four common standard spectral bands (red band: 630–690 nm, green band: 510–580 nm, blue band: 450–510 nm, and near-infrared band: 770–895 nm), but also provide the coastal band (400–450 nm), yellow band (585–625 nm), red fringe band (7055–745 nm), and near-infrared 2 band (860–1040 nm). Moreover, the WorldView-2 satellite has made significant advances in terms of accuracy, and its precision has reached 0.5 m.

Furthermore, to extract the engineering information, we used visual interpretations. The visual interpretation of the land types obtained by the study is shown in Fig. 3.

(2) Soil sampling and analysis.

To accurately reflect the organic matter content of the soil in the study area, soil was collected using a hand-held global positioning system device through a plum-shaped distribution method. In total, 33 surface soil samples were collected from a depth of 0–20 cm. Figure 4 shows the distribution of the sampling sites. The soil samples were naturally dried, plant residues and debris were removed, and the samples were mixed, ground, and sieved with a 20-mesh sieve. Each sample was divided into two parts: one part was subjected to soil analysis, including the determination of the organic matter content using the potassium dichromate method, and pH by the Kjeldahl method; the other part was used to obtain hyperspectral soil data by indoor ASD hyperspectral analysis.

(3) Measurement of soil hyperspectral data.

The soil hyperspectral data were measured using a FieldSpec 3 spectrometer (ASD, USA). The spectral range was 350–2500 nm, spectral resolutions for the 350–1000 nm and 1000–2500 nm bands were 3 and 10 nm, respectively, and the sampling interval was 1.4 nm. The re-sampling interval was 2 nm. The soil sample was filled in a container (diameter = 10 cm, thickness = 2 cm) up to the brim and excess soil was scraped with a straightedge. The probe of the spectrometer (15 cm in height), with a view field of 25°, was placed vertically on top of the soil sample surface. A 50 W halogen lamp with a spectrometer was used as a light source. It was placed 50 cm from the soil sample at an irradiation angle of 45°. Considering that the flatness of the soil sample surface and soil particles may influence the measurement results, the spectra of each soil sample were measured in four directions (three turns, 90° each time, and five spectral curves in each direction), for a total of 20 curves. The average value was considered as the spectra of the soil sample.

(4) Spatial interpolation of the soil quality parameters.

Fig. 3 Visual interpretation of land type

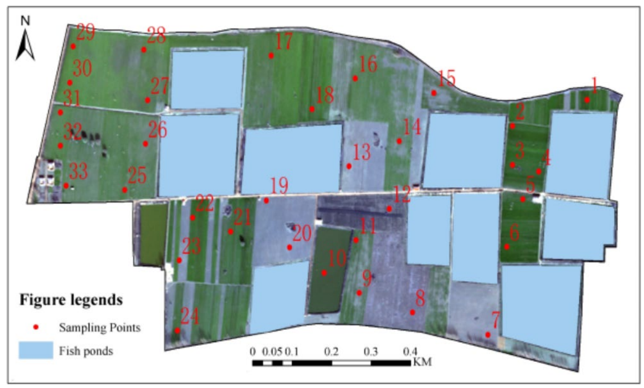

Fig. 4 Distribution of the sampling points in the study area

Hyperspectral inversion was used to predict the point shape of the study area, while quality evaluation was used to evaluate the entire study area. However, soil organic matter, total nitrogen, pH, and soil thickness are difficult to invert using hyperspectral inversion. Therefore, we used the kriging method provided by the 3D Analyst tool of ArcGIS10.2 for interpolating and calculating the soil quality parameters of the entire study area. Further, ordinary kriging interpolation was performed for the four soil quality indicators (total nitrogen content, effective soil thickness, organic matter content, and pH) using the collected soil data. Additionally, the spherical function of the semi-variance model was used to obtain the spatial distribution of each indicator, as shown in Figs. 5, 6, 7 and 8.

2.4 Evaluation indicator system

Generally, the land reclamation quality is evaluated for specific utilization types, and selecting appropriate evaluation indicators is an important component of this evaluation process (Bandyopadhyay et al. 2020).

According to the "Regulations for the Preparation of Land Reclamation Program" (TD/T1031.1–2011)," "Land Development and Consolidation Standards (TD/T1013–2000),"

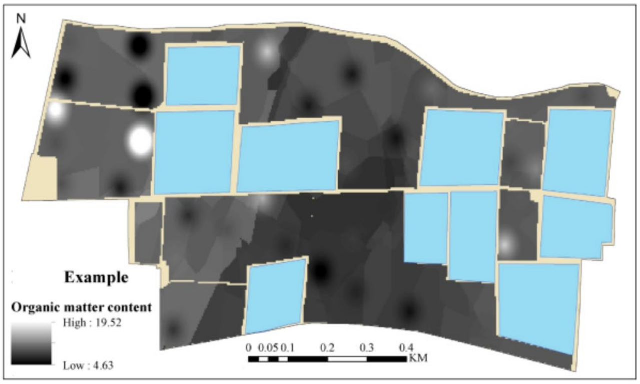

Fig. 5 Spatial distribution of soil organic matter in the study area

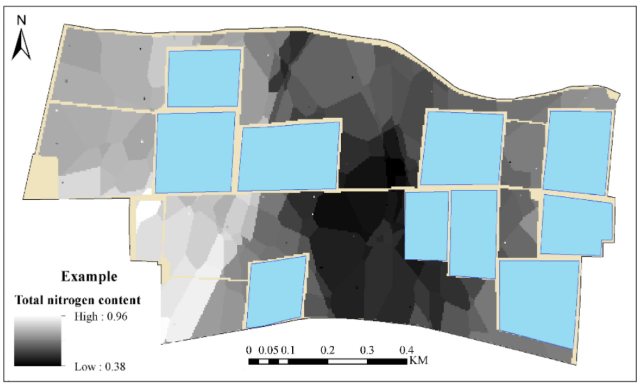

Fig. 6 Spatial distribution of soil total nitrogen in the study area

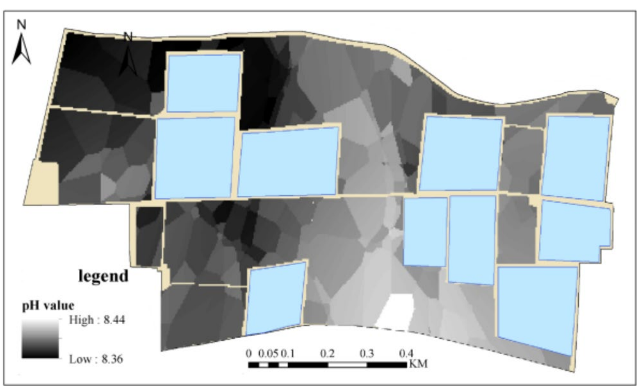

Fig. 7 Spatial distribution of soil pH value in the study area

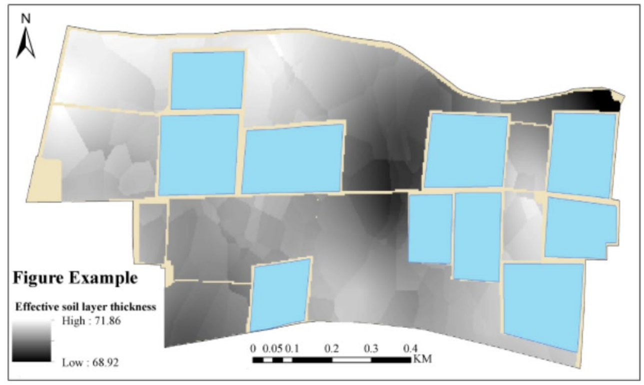

Fig. 8 Spatial distribution of soil layer thickness in the study area

Table 2 Evaluation indexes of mining land reclamation quality

Type of indicators	Evaluation factor
Engineering quality	Proportion of cultivated land area after reclamation
	Field road information
	Slope
Soil quality	Total nitrogen content
	Effective soil thickness
	Organic matter content
	pH value
Ecological service value	Food production value
	Improved soil value
	Maintain nutrient cycle value

"Land Reclamation Regulations (2011)," "Agricultural Land Quality Classification," and technical specification documents, such as the "Regulations (GB/T28407–2012)," and previous relevant research (Abuzaid et al. 2021; Na et al. 2021), the evaluation indicators were selected. Subsequently, they were combined with the geometric information extracted through remote sensing and with the hyperspectral inversion parameters in the natural and socioeconomic status of the study area. Further, based on the soil quality, engineering quality, and ecological service value, we selected independent and complementary evaluation factors to build a land reclamation quality index system (Table 2).

2.5 Land reclamation quality evaluation

2.5.1 Evaluation method

The evaluation of land reclamation in mining areas mainly includes the index summation, fuzzy comprehensive evaluation, and extension methods. Each method has some advantages and disadvantages. However, the index sum method not only comprehensively considered the importance of each index, but also quantified the attributes of the participating indices, which is rational and logical. Combined with the data characteristics of this study, the index sum method was used to evaluate the quality of the mining area. The formula for the index sum method is as follows.

$$R(j) = \sum_{i=1}^{n} w_i s_i \quad (1)$$

where R (j) represents the score of the evaluation unit j, W_i is the weight value of the i^{th} indicator score, and S_i is the score value of the i^{th} indicator.

2.5.2 Evaluation process

(1) Division of the Evaluation Units.

The evaluation unit is the minimum spatial unit of the land reclamation quality evaluation object and is the basis of the land reclamation quality evaluation. The division of the evaluation unit plays a key role in the accuracy and availability of the evaluation results (Li et al. 2016). Further, the application of the evaluation area plays a decisive role in dividing the evaluation units (Hu et al. 2020; Li et al. 2019; Li 2019). Using the characteristics of this study area along with the division of engineering governance, we used the plot method to divide the evaluation units; that is, the field roads in the study area were used to divide the evaluation units (Fig. 9). The plot method is more appropriate because the study area has a single land use type, the field road boundaries are evident, and only reclaimed cropland was studied.

(2) Evaluation Index Grading Standards.

According to the “Agricultural Land Classification Regulations,” “Agricultural Land Grading Regulations,” “Land Development and Consolidation Standards,” “Land Reclamation Quality Control Standards,” and other land reclamation acceptance criteria and procedures, we considered the actual situation of land reclamation in the district along with the acquired data of the study area to determine the grading standards for the evaluation index of land reclamation quality in the mining area (Table 3).

(3) Determination of the indicator weights.

Whether the weights of the evaluation indicators are practical directly determines the quality of land reclamation evaluation in mining areas. This can also affect the quality of land reclamation. The weights reflect the importance of the evaluation index in the evaluation system of the land reclamation quality. The greater the weight, the more important the corresponding evaluation index, the more information it can contain, and consequently, the stronger the ability to express the evaluation object. To ensure that the land reclamation quality evaluation in the mining area is more scientific and objective, scientific methods must be used to determine the weight. Presently, the weights in the land reclamation quality evaluation system of mining areas are determined mainly through techniques, such as the analytic hierarchy process (AHP), entropy weight method, and expert scoring method. According to the source and calculation method of different raw data, the main points of weight determination are summarized in the following three categories: subjective weighting, objective weighting, and subjective and objective comprehensive weighting methods. Currently, subjective weighting is the most advanced method, wherein experts with excellent experience can reasonably rank the weights of evaluation indicators according to the actual situation, thus, ensuring that the weights of the evaluation indicators are consistent with their actual importance. However, the disadvantage is that the weight determination is subjective and random, and thus, objectivity is poor. Commonly used subjective weighting methods are the Defeier method, AHP, and order relationship analysis. An objective weighting method can compensate for the drawbacks of the subjective weighting method. It is based on the amount of information in the original data and the degree of connection between them. The weight of each evaluation index was determined using the value of each evaluation index, and the magnitudes of the differences were determined. The greater the difference, the greater the weight of the evaluation index and vice versa. Although the objective weighting method avoids the shortcomings of the subjective weighting method, it mainly relies on mathematical theory and cannot consider the subjective intention of the decision-maker; therefore, the determined weight may differ from the actual situation. Moreover, the calculation method is more complicated. Commonly used objective weighting methods are the data envelopment analysis (DEA), maximum entropy technology, principal component analysis, and open grade methods.

Fig. 9 Map of the evaluation units in the study area

To make the distribution of weights more practical and scientific, and to balance subjectivity and objectivity, the subjective and objective comprehensive weighting method, also known as the combination weighting method, was applied. This weighting method considers the subjective preferences of decision-makers and reduces the subjective randomness of the interference of decision-making. In this study, the AHP–DEA combination weighting method was used to determine the index weights. The specific formula is as follows:

$$w_i = \lambda\alpha_i + (1-\lambda)\beta_i \ (0 \leqslant \lambda \leqslant 1) \tag{2}$$

where, w_i *is* the combined weight of indicator i, α_i and β_i are the objective and subjective weight values, and λ and $(1-\lambda)$ are the objective and subjective preference

Table 3 Grading standards and corresponding scores of the land reclamation quality evaluation indicators in the mining area

Criteria layer	Evaluation indicator	Classification criteria	Corresponding score
Engineering quality indicators	Cultivated land area after reclamation (%)	(90, 100)	100
		(70, 90)	80
		(50, 70)	60
		(0, 50)	40
	Field road accessibility	Road access	100
		There is a road but its width is insufficient to pass machinery	80
		There are roads, but only people can pass	60
		Roads are completely absent	40
	Slope (°)	(0, 2)	100
		(2, 5)	80
		(5, 7)	60
		> 7	40
Soil quality indicators	Total nitrogen content (g/kg)	≥ 1.5	100
		(1, 1.5)	80
		(0.75, 1)	60
		(0, 0.5)	40
	Effective soil thickness (cm)	(70, 100)	100
		(60, 70)	80
		(40, 60)	60
		(0, 40)	40
	Organic matter content (g/kg)	≥ 30	100
		(20, 30)	80
		(6, 20)	60
		(0, 6)	40
	pH value	(6.0, 7.0)	100
		(5.5, 6.0] or (7.0, 7.5)	80
		(5.0-5.5) or (7.5-8.0)	60
		< 5.0 or > 8.0	40
Ecological service value indicators	Food production value (10^4 Yuan)	≥ 20	100
		(15, 20)	80
		(10, 15)	60
		(0, 10)	40
	The improved soil value (10^5 Yuan)	≥ 8	100
		(6, 8)	80
		(4, 6)	60
		(0, 4)	40
	Maintenance nutrient value (10^8 Yuan)	≥ 8	100
		(6, 8)	80
		(4, 6)	60
		(0, 4)	40

coefficients. This study considered the AHP and DEA to be more moderate in reflecting the subjective and objective preferences of the decision-makers, respectively; thus, the value of λ was set as 0.5. The combined weight of the indicator calculated using this method is given as:

$$w_i = 0.5\alpha_i + 0.5\beta_i$$

where w_i is the combined weight of the indicator i, and a_i and β_i are the objective and subjective weight values, respectively.

Table 4 Weights of the evaluation indexes

Evaluation indicator	Weights		
	AHP Method	DEA Method	AHP-DEA Method
Cultivated land area after reclamation	0.1138	0.0926	0.1032
Field accessibility	0.0876	0.0756	0.0816
Slope	0.1169	0.1201	0.1185
Total nitrogen content	0.1180	0.0682	0.0931
Effective soil thickness	0.1064	0.0908	0.0986
Organic matter content	0.1139	0.1247	0.1193
pH value	0.0838	0.1046	0.0942
Food production value	0.0980	0.1186	0.1083
The improved soil value	0.1029	0.1171	0.1100
Maintain nutrient cycle value	0.0587	0.0877	0.0732

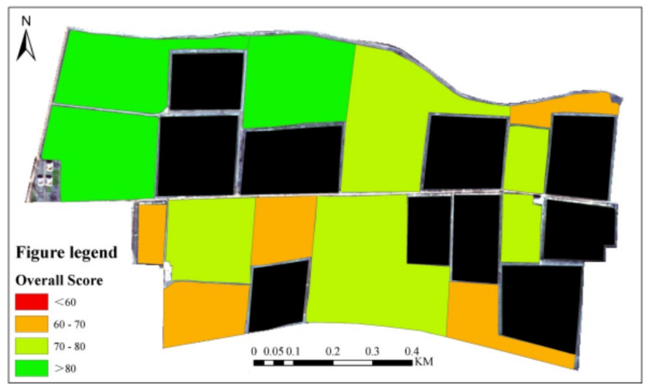

Fig. 10 Results of comprehensive evaluation in the study area

The weight of the land reclamation quality evaluation index of the mining area was calculated according to Eq. (2), and the results are shown in Table 4.

3 Results and analysis

3.1 Evaluation results

According to Eq. (1) and in combination with the index weight distribution, we calculated the scores of each evaluation unit using the ArcGIS software. Based on the acquired results, the grade map and score table of the land reclamation quality evaluation results in the study area were obtained, as shown in Fig. 10; Tables 5 and 6.

Figure 10 shows that, except for the removal of roads, houses, and fish ponds in the study area, the 13 evaluation units reached 60 points or higher, thus, meeting the standards. Moreover, all three evaluation units to the northwest of the study area reached above 80 points and the effect of reclamation was the highest. The scores of other evaluation units in the northeast, southeast, and south were relatively low, possibly due to the poor road accessibility of the

Table 5 Evaluation units scores

Evaluation unit	Score
1	87.85
2	68.07
3	77.47
4	68.24
5	69.87
6	77.45
7	68.67
8	70.66
9	70.66
10	65.01
11	77.30
12	80.10
13	81.66

Table 6 Evaluation grades

Score interval	Evaluation grade
<60	Does not meet the standards
60–70	Meets the standards
70–80	Good
>80	Excellent

two evaluation units relative to other units. The evaluation results were consistent with the conclusions of the field survey and the project acceptance report, illustrating the reliability and feasibility of the method developed in this study.

3.2 Discussion and analysis

The existing indicators for the evaluation of reclaimed land in mining areas were selected in a single way and could not comprehensively evaluate its quality. Based on the national and local reclamation regulations and standards, we considered data obtained by RS and GIS technology as important data sources, and we determined the ease of obtaining various indicators, and the magnitude of landmarks and significance. We selected the quality evaluation indicators for the reclaimed land in the study area from three aspects: engineering indicators, soil quality indicators, and ecological service value indicators, and determined a quality evaluation indicator system for the reclaimed land in the mine area.

The previous lack of a unified and standard method for determining the weights of indicators in the evaluation of reclaimed land in mining areas can affect the stability and accuracy of evaluation systems. Considering the complexity of the topography of different regions and the variability of land in mining areas, we established a standard and objective comprehensive quality evaluation system of indicator weights that considers the subjective intentions of decision-makers, and the relevance of information and weights in mathematical theory. Hierarchical analysis (AHP) and data envelopment analysis (DEA) were combined to determine the indicator weights, making the allocation of weights more reasonable and scientific, and achieving unity of subjectivity and objectivity. A comprehensive evaluation of the quality of reclaimed land in the study area was conducted following the sum-of-indices method, and a complete and effective rapid index system for evaluating the quality of reclaimed land in mining areas was constructed.

4 Conclusions

In this study, using the Xinzhuang coal mine as an example, we established a practical and feasible method for land reclamation quality evaluation in mining areas. The main conclusions drawn are as follows:

(1) Based on the existing national and local reclamation norms and technical standards, with reference to the relevant research results, and in combination with the characteristics of the study area, we constructed a land reclamation quality evaluation index system for the mining area regarding three aspects: soil quality (total nitrogen content, effective soil thickness, organic matter content, and pH value), engineering quality (the area of cultivated land after reclamation, the accessibility and slope of the field), and the value of ecological services (food production value, soil value improvement, and nutrient recycling value).

(2) Based on these characteristics, the study area was divided into 13 evaluation units. The AHP-DEA method along with the weighting method was used to determine the weight of the evaluation index. Based on this, index and method evaluation models were established to comprehensively evaluate the land reclamation quality in the study area. The results showed that all 13 evaluation units met the reclamation standards, and the three evaluation units to the west of the study area reached 80 points or higher. These results of the rehabilitation evaluation system were the highest, which was consistent with the field investigation results, thus, verifying the feasibility of the evaluation method proposed in this study. As land reclamation work in the Yongcheng mining area is common in Henan Province, it was selected as the study area. It showed strong representativeness and provided a scientific basis for selecting the quality evaluation index and determining the quality evaluation index system of reclaimed land in the mining area.

The quality evaluation of the land reclaimed from mines was studied, thereby providing, to some extent, a technical reference for quick and efficient evaluation of the quality of such lands. Mine reclamation land quality evaluation is a comprehensive and systematic project, that involves many disciplines, such as agronomy, remote sensing, GIS, and mathematics. The results obtained from the comprehensive evaluation of the land reclamation project in the Xinzhuang mine area in Henan Province through GIS and RS in this study can provide some support to the acceptance of the land reclamation project by the land department, but certain problems that require further research remain. The amount of data acquired was not sufficient. Due to the limited size of the study area, fewer soil samples were collected. If the study was conducted over a larger area and more soil sample data were collected, the accuracy of the prediction model could be increased. The evaluation of the quality of reclaimed land in mining areas requires further improvement. The evaluation system was only validated in the field at the Xinzhuang mine; therefore, the effectiveness of the evaluation in reclaimed land in other mining areas needs further validation and refinement.

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