DOI:10.13476/j.cnki.nsbdqk.2020.0078
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Analysis of the impact of coal mining on the ecological environment of the nature reserve

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Abstract:With the gradual attention of the state to the protection of natural ecological environment,the planning and layout of the nature reserve will overlap with some coal mine areas. In order to strengthen the construction of ecological civilization,it is necessary to study the impact of mining on the ecological environment of the nature reserve. Through the methods of GIS and RS,and evaluation of ecological protection index system,the differences and impacts of ecological environment changes before and after the planning of the nature reserve are analyzed. The results show that since 2002,the effect of water collection and artificial soil and water conservation measures on improving the ecological environment of vegetation are obvious,the dominant species of vegetation type in the overlapping area of coal mine and nature reserve have changed from grass vegetation to shrub vegetation,in which the area of arbor forest land has increased significantly,the vegetation coverage in the overlapping area has also increased considerably. The intensity of soil erosion has decreased year by year after mining the coal resources. Post-harvest hydraulic erosion intensity is mainly below mild,and the area of artificial soil and water conservation has increased significantly. The negative impact of the ground subsidence caused by coal mining on the ecological environment is less than the positive effect brought by artificial soil and water conservation measures,and it is generally developing in a more stable direction. The ecological protection status index increased from 32. 98 to 45. 94,and the change degree of ecological protection status in nature reserves is 12. 9≥10. The ecological protection status of the nature reserve improved significantly. On the basis of ecological environment protection and restoration measures in the nature reserve,coal mines need to further study the comprehensive impact of human activities on the ecological environment of the nature reserve.

Key words:coal mining;nature reserve;ecological environment;soil-water conservation;vegetation

Chinese Library Classification No.:X52 **Document Code**:A OSID:

In 1997,as the country proposed the development strategy of mineral resources in Western Development,the idea of green mining had been present. Due to the impact of natural resources mining on the natural environment, this concept has attracted attention. In recent years,with the continuous expansion of mining, the impact of mining on the ecological environment has also increased, which restricts the sustainable development of society. Nature reserves are the key areas for the pro-

Received:2020-04-06 **Revised**:2020-05-06 **Online publishing**:2020-05-08
Online publishing address:http://kns. cnki. net/kcms/detail/13. 1430. TV. 20200508. 1624. 002. html
Funds:National Key Research and Development Program of China(2017YFC0804100);Science and Technology Innovation Fund of Xi′an Research Institute of China Coal Technology & Engineering Group Corp(2017XAYZD012)
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tection of biodiversity and natural resources in China, and are the carriers for building a beautiful country. The construction and protection of nature reserves are closely linked to the promotion of ecological civilization[1-2]. A lot of factors could affect the stability of nature reserves, and mining is one of them. At present, with the planning of the national main coal bases and the natural reserves. There are few research on the impact of coal mining on the ecological environment of the nature reserve. In order to improve the management and utilization of natural resources, it is necessary to conduct analysis and researches. It can further improve the sustainable economic development of coal mining enterprises, make better use of natural resources and guide the measures for the protection and restoration of the ecological environment in coal mining areas[3-5].

The coal mine is situated in the northern edge of Qinshui coalfield in Shanxi Province, and the western foot of Taihang Mountain. Started from May 1st, 1951, the mine has a long history of resource mining. After the establishment of Shanxi Yaolinsi Guanshan Provincial Nature Reserve, it partially overlaps with the coal mine in the area of 13.654 km^2. Additionally, the mine has formed a goaf with an area of about 4.742 km^2 in the overlapping area. In order to fully implement the major decisions of the 19th CPC National Congress on the construction of ecological civilization and environmental protection, it is urgent to analyze and evaluate the ecological impact of underground coal mining on nature reserve[6-8]. Based on the collected data from the mine, the nature reserve, and field surveys. By the GIS and RS technology, the satellite remote sensing data from July 2002 and July 2017 were used for analysis. The changing trend of vegetation type, vegetation coverage, land use type and soil erosion intensity before and after the planning of the nature reserve were analyzed. Meanwhile, the change of ecological environment in the overlapping area were evaluated by the ecological protection condition and grading index. The evaluation of the impact of underground mining on the ecological environment to the nature reserve is conducted to further analyze the trend of ecological environment change[9].

1 Overview of mining area and nature reserve area

1.1 Overview of the coal mining area

The range of coal mine wells is about 7.8 km long, with a tendency of about 7.7 km long, an area of 60.060 3 km^2, a production scale of 4×10^6 t/a, and a mining depth of 713.5～463.3 m. The mining area is adjacent to other mines in its east, west and south and the north is bounded by the Shitai Railway. The mine field is located in the Loess Plateau of Shanxi and belongs to the middle and high mountainous areas. Furthermore, its terrain is steep, the valleys are criss-crossed, and the terrain height is highly disparate. From a regional perspective, the mine field is eroded and stacked geomorphic in the Loess Plateau. Growth strata within the mine including middle Ordovician Shangmajiagou formation (O_2s) and Fengfeng formation (O_2f), middle Carboniferous Benxi formation (C_2b), upper Carboniferous Taiyuan formation (C_3t), lower Permian Shanxi formation (P_1s) and Xiashihezi formation (P_1x), upper Permian Shangshihezi formation (P_2s) and Shiqianfeng formation (P_2sh), lower Triassic Liujiagou formation (T_1l), Quaternary middle and upper Pleistocene (Q_{2+3}), and Holocene (Q_4)[10].

1.2 Overview of the Nature Reserve

Shanxi Yaolinsi Guanshan Provincial Nature Reserve is located in the eastern part of Shanxi Province and belongs to the Taihang Mountains. Its total area is 11 017.0 hm^2, which is composed of Qiulin district and Yaolinsi district. Qiulin district is located in the north of Pingding County, bordering Yu County and Hebei Province. It is 9 km long from east to west, 8 km wide from north to south, and covers an area of 3 113.8 hm^2. Yaolinsi district is located in the south of Pingding County, bordering Shouyang County and Xiyang County. It is 11 km wide from east to west and 20 km long from north to south, with an area of 7 903.2 hm^2. The altitude is +1100 m-+1400 m.

The stratigraphic sequence in this area is obvious, and its distribution characteristics are from east to west, from old to new, which is followed by Great Wall system of Mesoproterozoic, Cambrian and Ordovician of lower Paleozoic, Carboniferous and Permian of upper Paleozoic, Triassic of Mesozoic, and Cenozoic. The rocks are mainly sedimentary, accounting for 99% of the total area, followed by basalt, accounting for 1% of the total area. The geological structure changes, which have experienced a giant tectonic cycle of descending, ascending and descending. The reserve is high in the west and low in the east. After long-term flash flood cutting and weathering and erosion, the number of steep gullies was formed.

The overlapping area between the mine field and the core area of the reserve is 100.1 hm^2, the overlapping area between the mine field and the buffer zone is 161.6 hm^2, and the overlapping area between the mine field and the experimental area is 1 103.7 hm^2, accounting for 0.91%, 1.46% and 10% of the total area of Yaolinsi Guanshan Provincial Nature Reserve respectively. The area of goaf formed by mining in the overlapping area is about 4.742 km^2.

2 Analysis of ecological environment changes in the Reserve

In this paper, RS and GIS technology were performed to compare and analyze satellite remote sensing data from SPOT-5 in 2002 and 2017. By comparing the changes in supergene vegetation types, vegetation coverage, land-use patterns, and soil erosion intensity before and after mining, the ecological environment in the subsidence area is analyzed, and the impact of coal mining on the local ecological environment is quantitatively evaluated, further analysis of the trend of ecological environment changes is implemented[11-12].

2.1 Geomorphic type characteristics

The perimeter of the Yaolinsi Guanshan Nature Reserve was expanded by 300 m and the evaluation area is 21.54 km^2. In terms of the 2009 National Geographic Information Ground Elevation Mapping Data, a topographic map was drawn using ArcGIS software, as shown in Fig. 1. It can be seen that the area has large undulations, with a maximum ground drop of 388 m. Moreover, the reserve area is characterized by high mountains in the north and south and valleys in the middle. The developed seasonal rivers in mountainous areas are mainly Danangou, Xiaonangou, Beichuan River, etc., which merge into the border Tao River to the south and north, and the water system is distributed as branches. The key survey area of mining-induced subsidence is located in the middle and the north of the evaluation area, with an area of 10.25 km^2.

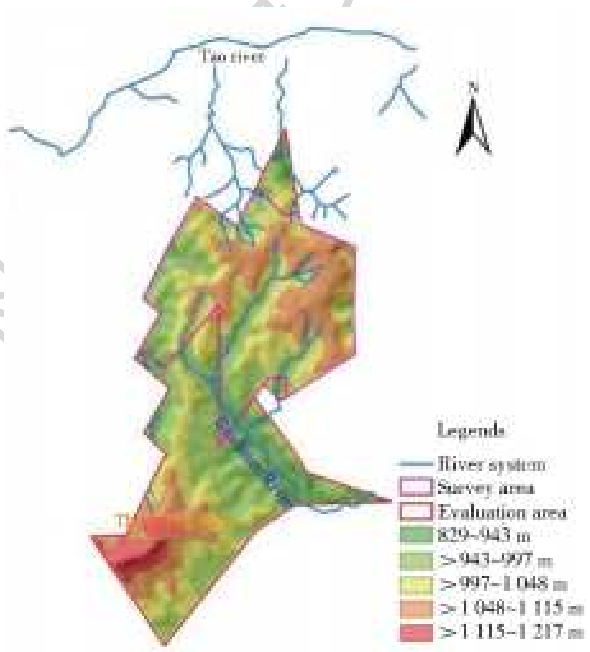

Fig. 1 Topographic map of Guanshan nature reserve evaluation area and survey area

2.2 Variation trend of vegetation types

Due to regional coal mining and artificial disturbances, the ecosystem and underlying surface conditions have changed. Through the statistical comparison of different types of vegetation areas, the change degree of vegetation type is analyzed. Using ArcGIS software to draw the distribution map of vegetation types in the evaluation area and investigation area, and measure the area represented by grid of different vegetation types, so as to calculate the proportion of the distribution area and total area of different vegetation types[13]. The results are shown in Tab. 1.

Tab. 1 Statistics table of an area of different vegetation types

Research area	Year	Area	Vegetation Types				Total
			Temperate grass	Temperate bush	Cultivated crops	Forestland	
Evaluation area	2002	Area/km²	18.93	0.59	2.02	—	21.54
		Proportion/%	87.90	2.74	9.36	—	100.00
	2017	Area/km²	9.83	8.26	0.72	2.73	21.54
		Proportion/%	45.64	38.33	3.35	12.68	100.00
Survey area	2002	Area/km²	10.25	—	0	—	10.25
		Proportion/%	99.99	—	0.01	—	100.00
	2017	Area/km²	3.67	4.29	0.50	1.79	10.25
		Proportion/%	35.79	41.83	4.87	17.51	100.00

Tab. 1 Statistics shows that 2002-year assessment district dominant vegetation types mainly in the temperate zone of dwarf bushes, accounting evaluation area of 87.90%, the table shows the evaluation former mining area mainly in the original grass-based, less affected by the degree of human disturbance. After coal mining, temperate grass area decreased by a proportion of 42.26%, a higher proportion of the area of bush and forestland area accounted for a significant increase. It indicates that under the influence of environmental protection measures such as soil and water conservation, the dominant vegetation types in the evaluation area gradually changed from dwarf vegetation to shrubs and trees. Almost all of the vegetation in the key survey areas were grasses before mining. After mining, the dominant vegetation type transitioned to bush vegetation. At the same time, the area of arbor forests also increased markedly, and biodiversity is more pronounced.

2.3 Vegetation coverage variation analysis

Vegetation coverage is generally expressed by the vegetation coverage index. It is a characteristic index that reflects the growth status and distribution of green vegetation by the linear and non-linear combination of detection data from different bands of remote sensing satellites. The classification principle of vegetation coverage refers to the "Grade Index Scheme for Desertification Mapping in Northern China" compiled by Gao Shangwu et al., Using ArcGIS software to draw the vegetation coverage distribution map of the evaluation area and the investigation area, measure the area represented by different vegetation coverage grids, and calculate the proportion of different vegetation coverage area and total area. The results are shown in Tab. 2.

Tab. 2 Statistical table of the area covered by different vegetation

Research areas	Years	Areas	Vegetation coverage levels and ranges					Total
			Low coverage	Low to medium coverage	Medium coverage	Medium to high coverage	High coverage	
Evaluation area	2002	Area/km²	0.10	0.58	2.23	10.16	8.47	21.54
		Proportion/%	0.48	2.68	10.35	47.16	39.33	100.00
	2017	Area/km²	0.01	0.25	1.84	7.11	12.33	21.54
		Proportion/%	0.04	1.17	8.54	33.00	57.25	100.00
Survey area	2002	Area/km²	0.02	0.28	1.10	4.89	3.96	10.25
		Proportion/%	0.23	2.68	10.72	47.75	38.62	100.00
	2017	Area/km²	0.01	0.13	1.00	3.61	5.50	10.25
		Proportion/%	0.07	1.27	9.77	35.21	53.68	100.00

According to the data, it can be found that the vegetation coverage in the evaluation area in 2002 was mainly above the middle to high coverage, with less bare land and desertification. Overall, the vegetation coverage in the area was good. After coal mining, the coverage in the evaluation area above mid-to-high accounted for 90.25%, of which the high coverage increased by 17.92%. During this period, regional precipitation did not significantly increase. It demonstrates that artificial afforestation or other soil and water conservation measures worked well in improving regional vegetation ecology. In 2002, vegetation coverage in key survey area accounted for 86.38%, indicating that the original vegetation distribution in the reserve area was more even. After coal mining, the coverage of vegetation above the middle to high has increased to 88.89%, and the proportion of high coverage types has increased by 15.06%. It indicates that the catchment effect formed in the mining subsidence area and artificial soil and water conservation measures have a significant effect on improving the ecological environment of vegetation. After comparing the data of the remote sensing effects of the two periods before and after mining, the negative ecological effects brought by coal mining in the reserve area are minimal. In 2017, subsidence in the area induced by mining has essentially stopped, and the shallow ecological water level that has a large impact on vegetation has gradually restored. Besides, the subsidence-formed catchment effect and the artificial soil and water conservation measures have been implemented in recent years, and the regional ecological vegetation has been further improved[14].

2.4　Analysis of changes in land-use status

According to the classification standard of land-use status (GB/T 21010—2007) issued by the Ministry of Land and Resources[15-16], Statistics on the changes of land-use types before and after mining are shown in Fig. 2 and Fig. 3. Generally speaking, due to the influence of topographical conditions, the utilization degree of land resources before mining is relatively low. With the increasing emphasis on the ecological environment, measures that are beneficial to the ecological environment, including afforestation, are gradually implemented. Meanwhile the behaviors that are not conducive to the ecological environment, such as wasteland reclamation, are gradually reduced[17-18].

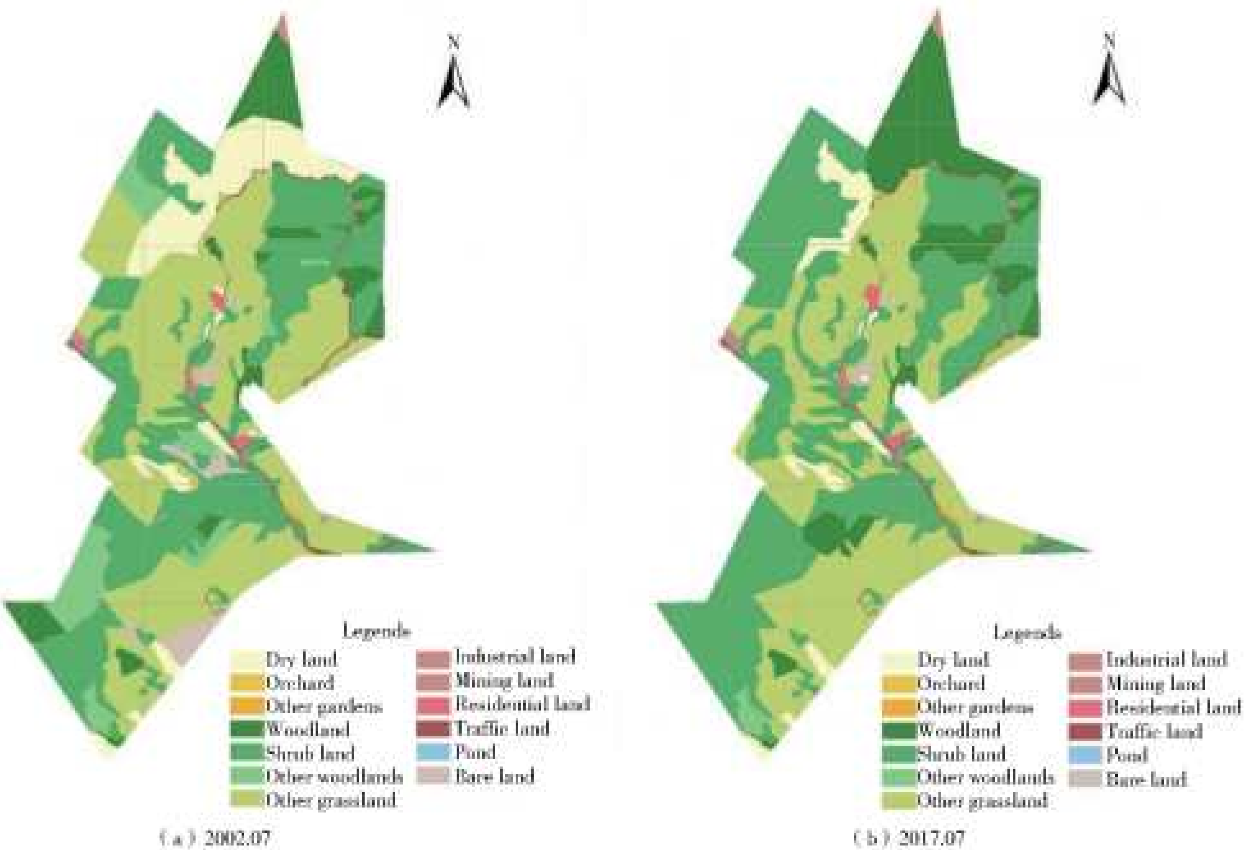

Fig. 2　Comparison of land use types in the evaluation area

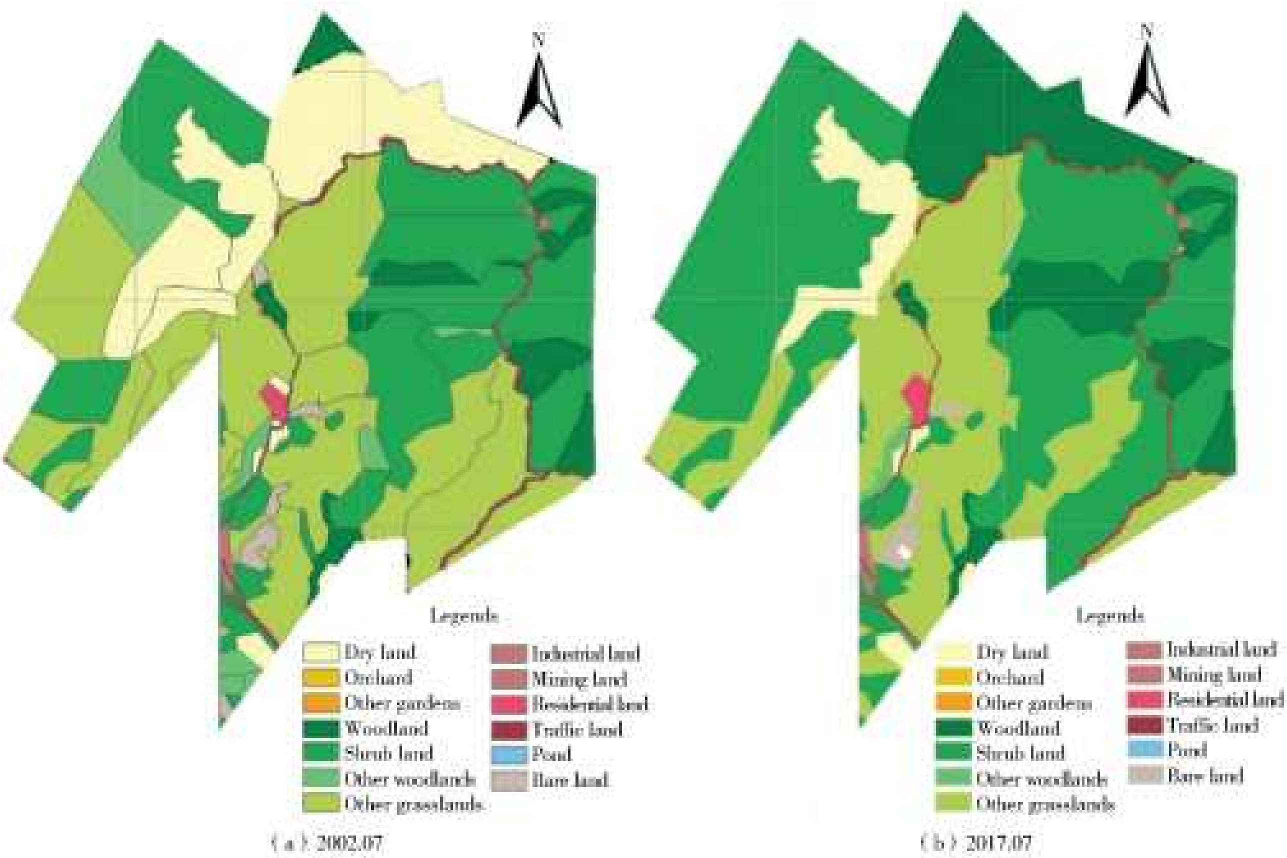

Fig. 3 Comparison of land use types in the survey area

2.5 Trend analysis of soil erosion change

According to the "Soil Erosion Classification and Grading Standards" (SL 190—2007) issued by the Ministry of Water Resources[19], the changes in the area of different erosion intensities in soils in the evaluation area and survey area were calculated, as shown in Fig. 4 and Fig. 5, The soil in the area before and after mining is mainly dominated by types of erosion intensity below mild. In the evaluated area, the proportion of areas with moderate or higher erosion intensity before mining primitive landform fell by 21.84%. The proportion of areas with moderate or higher erosion intensity after mining fell by 0.81%. In the survey area, the proportion of areas with moderate or higher erosion intensity before mining fell by 19.25%. The proportion of areas with moderate or higher erosion intensity after mining fell by 0.85%. The statistical results show that the intensity of soil erosion in 2017 is significantly better than that in 2002, and the trend of soil erosion intensity decreasing year by year is closely related to the change of vegetation type, vegetation coverage and land use type. This change is mainly because vegetation can conserve water, improve soil, increase vegetation coverage on the ground, prevent soil erosion, and the root system of vegetation is to improve soil erosion. Important environmental factors can effectively reduce soil nutrient loss, and are affected by artificial soil and water conservation measures and regional climate improvement. The diversity of vegetation types has a significant effect on changing soil physical and chemical properties and improving soil erosion resistance[20].

3 Ecological status analysis

Using the analytical method of the ecological protection status evaluation index system in the "Technical Specifications for the Evaluation of the Ecological Environment Status" (HJ 192—2015), the impact of the ecological environment on the nature reserve in underground mines is evaluated. The evaluation of the ecological protection status of nature reserve is to evaluate the ecological protection status with the Nature Reserve Ecological Protection Status Index (NEI)[21]. NEI= 0.10 × area

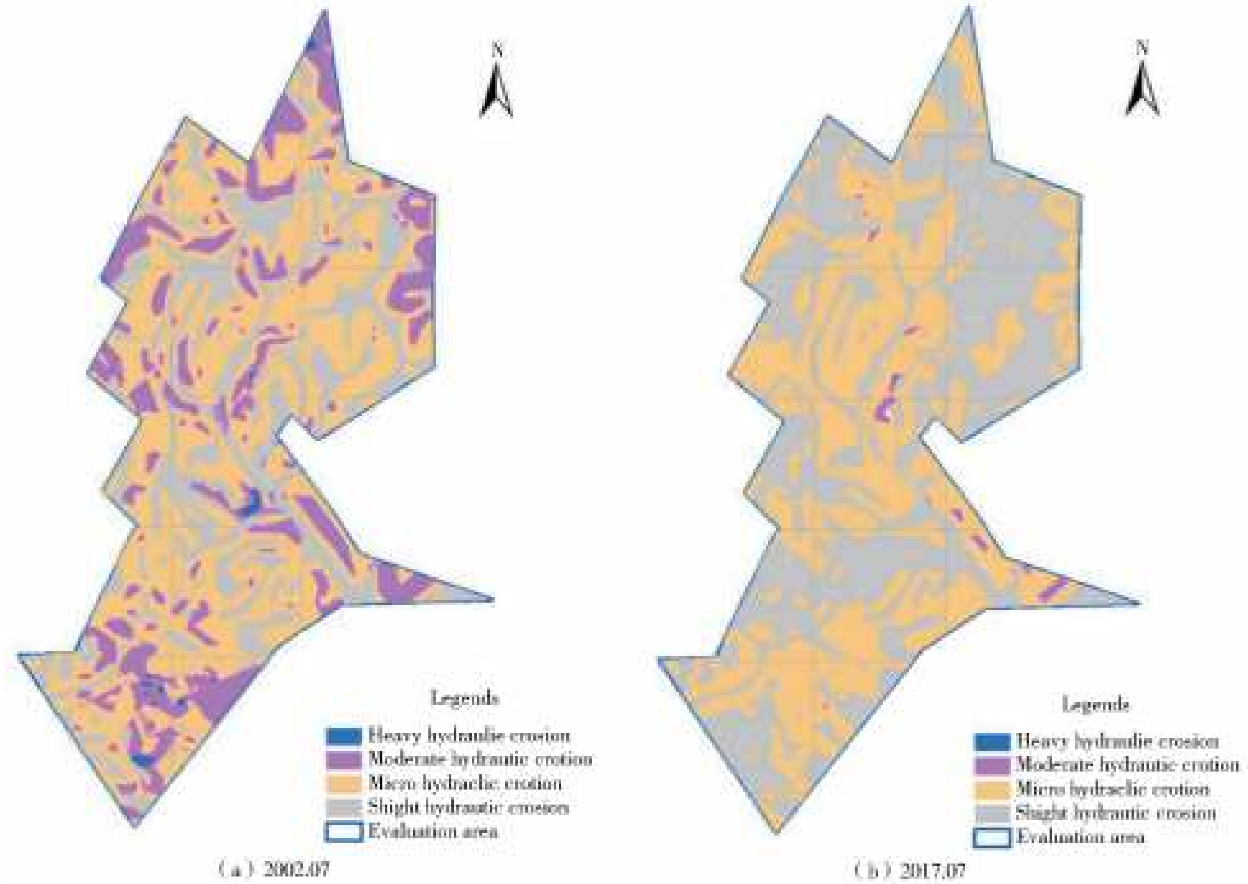

Fig. 4　Comparison of soil erosion intensity in the evaluation area

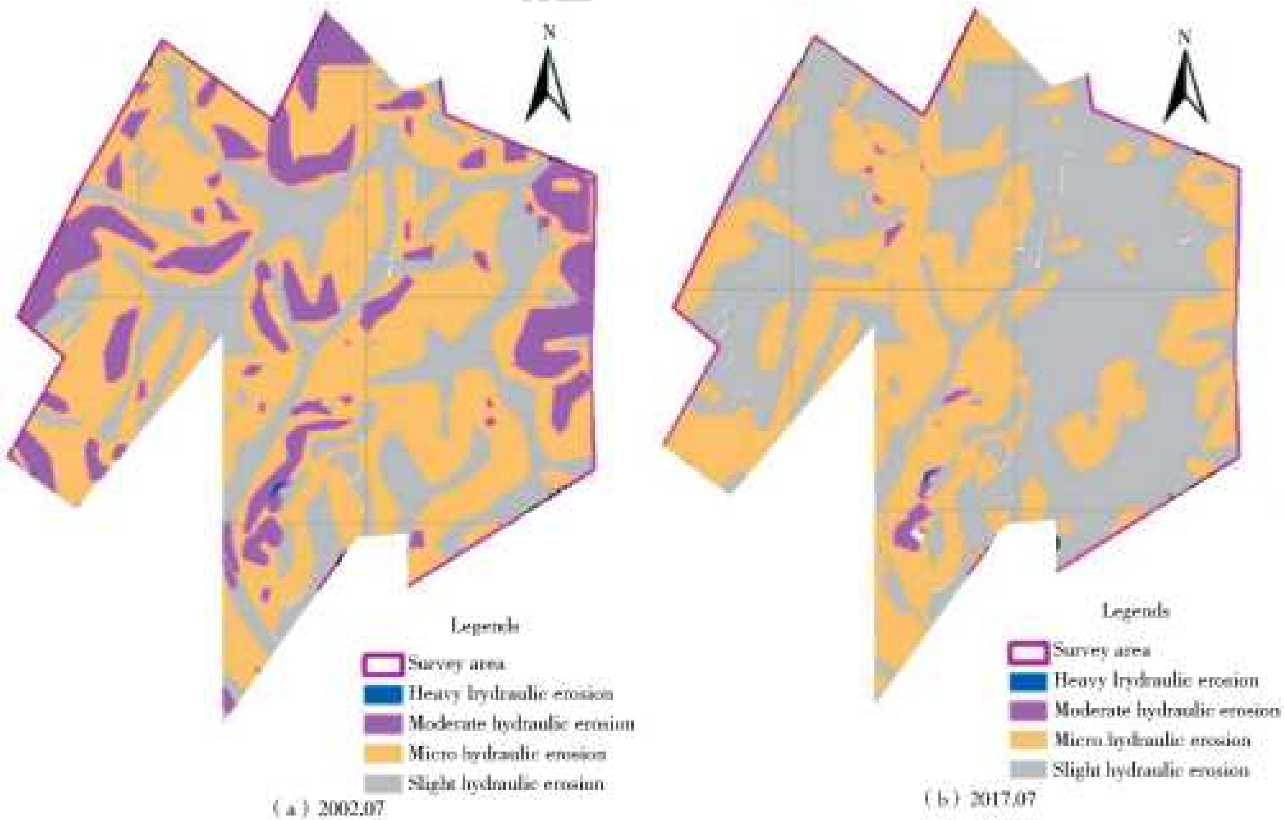

Fig. 5　Comparison of soil erosion intensity in the survey are

suitability index + 0.10 × (100 − alien species invasion index) + 0.40 × habitat quality index + 0.40 × (100 − development interference index). The ecological protection status of the nature reserve is classified in line with NEI. See Tab. 3 for details. According to NEI and the changes in the reference value, the change of ecological protection status is divided into 4 levels. Refer to Tab. 4 for the changes and evaluation methods of each index[22-23].

Tab. 3 Grade table of an index of ecological protection status in nature reserves

Grades	Excellent	Good	General	Worse	Worst
Index	$75 \leqslant NEI$	$55 \leqslant NEI < 75$	$35 \leqslant NEI < 55$	$20 \leqslant NEI < 35$	$NEI < 20$
Descriptions	The primary habitats of the main protected objects are effectively protected with no obvious signs of development disturbance.	The primary habitats of the main protected objects are protected in good condition. There is development interference, but to a lesser extent.	The primary habitats of the main protected objects are damaged, and development interference was obvious.	The primary habitats of the main protected objects present partial loss, and development interference was severe.	The primary habitats of the main protected objects present severe loss, and development interference was the most severe.

Tab. 4 Grade table of change degree of ecological protection status in nature reserves

Grades	No Significant Change	Slightly Change	Obvious Change	Significant Change
Change Values	$\lvert \Delta NEI \rvert < 2$	$2 \leqslant \lvert \Delta NEI \rvert < 5$	$5 \leqslant \lvert \Delta NEI \rvert < 10$	$10 \leqslant \lvert \Delta NEI \rvert$
Descriptions	Ecological protection status has not changed significantly.	If $2 \leqslant \Delta NEI < 5$, the ecological protection status becomes slightly better; if $-2 \geqslant \Delta NEI > -5$, the ecological protection status is slightly worse.	If $5 \leqslant \Delta NEI < 10$, the ecological protection status becomes better; if $-5 \geqslant \Delta NEI > -10$, the ecological protection status becomes worse.	If $10 \leqslant \Delta NEI$, the ecological protection status becomes best; if $-10 \geqslant \Delta NEI$, the ecological protection status becomes worst.

Based on the data from the two remote sensing surveys and other data collected from the nature reserve, the analysis parameters of the ecological protection status of the nature reserve are shown in Tab. 5. As can be seen, when the reserve area was established in 2002, the ecological protection status index NEI = 32.98. It means that the primary habitats of the main protected objects native habitats of the main protected objects present partial loss, and have severe development interference. Currently, NEI is 45.94, and ΔNEI is $12.9 \geqslant 10$. Following gradation table of changes, it can be seen that the ecological protection status of the reserve area has been improved[24-25].

4 conclusions and recommendations

(1) Based on the collected data and field surveys, by the GIS and RS technology, the satellite remote sensing data from July 2002 and July 2017 were used for analysis. By comparing the changes in supergene vegetation types, vegetation coverage, land-use patterns, and soil erosion intensity before and after mining. Since 2002, the effect of water collection and artificial soil and water conservation measures on improving the ecological environment of vegetation are obvious, the dominant species of vegetation type have changed from grass vegetation to bush vegetation on the overlapping area between the mine field and the core area of the reserve, and the biodiversity is more obvious. The medium and high coverage of original vegetation is obviously increased. The intensity of soil erosion improved significantly. The proportion of hydraulic erosion in the moderate and above has decreased. Ground subsidence induced by coal mining remains long-term stable, and the shallow ecological water level which has a great impact on vegetation is gradually restored. Its negative impact on the ecological environment is less than the positive effects presented by artificial soil and water conservation measures. The ecological protection status index increased from 32.98 to 45.94, and the change degree of ecological protection status in nature reserves is $12.9 \geqslant 10$. It can be known that the ecological protection status of the nature reserve has been improved. In the meantime , the regional ecological environmental

vulnerability is gradually weakened. Its overall development is more stable and less vulnerable.

Tab. 5 Eco-environmental status evaluation normalization coefficient table

Projects	Weights	Parameters				
		Sub-items		2002	2017	Sub-weights
Area suitability index	0.10	Area of the core region		1.597	1.001	—
		Area of the Nature Reserve		21.54	21.54	—
		Normalization coefficient		100		—
Alien species invasion index	0.10	Number of invasive alien species		0	0	—
		Normalization coefficient		2.083 333 333 3		—
Habitat Quality Index	0.40	Woodland 0.40	Forest land	2.4	2.81	0.60
			Shrubland	6.82	9.53	0.25
			Sparse forest and others	1.31	0.19	0.15
		Grassland 0.18	High coverage grassland	3.965	3.765	0.60
			Medium coverage grassland	2.379	2.259	0.30
			Low coverage grassland	1.586	1.506	0.10
		Waters and wetlands 0.23	Rivers (ditches)	0.01	0.01	0.30
			Lakes (canals)	0	0	0.30
			Tidal wetland	0	0	0.30
			Permanent glacier	0	0	0.10
		Cultivated land 0.08	Paddy field	0	0	0.60
			Dry land	2.09	0.86	0.40
		Construction land 0.01	Land for urban construction	0	0	0.30
			Rural settlement	0.06	0.09	0.40
			Other construction land	0.41	0.41	0.30
		Unused land 0.10	Sand	0	0	0.20
			Saline land	0	0	0.30
			Bare land	0	0	0.20
			Bare rock land	0	0	0.20
			Other unused land	0.52	0.11	0.10
		Normalization coefficient		417.439 962 244 3		—
Development Interference Index	0.40	Core area		1.597	1.001	0.60
		Buffer area		0.93	1.616	0.30
		Experimental area		19.013	18.923	0.10
		Urban construction land		0	0	0.40
		Rural settlement		0.06	0.09	0.10
		Other construction land		0.41	0.41	0.40
		Cultivated land		2.09	0.86	0.10
		Normalization coefficient		1 520.336 383 017 4		—
Index of Ecological Protection Status of Nature Reserve NEI				32.98	45.94	—

(2) It is recommended to strengthen the observation of rock movements in the overlapping area of the mine field and Yaolinsi Guanshan Nature Reserve and surrounding areas to obtain the measured data on mining subsidence impacts. On this basis mine continues to study the impact of underground mining on the ecological environment of Yaolinsi Guanshan Nature Reserve. It is also indispensable to strengthen communication with the management department, and supervise the operation of facilities in the Nature Reserve. Underground mining shall be performed under the requirements of the local government and the nature reserve authorities.

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