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Ecological risk assessment of open coal mine area

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Abstract The coal mine areas in China have the serious conflicts between resources exploitation and ecology safety, therefore the coal mine ecological risk assessment is an important problem which relates to the sustainability of coal mines to regions and the whole country. In this study, open coal mine area serves as researching object, heavy metals, soil erosion and coast are screened out as risk resources, soil wireworm as the receiver of heavy metals risk, biotope ecosystem as the receiver of soil erosion and coast risk; ecological indexes are calculated with species background index, biological diversity index and natural degree index, ecological friability indexes are calculated with soil fertility index, plant coverage, plant species diversity index, soil wireworm index and maturity index, and the typical coal mine area assessment indexes system is established. In addition, the regional ecological risk assessment is conducted on the friable ecological system of Fuxin Haizhou open coal mine area. Examples are researched of Haizhou open coal mine, the coal mine risk distribution is established, and foundations are provided for the administrative decision-making.

Keywords Open coal mine area · Ecological risk assessment · Soil erosion · Heavy metals · Coast

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Introduction

The ecological risk assessment has its legal bases in Europe and America. In 1993 the EU enacted regulations and instructing documents on ecological risk assessment of chemicals. Within the legal support, the European countries carried on systematic ecological risk assessment of chemicals and wide ecological risk assessment of industrial pollutants disposal and have gained plentiful experiences on ecological risk assessments of pollutants (Duo-sen and Zhi-yuan 1987). The EPA enacted ecological risk assessment guide in 1998 officially, and established corresponding technical regulations on risk assessment of various ecological systems. In China, although the research is comparatively few, several scholars have commenced on its researching and applying, for example, Qian-Yinqian,, Li-Guoqi, Cao-Hongfa, Yin-Haowen, Xu-Jingbo etc. illustrated the idea of ecological risk assessment(Fenghua 1998; Guijian Yang Dingyue 2000; Hu 2000; (Jin-chuan and Zhong-ke 2000; Li et al. 1999), Liu-Wenxin, Ma-Baoyan etc. researched on ecological risk of microelement and heavy metals (Li and Zhi jun 2001; Liu and Rong_yong 2001) Zhang-Xuelin, Xu-Xuegong, Fu-Zaiyi etc. researched on ecological risk assessment of agriculture and wetland area (Man-hua et al. 2001; Min 2001; Qian et al. 1998). Whereas for the coal mine area that belongs to a combination of typical ecology friability and mine resources, its internal risk factors and developing directions are both different from natural and half-nature systems such as agriculture and wetland, and from modern metropolis, it has unique features on the progress of environment, economy and society. Presently there are few reports on the theory and apply of ecological risk assessment and management, therefore to choose typical open air coal mine area for ecological risk assessment, to determine risk origin of mine area, risk receivers and assessment endpoint, and to confirm quantificationally the probability and intensity of negative effects of environmental damage on human, are in favor of further ecological risk management of coal mine area and the realization of ecological risk prevention; the establishment of open coal mine ecological risk assessment system is in favor of the recovery and rebuilding of coal mine area under a standard of ecological health and the realization of the harmonious development between coal resource exploitation and environment. Combined with the political, economical and social factors of coal mine, to put forward the theory and methods of ecological risk assessment which are suitable for Chinese mining characteristics is in favor of the enrichment of ecological risk assessment theory and has means of innovation.

Materials and methods

Summary of open air coal mine

The FuXin-Haizhou open air coal mine area locates on the foot of Yiwulv Mountain, with the geographic coordinate: East longitude 121°41′ and North latitude 41°59′. The open coal field locates on north of FuXin coal field. The coal bed was formed by continental deposit in upper Jurassic System, most of its rocks are sandy shale, and the rest in turn are sandstone, mudstone and carbon shale, conglomerate, Quaternary topsoil, wash and basalt. The total area is about 30 km^2, including stope about 8 km^2, earth-line area and gangue-line area about 14.8 km^2, industrial square 3.84 km^2, resistance and life establishment area 2.18 km^2 (Fig. 1).

Determination of assessment area

The coal mine is a unique artificial or half-artificial ecosystem that has the core of mine operation area. The radiating scope includes the locus of employees and farmers, even the towns, countries and industry areolas formed by the support of mining (Gemmell 1987). The worse of the structure and function of coal mine area ecological system will heavily influence the ecological benefit and social benefit of the coal mine area. The area and ecosystem that are possible to be or have already been polluted and destroyed are the most important area for ecological risk assessment. Before the assessment, better knowledge should be achieved to determine the space-time scope of the studying area correctly and to avoid blindness. In this study the assessing area include Hai-zhou open air coal mine, earth-line area, gangue-line area and the villages and farmlands in 5 km around.

Methods of sampling

According to the principle of equality of sight ecology, the earth-line area, gangue-line area, stope, farmland and residential area are separated into different sight spots. The stope, earth-line area and gangue-line area come into ladder style landform where platform and side slope are alternated; On the contrary, the platform/side slope of the earth-line area and gangue-line area is increased in turn in time from up to down, based on the platform/side slope from various generations, the risk intensity and distribute within the earth-line area, gangue-line area and stope can be measured. In this study, risk degree index, ecology index, ecological friability index and potential ecological loss degree index are used for the calculating of ecological risk values between various spots and within the terrace level of different ages in open mine area.

By visits of missionary of the mine area and data investigation, the terrace age levels of the earth-line area, gangue-line area and stope are determined. Then choose the terraces with a certain age intervals, for the north of trope, the age of 7, 10, 15, 20, 25, 30,

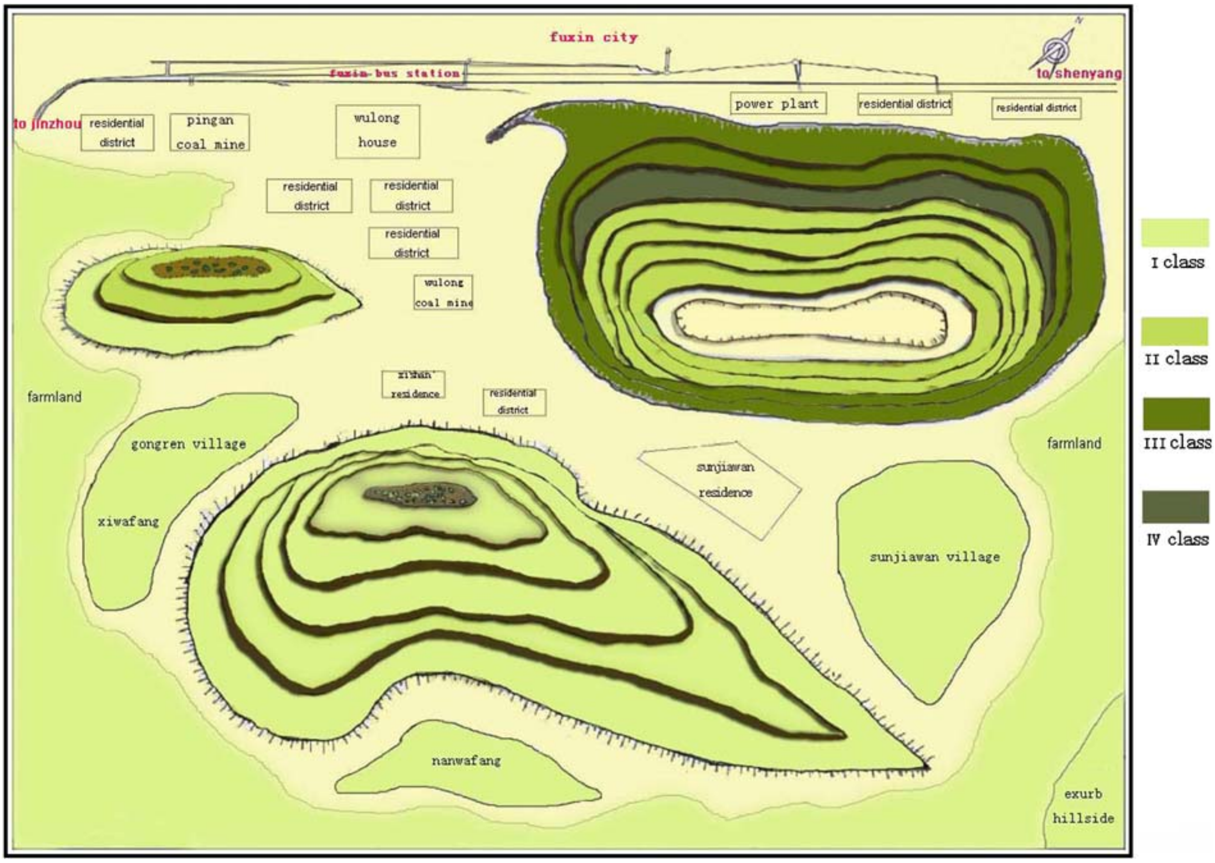

Fig. 1 Map of comprehensive regional ecological risk assessment in Haizhou opencast coal mine

40 years are chosen from the bottom to the top in turn, for the south, it cannot be investigated because of sloping. For the earth-line area, 40, 20, 10, 8, 4 years are chosen from the bottom to the top in turn, and for the gangue-line area, 5, 12, 18 years in turn. And then the farmland of western tile-roofed house, southern tile-roofed house, Sun-Jiawan village, west of gangue-line area, south of earth-line area, east of Sun-Jiawan village, and the faraway hillside are chosen. First the overview investigation at every chosen spot: all the species at the spots are kept down, and primary understanding of vegetation type and distributing status are gotten. Then the sample investigation of typical vegetation: 25 samples of 1 m ×1 m are investigated, the species, multiplex, height, cover degree of vegetation in the sample spot are kept down. At the same time, five complex earth samples are gathered at random on the typical site, each sample includes ten sub-samples at random within 25 m diameter of the main sampling point (Yiecheng and Xue-xin 1995). Two layers of earths are gathered (0–5, 5–10 cm), the spots are distributed at random around the village and faraway hillsides, and in farmlands S shape is employed, five complex soil samples are gathered in separate layers, kept into cloth pocket, air-dried and analyzed; at the same time, biologic analysis samples are gathered, kept into sealed plastics and distinguished in the lab.

In the following diagrams, A1, A2, A3, A4, A5, A6, A7 represent the terraces of 7, 10, 15, 20, 25, 30, 40 years from bottom to the top north of stope, respectively; B1, B2, B3, B4, B5 represent the terraces of 40, 20, 10, 8, 4 years from bottom to top in the earth-line area, respectively, in which B4 is used as compound farmland for excluding surface soil; C1, C2, C3 represent the terraces of 5, 12, 18 years from bottom to the top in the gangue-line area, respectively; D, E, F represent mine area farmland, village milieu and hillside soil in the outskirt.

Methods of soil analysis

Soil moisture content: drying (GB 7172–87), Soil bulk density: cutting ring (for common soil layer) and pit burying (for earth and stone mixture layer and gangue layer).

The soil sample should air-dry naturally, crush while half dry, remove the vegetable nub, spread into folium, turn over often and dry in the shade. After drying, crush down the sample with organic glass to remove the grits and plant remains of more than 2 mm. Then separate with quartation for several times and remain sufficient for analyzing (about 50 g). And then mill with organic glass stick for 100 griddles.

pH: potentiometer (GB 7859-87); organic: potassium dichromate oxidation plus heating; TN: semi-micro-Kjeldehals; quick nitrogen:potassium chloride digestion-streaming analyzer; TP: acid-dissolved 钼锑抗 colorimeter; effect P: sodium bicarbonate -钼锑抗 colorimeter; TK, TNa: hydrofluoric acid–perchloric acid–nitric acid slaking, atomic absorption spectrophotometer; quick K: ammonium acetate digestion-flame photometer; heavy metals TZn, Cu, Cd, Cr, Ni, Mn, Ca, Mg, Fe, in reference to Lu Ru-kun (Rong Liang 1996).

Methods of data analysis

The average is taken according to every sample for soil quality index of the terrace of every age, and for the synthesized evaluation of fertility, it is based on the physical and chemical indexes, and standardized with SPSS12.0, then the contribution rate and accumulated contribution rate of main components are calculated, and then the characterized contribution rate of each main component is weighted, and the synthesized fertility of the soil of every age is calculated (Ru-kun 1999)).

The analyzed method of plant community is as follows: Shannon–Weiner Index $H = -\sum_{i=1}^{n} p_i \times \ln p_i$ is applied for species diversity index, in which $p_i = n_i/N$ represents the percent which the numbers of no. I species occupy the total numbers of species.

The Pielou uniformity index is applied for species uniformity: $E = H/H_{\max}$, in which H is the Shannon–Weiner Index, $H_{\max} = \log_2 S$, and S is the number of species.

Importance of species = (relative density + relative appearance frequency + relative cover degree + relative plant average height)/4, in which:

Relative density = numbers of a certain specie/numbers of total species × 100;

Relative cover degree = cover degree of a certain specie/cover degrees of total × 100;

Relative plant average height = plant average height of a certain specie/plant average height of total species × 100;

Relative appearance frequency = quad number of a certain specie/quad numbers of total species × 100.

The analyzed method of wireworm community: wireworm belongs to Shannon–Wiener, diversity index: $H = -\sum_{i=1}^{n} p_i \times \ln p_i$, p_i is the number of no. i wireworm occupy the total number of wireworms.

Ecological risk assessment system of open air coal mine area

Ecological risk assessment value is the product of risk degree and potential ecology loss degree, in which potential ecology loss degree refers to the product of coal mine ecology index and coal mine ecology friability index. Different from the former regional ecology evaluation research, in this study the soil animal index is applied when the soil system friability is evaluated. Because in coal mine soil the common arthropod and mollusk have low quantity, the wireworm community index is introduced, which is now the hot research spot on soil environmental quality sensitivity sensor of foreign scholars. The analysis of soil wireworm in Haizhou coal mine has indicated that, the wireworm animals which have better survival and adaptable abilities are more suitable for the evaluation of wicked and severely jamming soil environment than other soil animals, and the wireworm community has important indicating effect on environment quality and pollution conditions.

Ecology index in Haizhou coal mine

The ecology indexes in open air coal mine area include the species background index, biological diversity index and natural degree index.

Species background index O_i: sequence the species of every spot from high to low according to the importance. The background species are chosen with the accumulated importance of hillside species as much as 90%, the number is C_i, $O_i = C_i/C$, I refers to no. I spot. Species background index reflects the plant succession degree. The outskirt plant is less disturbed by mankind, and the relative succession degree is high, so the community has a high stability. Compared with the outskirt plant as background, the coal mine spot plant has a high species background index, which indicates that the plant has high recovery ability, and good ecological sense, and should be protected better.

Biological diversity index V_{i}: the proportion of the number of species in a certain spot occupy the total plant species in the coal mine, $V_i = N_i/N$, in which V_i refers to biological diversity index of the no. i spot, N_i refers to plant species number of the no. i spot, N refers to plant species number of the whole coal mine.

Natural degree index Z_i: evaluation of the disturbing degree of human activities on spot, in open coal mine the age of each terrace expresses the naturality of the terrace, $Z_i = A_i$, Z_i refers to the natural degree of no. i spot, A_i refers to the age of no. i spot. For the milieu of farmland and village the age is 1 year because of less human disturbance. For outskirt hillside (background) is as top as 50 years because of the least human disturbance.

Ecological index E_i :$E_i = aO_i + bV_i + cZ_i$, in which E_i is the ecological index of no. i spot, a, b, c refer to the weight of each index, 0.399, 0.403, 0.198, respectively with variation coefficient.

According to the above formulas, O_i, V_i and Z_i are calculated, because of the different magnitude, they should be treated before statistics, the formula is: $X_i' = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}$, in which X_i' refers to the standardized value of the no. i spot, between 0 and 1, X_i is the original value, $X_{\max}$ is the max among all the status and $X_{\min}$ is the min among all the status.

Haizhou coal mine ecological friability degree

Ecological friability of open coal mine ecological system mainly exhibit landform and physiognomy, plant retrogress, low productivity, low soil quality and so on, usually it is got by the investigation of plant conditions and soil quality. For the plant shading degree and diversity are chosen as indexes, plant indexes indicate the stability of the plant system; for soil animals wireworm diversity and maturity are chosen as indexes, wireworm indexes indicate the stability of the construction and function of soil invertebrate wireworm community. Plant index, wireworm index and fertility index compose the stability of ecological system, and weight is determined by variation coefficient, the count backwards of stability index is friability index.

Results and discussion

Rick sources identification

Risk sources identification is to find the risky factors according to evaluation purpose. The choosing of risk sources in coal mine area should well consider that it is different from the normal natural ecosystem, the particular characters of itself impose important effect on the evaluation. For example, the earth-line area, gangue-line area occupy and destroy the soil resources, the drainage of coal mine hole and the percolation filtration of gangue-line area pollute the water resources, the self-ignite of gangue-line area and emission of motors pollute the air, all have threaten the friable ecosystem of coal mine area. Therefore the damaged soil because of digging and pressing and the pollution from poisonous substances (Cd, Pb, Hg, As and inorganic sulfur) should been paid special consideration.

Through synthesized analysis, in this study water and soil running off, coast, soil contaminations (heavy metals) are chosen as risky sources of open coal mine ecological risk assessment.

Description of risk sources

Description of risk sources is the qualitative and quantitative analysis to each risk resource, in order to determine the probability, intensity, time and scope of risks. The following is the analysis of the three risk sources coast, water and soil running off and heavy metals in Haizhou open coal mine area.

Coast

North of stope shapes in terrace, railway transit paves on plat roof. According to the elevations on data, the terrace level is determined, and coast frequency of different terrace level is calculated, coast risk degree: $P = \sum_{j=1}^{3} \beta_j \times P_j$, P_j refers to coast frequency of no. j

Table 1 The frequency and risk degree index of landslide in open-pit in Haizhou opencast mine

Platform	Big	Middle	Small	Risk degree
A1	–	–	–	–
A2	–	–	–	–
A3	0.00	0.067	0.133	0.033
A4	0.050	0.100	0.00	0.060
A5	0.16	0.120	0.480	0.180
A6	0.033	0.100	0.433	0.093
A7	0.025	0.125	0.55	0.108
South	0.057	0.1	0.18	0.082

level, β_j refers to weight of coast risk of no. j level. South of stope the plant is few, so it is difficult to sample and investigate, and the whole south serve as one active spot for the calculation. The result is as in Table 1:

Water and soil running off

The influencing factors of water and soil running off includes climate, soil, landform, vegetation and human activities. As above, USLE equation summarizes the influencing factors into five quantitive indexes. In the practical research, the assessing index should be determined according to research area and purpose.

Infinitude the indexes of water and soil running off, in which plant coverage and running off relate negatively, treated with the formula $y_i = \frac{\max x_i + \min x_i - x_i}{\max x_i}$ For the running off strength, the result is in Table 2.

Heavy metals

The average content of heavy metals on 0–5 cm soil surface in Haizhou open coal mine is in Table 3. Compared with the heavy metals background in Fuxin City (Shook 1997), except the As content, the contents of the rest microelements are higher than those of background. The contents of heavy metals Mn, Ni, Cd are 1.53, 1.22 and 1.56 times higher than background, the contents of Cr and Pb are 2.60 and 2.03 times than background, and the contents of Cu and Zn increase notably, which are more than four times than background. Although the content of Cu is much higher than background, except that the content of farmland, village milieu, and stope A6 layer soil a little bit excess national pollution standard of grade two (pH 6.5~7.5),the rest Cu content does not excess the standard. For the Zn content, except background, farmland, C1 and C3 the rest has exceed the standard of first grade, but all are low of the standard of second

Table 2 Relative intensity of water and soil loss in different patches in Haizhou opencast coal mine

Sampling site	Rainfall in flood season	Grit content	Plant coverage	Landform factor	Administration factor	Soil running off strength 10^{-6}
A1	0.056	0.080	0.979	0.079	0.059	20.15
A2	0.056	0.077	0.916	0.079	0.059	18.19
A3	0.056	0.068	0.758	0.049	0.059	8.29
A4	0.056	0.058	0.579	0.034	0.059	3.70
A5	0.056	0.058	0.474	0.034	0.059	3.03
A6	0.056	0.062	0.389	0.034	0.059	2.66
A7	0.056	0.038	0.284	0.028	0.059	0.99
B1	0.056	0.031	0.389	0.069	0.059	2.70
B2	0.056	0.038	0.463	0.087	0.059	5.02
B3	0.056	0.054	0.716	0.087	0.059	10.96
B4	0.056	0.025	0.863	0.087	0.059	6.07
B5	0.056	0.042	0.958	0.060	0.059	7.98
C1	0.056	0.108	1.000	0.063	0.059	22.17
C2	0.056	0.103	0.926	0.079	0.059	24.63
C3	0.056	0.080	0.705	0.095	0.059	17.39
D	0.056	0.025	0.021	0.003	0.000	0.00
E	0.056	0.023	0.442	0.003	0.059	0.11
F	0.056	0.029	0.179	0.031	0.059	0.53

Table 3 The concentration of heavy metal in soil (0–5 cm) in Haizhou coal mine

Average value	Mn	Ni	Cr	Cu	As	Cd	Pb	Zn
Coal mine	475.4	17.8	85.26	66.1	3.2	0.1	20.8	113.8
Background value[122]	310.58	14.57	32.12	9.87	6.1	0.05	10.22	28.18
Times	1.53	1.22	2.60	6.70	0.53	1.56	2.03	4.04

grade (pH<6.5), which shows that the transference of heavy metals to the surrounding soil is a slow process.

General assessment of open coal mine area

The ecology index and friability index of open coal mine are in Table 4 and Table 5. The general trend of species background indexes (O_i) of open stope, earth-line and gangue-line is that it is low in young terrace, high in old terrace, and the lowest on top of earth-line area; while biological diversity (V_i) increase with the age of terrace evidently, and lowest on top of earth-line area.

Biological indexes of stope, earth-line and gangue-line are lowest among the young terrace, and increase with the age increasing; biological index of farmland is low because of the frequent disturbance of human; biological index of outskirt plant is the highest, 1, and then in turn B1, A7; biological indexes of the spots which have more and frequent disturbance are low.

Plant index increases with the age of stope increasing, a little low in A5 layer; plant index of earth-line area increases from B5 to B2, a little low in B1 layer; plant index of gangue-line area increases with the age. All this shows that the old terrace plant has a high stability and low friability, the young terrace has a low wireworm index, and increases with the age, the earth-line area increases from B4 to B1, C2 layer in gangue-line area has the lowest in wireworm index, and C1 layer the highest. The highest wireworm index is in A7 layer, then village surroundings and background hillside. All shows that these areas have high stability and low friability in wireworm index.

The terrace soil in stope, earth-line area and gangue-line area have high friability, and decrease with the age increasing. A1 and A2 layer of open coal mine area have the highest in friability, 12.915 and 6.416 respectively, then in turn A2 and B5, 6.263 and 5.719 respectively, farmland has the lowest 1.153, which accord with the fact that farmland depend on high investment for its stability; background has the friability of 1.528, which shows that the system without human disturbance has high stability and low friability. The product of ecological friability and ecological index is potential ecological loss index.

Table 6 shows the ecological risk indexes of heavy metals. The content of heavy metals in the surface (0–5 cm) of soil in Haizhou open coal mine area is higher that that in the subsurface, in which the contents of Cu, Zn and Cr have evident layerings, the contents of metals in coal mine area have relationship with the input from the environment. Researchers in and abroad study on the content and transference of microelements in coal (Xin-lin 2000; Yan-yu 1994), the results show that, the contents of microelements in coal vary in big scope, and even can change into more poisonous compounds, destroying and polluting the soil. The contents of Cu and Zn in Haizhou are much

Table 4 Ecological index of different fragments in Haizhou opencast coal mine

Spot	O_i	V_i	Z_i	E_i
Stope A1	0.222	0.204	0.122	0.176
A2	0.222	0.227	0.143	0.192
A3	0.444	0.204	0.224	0.276
A4	0.334	0.295	0.306	0.310
A5	0.222	0.341	0.429	0.345
A6	0.555	0.477	0.531	0.520
A7	0.667	0.704	0.633	0.666
Earth-line B1	0.555	0.704	0.796	0.703
B2	0.333	0.523	0.388	0.418
B3	0.555	0.250	0.184	0.304
B4	0.222	0.023	0.143	0.124
B5	0.000	0.000	0.061	0.025
Gangue-line C1	0.111	0.227	0.082	0.138
C2	0.444	0.182	0.224	0.269
C3	0.333	0.159	0.347	0.281
Farmland D	0.444	0.386	0.000	0.246
Village E	0.667	0.341	0.000	0.290
Background	1.000	1.000	1.000	1.000
F weight	0.265	0.332	0.404	

Table 5 Ecological frangibility degree in different fragments in Haizhou opencast mine

Spot	Plant		Plant index	Soil animal		Wireworm index	Fertility index	Stability index	Friability index
	Coverage (%)	Diversity		Diversity	MI				
Stope A1	0.085	0.000	0.049	0.467	0.171	0.342	0.398	0.077	12.915
A2	0.171	0.327	0.237	0.304	0.272	0.291	0.561	0.160	6.263
A3	0.634	0.302	0.494	0.478	0.700	0.572	0.565	0.328	3.053
A4	0.695	0.417	0.578	0.543	0.735	0.625	0.693	0.402	2.488
A5	0.634	0.248	0.472	0.239	0.687	0.428	0.588	0.281	3.555
A6	0.854	0.377	0.653	0.707	0.587	0.656	0.674	0.430	2.327
A7	0.939	0.802	0.881	1.000	0.660	0.856	0.895	0.618	1.618
Earth-line B1	0.939	0.692	0.835	0.576	0.715	0.635	0.924	0.542	1.844
B2	0.756	1.006	0.861	0.467	0.658	0.548	0.991	0.540	1.852
B3	0.512	0.578	0.540	0.196	0.493	0.322	0.550	0.259	3.859
B4	0.293	0.729	0.477	0.000	0.701	0.297	0.939	0.331	3.025
B5	0.085	0.322	0.185	0.174	0.636	0.369	0.585	0.175	5.719
Gangue-line C1	0.000	0.500	0.211	0.457	0.480	0.466	0.521	0.197	5.081
C2	0.146	0.625	0.348	0.076	0.120	0.095	0.653	0.156	6.416
C3	0.341	0.689	0.488	0.163	0.716	0.397	0.938	0.365	2.738
Farmland D	1.000	0.699	0.873	0.761	0.000	0.438	2.402	0.867	1.153
Village E	0.634	0.668	0.648	0.891	0.717	0.818	0.631	0.468	2.137
Background F	0.878	0.822	0.855	0.435	0.996	0.672	1.297	0.654	1.528

higher than those in Fuxin. In this study, Cu and Zn are chosen for ecological risk assessment.

Infinitude the value of soil erosion and landslide according to the formula: $X_i^{'} = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \times 9 + 1$, $X_i^{'}$ is in the range of 1, 10, and the product of risk degree and potential ecological loss degree is ecological risk value, which shows in Table 7. The ecological risk value is the highest in A5, so this layer should be protected, inspected and managed with emphases to avoid large scale and paroxysmal coast.

Table 6 Ecological risk index of heavy metal (Cu, Zn) in Haizhou opencast coal mine

Sample layer	Cu (mg/kg)	Zn (mg/kg)	Q (Cu)	Q (Zn)	Sum
A1	29.94	129.17	0.461	1.292	1.752
A2	41.57	157.44	0.639	1.574	2.214
A3	36.63	138.06	0.564	1.381	1.944
A4	68.40	108.05	1.052	1.081	2.133
A5	28.13	105.99	0.433	1.060	1.493
A6	105.89	150.21	1.629	1.502	3.131
A7	75.32	103.80	1.159	1.038	2.197
B1	35.51	71.75	0.546	0.718	1.264
B2	99.30	115.42	1.528	1.154	2.682
B3	73.19	91.67	1.126	0.917	2.043
B4	70.55	145.50	1.085	1.455	2.540
B5	37.66	104.33	0.579	1.043	1.623
C1	71.99	105.72	1.108	1.057	2.165
C2	62.14	119.68	0.956	1.197	2.153
C3	70.31	90.14	1.082	0.901	1.983
D	109.88	71.60	1.690	0.716	2.406
E	103.95	165.39	1.599	1.654	3.253
F	69.03	68.04	1.062	0.680	1.742

Table 7 Ecological risk value of soil erosion and landslide in Haizhou open-cast coal mine

Platform	Soil erosion risk degree	Landslide risk degree	Potential ecology loss	Soil erosion ecology risk degree	landslide ecology risk degree
A1	8.36		10.00	83.64	
A2	7.65		5.06	38.70	
A3	4.03	1.00	3.20	12.88	3.20
A4	2.35	2.65	2.85	6.70	7.57
A5	2.11	10.00	4.52	9.52	45.22
A6	1.97	4.67	4.24	8.37	19.83
A7	1.36	5.59	3.73	5.07	20.85
B1	1.99		4.47	8.87	
B2	2.83		2.75	7.79	
B3	5.00		4.42	22.12	
B4	3.22		1.70	5.45	
B5	3.92		1.62	6.34	
C1	9.10		3.21	29.22	
C2	10.00		6.72	67.24	
C3	7.36		2.90	21.31	
D	1.00		1.00	1.00	
E	1.04		2.29	2.38	
F	1.19		5.23	6.23	

The influencing degrees of ecological risk degree caused by heavy metals, soil erosion and landslide are different, the weights of the three risks are calculated with layer analytical method. Table 8 illustrates the three matrixes of risk layer analysis, in which 1 represents the same influence, 3 represents a little bit strong influence, 5 represents strong influence, 7 represents evidently strong influence, 9 represents absolutely strong influence. After calculating, the weights of each risk are: heavy metals 0.069, soil erosion 0.251, landslide 0.680, coincidence indicator CI = 0.0046, coincidence ratio CR = 0.0079, all this meets the coincidence test, and indicates that the disaccord of the matrix is in the scope of allowance. The synthesized ecological risk value is the adding of the three risks of heavy metals, soil erosion and landslide. Because that the coast risk only happens in the stope, the comparison of the ecological risks in other spots is not so clear, so the risk values of soil erosion and heavy metals are calculated separately, see in Table 9.

Sort the risk degree and ecological risk value, and divide the risk value and risk degree into four classes in combination with practical situations, see Table 10. The risk degree of stope coast is the fourth class on A5 layer, which shows that on this layer the coast is strong and frequent, then in turn A6, A7 the third class, and these terraces should be protected and administrated with emphases.

The strength of soil erosion is the fourth class on A1, A2 layer of stope and all the terraces in gangue-line area, serious; then in turn stope A3 and earth-line area, the third class. These terraces should be paid attention of soil maintaining, for plant recovery as soon as possible.

The risk of heavy metals: the fourth class on A6 of stope, B2 of earth-line area and village milieu; the third class on A2, A3, A4, A7 of stope, B3, B4 of earth-line area and farmland; the first class on B1 of earth-line area.

The combined risk value of heavy metals and soil erosion: the fourth class on stope A1 and gangue-line area C2; the third class on A2, C1.

Table 8 Judgment matrix of analytic hierarchy process for risk

	Heavy metal	Soil erosion	Landslide
Heavy metal	1	1/4	1/9
Soil erosion	4	1	1/3
Landslide	9	3	1

Table 9 Ecological risk values in different fragments in Haizhou opencast coal mine

Platform	Heavy metal Ecology risk degree	Soil erosion Ecology risk degree	Landslide Ecology risk degree	Soil erosion + metals ecology risk degree	Sum of Ecology risk degree
A1	3.21	10.00		10.00	3.88
A2	5.30	5.11		5.56	2.46
A3	4.08	2.29	1.00	2.32	2.32
A4	4.93	1.62	1.93	1.87	3.00
A5	2.03	1.93	10.00	1.37	10.00
A6	9.45	1.80	4.56	3.34	5.80
A7	5.22	1.44	4.78	1.77	5.50
B1	1.00	1.86		1.00	1.00
B2	7.42	1.74		2.70	1.55
B3	4.52	3.30		3.49	1.80
B4	6.78	1.48		2.26	1.41
B5	2.62	1.58		1.18	1.06
C1	5.08	4.07		4.44	2.10
C2	5.02	8.21		8.68	3.45
C3	4.25	3.21		3.32	1.74
D	6.17	1.00		1.59	1.19
E	10.00	1.15		2.83	1.59
F	3.17	1.57		1.32	1.11
Weight	0.069	0.251	0.680		

The combined risk value of heavy metals and soil erosion: the fourth class on stope A5; the third class on A6 and A7; the first class on bottom of earth-line area and gangue-line area, farmland, village and background hillside.

Conclusions

This study is based on the ecological risk assessment process which is approved in and abroad, that is risk resource analysis, receiver analysis, exposure analysis, harm analysis and risk assessment. For the first time, it discusses innovatively the open coal mine area ecological assessment, combining the ecological indexes, friability indexes and hazard indexes. The assessment result shows that, for the combined risk value of heavy metals and soil erosion, stope A1 and gangue-line area C2 the highest the fourth, and the third on stope A2 and gangue-line area C1, and A3, A6, B2, B3, B4, C3 the second; for the combined risk value of coast, soil erosion and heavy metals, A5 the fourth, A6, A7 the third, and earth-line area, bottom of gangue-line area, farmland, village milieu and outskirt hillside the first.

For the reason that it is the first time on open coal mine ecological assessment, uncertainty exist in the research, for example, it is difficult to determine the risk value of poisonous and hazardous substances, so the great uncertainty brings out in the extrapolation of the data between species, high dosage and low dosage, and various hazardous substances. This uncertainty needs further study, but the research processes and results of this study, have filled up the blank of open coal mine ecological assessment research, and have means of theory and innovation.

Table 10 Grade of ecological risk in opencast coal mine

Class	I	II	III	IV
Value	<2	2–4	4–7	>7
Risk degree	None	Slight	Middle	Serious

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