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Ecological Risk Evaluation and Ecological Restoration Model of Mining in the Source Area of the Yellow River Basin

Wenjia Xu [1,2], Weiling Yao [2], Zhongke Bai [1,3,4,*], Jinzhong Yang [2] and Li Li [2]

1 School of Land Science and Technology, China University of Geosciences, Beijing 100083, China
2 China Aero Geophysical Survey and Remote Sensing Center for Natural Resources, Beijing 100083, China
3 Key Laboratory of Land Consolidation and Rehabilitation, Ministry of Natural Resources, Beijing 100035, China
4 Technology Innovation Center of Ecological Restoration Engineering in Mining Area, Ministry of Natural Resources, Beijing 100035, China
* Correspondence: baizk@cugb.edu.cn

Abstract: Finding out about the ecosystem damaged by mining development and carrying out ecological risk diagnoses are important prerequisites for formulating mine ecological restoration strategies. This study established an integrated approach to quantitatively analyze mining ecological risks by combining water conservation and biodiversity conservation ecosystem service functions with natural ecological conditions, and based on these, proposes appropriate mine ecological restoration strategies. Results show that: (1) A total of 14,874.80 hm^2 of ecosystems were damaged in the Qinghai section of the Yellow River Basin, caused by mining excavation, crushing and hollow collapse, and of which 52.10% were located in national important ecological function areas and National Nature Reserves, which caused a decrease of the important ecosystem service functions of water conservation and biodiversity conservation in the area, and aggravated the ecological risks of the river source area; (2) The areas of high ecological risk and comparatively high ecological risk in the research area are 1,093,800 hm^2 and 902,100 hm^2, which accounted for 7.27% and 6.00% of the land area, respectively. Ecological risk hotspot areas are mainly distributed in the Qilian Mountains, Hehuang Valley, Sanjiangyuan and other key water systems and water sources; (3) According to the principle of "one mine, one policy", we propose five mine ecological restoration models: ecological reconstruction, artificial assistance and protection and conservation, artificial assistance, protection and conservation and natural restoration. This study provides a reliable basis for exploring the status of mining ecological risk at the source of the Yellow River and scientifically carrying out ecological restoration and risk management.

Keywords: the source region of the Yellow River; ecological risk; mine ecological restoration; Qinghai

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1. Introduction

In September 2019, China proposed a major national strategy for ecological protection and high-quality development of the Yellow River Basin, stressing the need to: "Focus on strengthening ecological protection and governance, ensuring the long-term peace and stability of the Yellow River, promoting the high-quality development of the entire river basin". As an important water supply area, the source area of the Yellow River Basin is called a "Chinese water tower", an ecological safety barrier and an important highland native germplasm bank. Because the harsh geographical and climatic conditions of the Qinghai-Tibet Plateau make its ecological conditions particularly fragile and sensitive, external human disturbances, especially the severe human disturbance of mineral development activities, are more likely to cause damage to the ecosystem, resulting in a reduction of ecosystem service functions and ecological risks. Therefore, it is urgent to carry out a diagnosis of the ecological risks of mining in the source area of the Yellow River Basin, identifying the high ecological risk area and prominent environmental problems and proposing appropriate ecological restoration and governance strategies to effectively improve the level of ecological risk management and the efficiency of ecological restoration and governance.

The current research on ecological risk mainly focuses on the ecological risk of soil pollution [1,2]: the water resources environment [3], the landscape [4,5], land degradation [6], an ecological health assessment [7] and an ecological security pattern [8]. The formulation of a scientific ecological risk diagnosis reference system and diagnostic methods is the prerequisite for scientifically diagnosing the ecological risks of mining development. The reference frame selection methods mainly include historical ecosystems, surrounding undisturbed ecosystems as reference frames, and expert definitions [9,10]. The main diagnostic technologies include remote sensing monitoring [11], scenario analysis, experimental testing [12], numerical simulation, etc. The diagnosis of mine ecological risk is usually divided into two types: direct diagnosis and indirect diagnosis. Direct diagnosis carries out ecological risk assessment by analyzing the impact of mining development on the ecological environment, ecological health, landscape patterns and other aspects. In recent years, with the construction of ecological civilization and the release of the Millennium Ecosystem Assessment [13], ecological health and ecological risk assessment based on ecosystem service functions have gradually emerged from the perspective of human welfare [14]. Li; Gao; et al. [15] proved that there is a positive correlation between the value of ecosystem services and the ecological risk index. Kang; Chen; et al. [16] discussed the feasibility and rationality of ecosystem service functions as the endpoint of ecological risk assessment. Researching ecological risk assessment based on ecosystem service functions [17], identifying ecological sources with ecosystem service functions assessment and proposing ecological security patterns [18], and assessing the degree of ecological risk in areas around cities caused by urbanization based on the value of ecological services have become the mainstream directions [19,20]. Indirect diagnosis mainly uses ecosystem self-repair and ecosystem resilience [21–23] as ecological risk assessment criteria, and carries out ecological risk assessment with bottom-line thinking. The vulnerability of the natural ecological condition also determines the sensitivity and resilience of the ecosystem under the disturbance and stress of external factors. The ecological damage, degradation degree and ecological self-repair ability caused by the disturbance and stress of mining under different natural ecological conditions are also different, and areas with fragile ecological conditions are more sensitive to external human interference and are more likely to cause higher ecological risks. However, it is difficult to fully reflect the regional ecological risk status by only assessing the ecological risks caused by mining development based on ecosystem service functions or natural ecological vulnerability. Therefore, this study uses high-resolution remote sensing technology to diagnosis the reduction of water conservation and biodiversity conservation ecosystem service functions under the stress of mining, and comprehensively integrates these with the spatial differentiation of the natural ecological condition to quantitatively evaluate ecological risk, and based on these, proposes corresponding ecological restoration strategies for each mine, so as to provide a scientific basis for the ecological protection and high-quality development of the source area of the Yellow River Basin.

2. Materials and Methods

2.1. Study Areas

This study took the main and tributary basins of the Yellow River within the administrative region of Qinghai Province as the study area (95°53′–103°4′ E, 33°1′–38°19′); in this study, we refer to it as the "source area of the Yellow River Basin" (Figure 1). The extent of the study area included Zhaling Lake and Eling Lake, which make up the original basin area of the Yellow River, to the main and tributary basins above Longyang Gorge and the alpine valley area from Longyang Gorge to Sigou Gorge, involving 35 counties (Districts) in 8 cities (Prefectures). The length of the main stream is 1694 km, which accounted for 31% of the total length, and the basin area is 153,100 km^2, accounting for 20.34% of the land area of Qinghai Province [24]. The average altitude of the study area is 3800 m, the annual average temperature is 0~4.4 °C. The study area belongs to plateau alpine climate; the average annual rainfall is between 357~647 mm, mostly concentrated in July, August and September, and the annual evaporation is 1500~1800 mm [25]. Most of the areas are semi-arid areas, a few are semi-humid areas, and a small number of areas are arid areas. The topography and landforms in the study area are high in the west and low in the east, high in the south and low in the north. The southwest belongs to the Qingnan Plateau area, the northwest belongs to the Qilian Mountains, and the northeast area belongs to the Loess Plateau area. The study area is a geographically sensitive area in Asia and the entire northern hemisphere. The landform types are mostly hilly and mountainous, and a few are river valley terraces. The northern part of the soil was mainly chestnut calcium soil, brown calcium soil and gray-brown desert soil, and the southern part was mainly alpine meadow soil, alpine shrub meadow soil, alpine steppe meadow soil and alpine desert steppe soil. There are 4077 lakes in the area, including Zhaling Lake, Eling Lake and Xingxinghai, which are the main sources of water in the Yellow River Basin. The vegetation is dominated by perennial herbaceous plant types, with fewer woody plants. The natural ecosystems are mainly three major ecosystems: alpine grassland, alpine meadow and alpine swamp wetland, which are the most important water and biodiversity conservation ecosystems in the study area [26]. Farmland ecosystems and settlement ecosystems were concentrated in the Loess Plateau geomorphological area and the Hehuang Valley area in the northeast of the study area. A forest ecosystem mainly contributed at the southeastern of the study area, which is composed of woodland, sparse forest land and alpine shrubland. Some alpine shrubland is distributed in some river valleys. The study area is also an important gene bank for plateau organisms, and is the habitat of many rare high-altitude land wildlife, such as the snow leopard (*Panthera uncia*), lynx (*Lynx lynx*), leopard cat (*Prionailurus bengalensis*), Chinese mountain cat (*Felis bieti*) and manul (*Otocolobus manul*). The unique geographical and climatic conditions, such as high altitude, cold and drought make the natural ecological condition of the study area extremely fragile. Due to the complex geological conditions in the study area, the mineralization conditions are diverse, and the types of mineral resources are also very rich. At present, a total of 52 kinds of mineral rights have been approved. These mainly are construction materials and other non-metallic mines, followed by metallurgical auxiliary raw materials, non-metallic minerals, energy minerals and non-ferrous metal minerals. The types of mines in the study area are mainly construction sand and clay for bricks and tiles, and the reserve of mineral resource is large. In addition to the concentrated distribution in the northeast of the study area, it is numerous, small and scattered in other places. Overall, the conditions and grades of mineral resources in this area are relatively poor, and high value-added mineral products and rich ores are relatively insufficient.

2.2. Data Sources

The data used in this study are shown as Table 1. The satellite remote sensing images used in this study are mainly concentrated in September to December, and the data of June to August was used to identify and interpret the damaged ecosystem. For better interpretation quality, we used GF1, GF2, ZY3, and SPOT6 types of data, of which most of the resolutions are 1 m and 2.5 m, and a few high-altitude areas are 5 m. In order to ensure the quality of data acquisition, we performed geometric accuracy correction, image registration, mosaicking, and fusion of different resolutions of image data. We checked for the quality of cloud snow coverage before the interpretation work was carried out; the cloud snow coverage rate needs to be less than 2%, and the mining rights are not stamped. The spatial resolution of land use remote sensing monitoring data is 30×30 m.

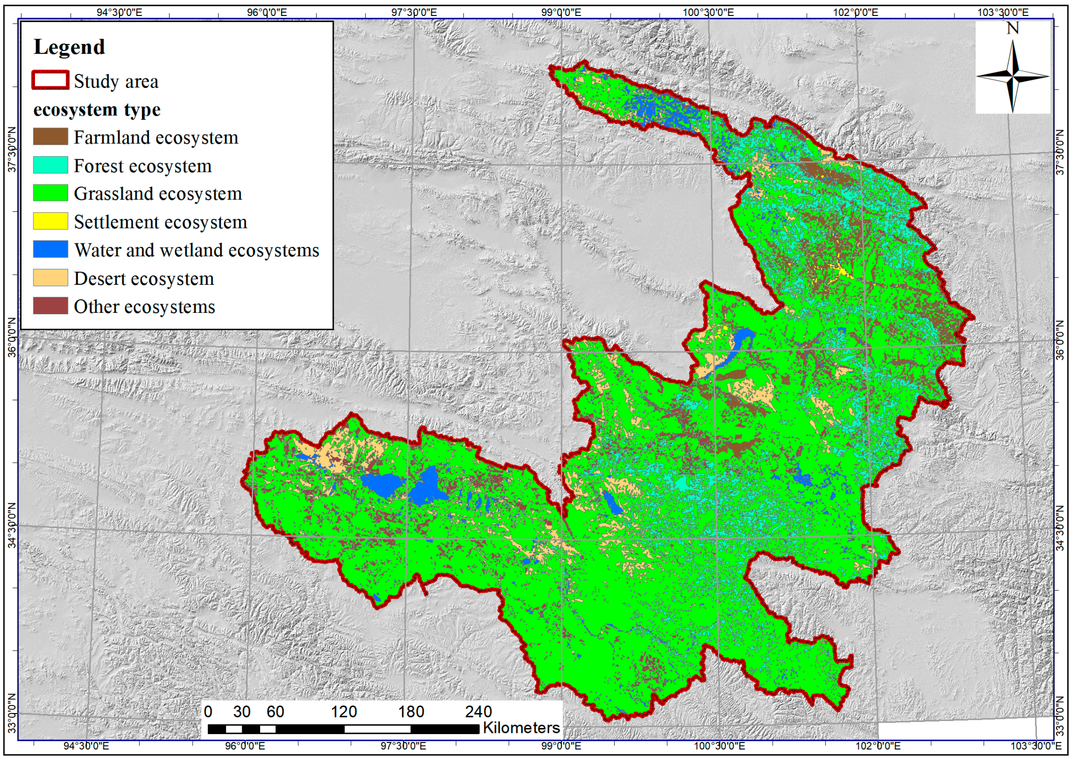

Figure 1. Schematic diagram of the distribution of ecosystems in the study area.

Table 1. Research data.

Data Name	Data Type	Data Resource
Qinghai Province's administrative boundaries	vector data	China Geological Survey
The extent of the Yellow River Basin	vector data	China Geological Survey
River systems of the Yellow River Basin	vector data	China Geological Survey
National important ecological function areas	vector data	China Geological Survey
National Nature Reserves	vector data	China Geological Survey
Historical vector data of mining environment	vector data	China Geological Survey
Satellite remote sensing images (GF1, GF2, ZY3, and SPOT6)	image data	China Geological Survey
Mining exploiting rights and prospecting rights	vector data	Information Center of the Ministry of Natural Resources
Land use remote sensing monitoring data	raster data	China land cover dataset (CLCD) [27]
Distribution of frozen soil data	vector data	the National Glaciology and Geocryology Desert Science Data Center (http://www.ncdc.ac.cn, accessed on 1 December 2000)

2.3. Methods

2.3.1. Theory Frameworks

In order to scientifically diagnose the ecological risks of mining in the study area and propose appropriate ecological restoration strategies, it is most appropriate to carry out an ecological risk diagnosis and ecological restoration with relatively complete natural geographical units of mountains, rivers and lakes, and thus, to consider the selection of damaged ecological reference systems and the integrity of natural ecosystem elements and ecosystem service functions [27]. In this study, the source of ecological risk is mineral development activities, including excavation, occupation and land subsidence, and we chose the original ecosystem type before it was damaged by mining as the reference system to carry out the ecological risk diagnosis. Based on the ecological protection objectives of the study area, we chose the stress of water conservation and biodiversity conservation ecosystem service functions to characterize the ecological stress caused by mining development. Therefore, based on the comprehensive diagnoses of the stress of water conservation and biodiversity conservation ecosystem service functions along with ecological vulnerability, we ascertained the degree of ecological risk, and scientifically propose ecological restoration strategies (Figure 2).

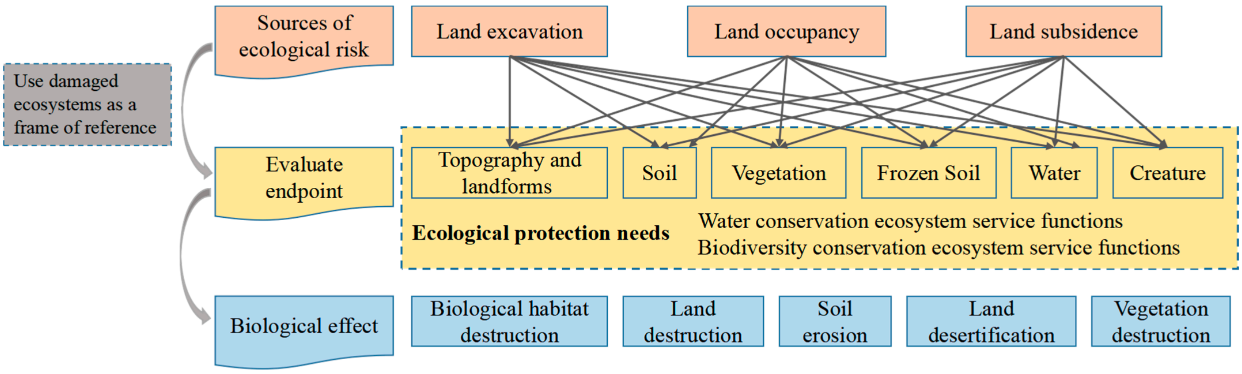

Figure 2. Schematic diagram of research ideas.

2.3.2. Extraction of Information on Mining and Damaged Ecosystems

Based on high-resolution remote sensing satellite imagery, the remote sensing interpretation of the mining environment in the source area of the Yellow River was carried out by a human–computer interactive visual interpretation, and the remote sensing information about the stope, transit site, solid waste, mine construction and underground mining collapse pit of the production mine, and abandoned mines, which included mines with a mining license and those without a mining license, were extracted, and the interpretation marks are shown in Figure 3.

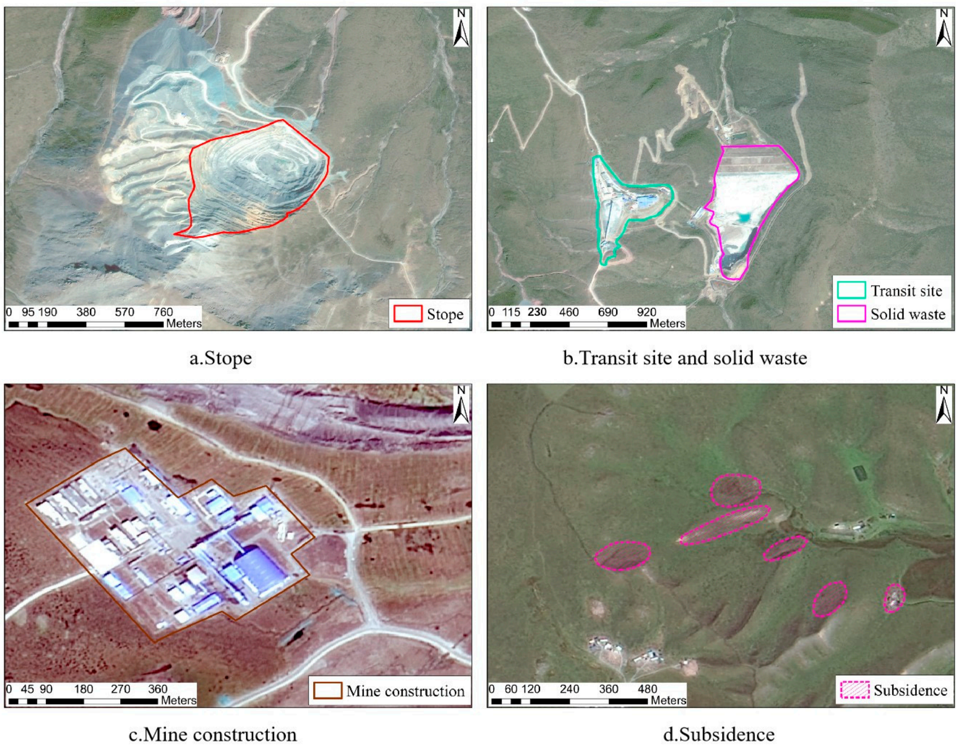

Figure 3. Mining remote sensing interpretation signs.

2.3.3. Assessment of Water Conservation Ecosystem Service Function Stress

The choice of calculation method for the water conservation index in the "Regional Ecological Quality Assessment Method (Trial)" (Environmental Monitoring (2021) No. 99) of the Ministry of Ecology and Environment was based on local practice, which can better affect the actual situation, and was improved to obtain the stress coefficient for water conservation. According to the equal-spacing sampling method of landscape ecology, a 2 km × 2 km grid in the source area of the Yellow River Basin was constructed as the evaluation unit, and the damaged area of river, lake, wetland, woodland and alpine grassland ecosystems in the study area that undertook important water conservation ecosystem service functions was used to determine the degree of the stress of mineral resources development activities on water conservation ecosystem service functions. The specific algorithm is as follows:

$$\mathrm{WRAC} = \frac{\mathrm{A_{con}} \times \{0.45\times[0.1\times \mathrm{I_a}+0.3\times \mathrm{I_b}+0.6\times \mathrm{I_c}]+0.35\times[0.6\times \mathrm{I_d}+0.25\times \mathrm{I_e}+0.15\times \mathrm{I_f}]+0.2\times[0.6\times \mathrm{I_g}+0.3\times \mathrm{I_h}+0.1\times \mathrm{I_j}]\}}{LA} \quad (1)$$

where WRAC is the stress index of the water conservation ecosystem service function, the normalization coefficient of the ACON stress index is 526.7926, $\mathrm{I_a}$ is the area of the river, $\mathrm{I_b}$ is the area of the lake reservoir, $\mathrm{I_c}$ is the tidal flats and swamp area, $\mathrm{I_d}$ is the area of forested land, $\mathrm{I_e}$ is the area of shrub woodland, $\mathrm{I_f}$ is the area of other woodland, $\mathrm{I_g}$ is the high coverage grassland area, $\mathrm{I_h}$ is the medium coverage grassland area, $\mathrm{I_j}$ is the low coverage grassland area, LA is the land area (km^2).

2.3.4. Assessment of Biodiversity Conservation Ecosystem Service Function Stress

The capacity for biodiversity conservation is directly proportional to the quality of habitat and inversely proportional to the degree of habitat fragmentation [28]. In this study, habitat quality and habitat fragmentation were used to jointly assess the stress degree of biodiversity conservation ecosystem service functions under the influence of mineral development activities.

1. Habitat quality

(1). The model calculation method

The InVEST model combines landscape sensitivity with the degree of ecological stress to calculate habitat quality, and the calculation formula is as follows:

$$\mathrm{Q_{xj}} = \mathrm{H_j}\left[1 - \left(\frac{\mathrm{D_{xj}^z}}{\mathrm{D_{xj}^z} + \mathrm{k^z}}\right)\right] \quad (2)$$

where $\mathrm{Q_{xj}}$ is the habitat quality of land use type j in raster cell x, k is the semi-saturation parameter (usually value 0.05), z is the normalization constant, which usually takes 2.5, $\mathrm{H_j}$ is the suitability of land use type J, $\mathrm{D_{xj}}$ is the degree of stress of land use type j in grid element x, which usually takes 0.5 of the maximum value. The $\mathrm{D_{xj}}$ calculation formula is as follows:

$$\mathbf{D}_{\mathrm{xj}} = \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left(w_r \Big/ \sum_{r=1}^{R} w_r\right) r_y i_{ryx} \beta_x S_{jr} \quad (3)$$

where R is the mining stress factor, y is the number of raster cells for the stress factor r raster layer, Y_r is the number of rasters occupied by the stress factor, w_r is the weight of the stress factor, r_y is the stress factor value of the raster cell y, β_x is the reachability level of grid x, S_{jr} is the sensitivity of habitat type J to stress factor R, i_{ryx} is the stress factor value of raster y and the level of stress on habitat raster cell x.

(2). InVEST habitat quality model parameters

In this study, the habitat quality under mining disturbance was calculated by taking the direct disturbance of ecosystems, such as mining dipping, crushing, mining collapse and mine geological disasters, as stress factors. According to previous research results [29], as well as field research experience and experts' opinions, the information of threat factor attributes and the land use sensitivity index are shown in Table 2.

Table 2. Sensitivity of different land-use types to threat factors.

Threat Factors			Mining	Road and Other Construction Land	Urban Land and Rural Settlement	Arable Land
Weight			1	0.8	1	0.3
Maximum impact distance/km			10	8	5	3
Decayed type			Exponential	Linear	Exponential	Linear
Land use type						
Level 1 class	Level 2 class	Suitability	Sensibility			
Arable land	Arid land	0.4	0.4	0.2	0.3	0
Forest land	Forest land	1	0.6	0.4	0.5	0.3
	Shrub wood	1	0.25	0.15	0.2	0.1
	Thinning woodland	1	0.15	0.05	0.1	0.05
	Other woodland	1	0.15	0.05	0.1	0.05
Grassland	High coverage grassland	1	0.6	0.4	0.5	0.3
	Medium coverage grassland	0.8	0.3	0.15	0.2	0.1
	Low coverage grassland	0.7	0.1	0.04	0.05	0.03
Waters	River	1	0.1	0.04	0.05	0.03
	Lake	1	0.3	0.15	0.2	0.1
	Pond	0.6	0.5	0.2	0.4	0.1
	Permanent glacier	1	0.1	0.05	0.05	0
	Flood land	0.6	0.5	0.3	0.4	0.2
Urban and rural resident land, industrial and mining land, residential land	Town land	0	0.3	0	0	0
	Rural settlements	0	0.4	0	0	0
	Other construction land	0	0.3	0	0	0
Unused land	Sandy land	0	0	0	0	0
	Gobi	0	0	0	0	0
	Salinate field	0.1	0	0	0	0
	Marshland	0.6	0.5	0.3	0.4	0.2
	Bare land	0	0	0	0	0
	Bare rock texture	0	0	0	0	0
	Other land	0	0	0	0	0

2. Habitat fragmentation

The formula for calculating habitat fragmentation is as follows:

$$C_i = n_i / A \quad (4)$$

where C_i is type i habitat fragmentation, n_i is the number of patches in type i habitats, and A is the area of the sample area.

2.3.5. Assessment of Ecological Vulnerability

According to the characteristics of natural ecological conditions and the regional distribution of ecological functions in the study area, we select five indicators to evaluate ecological vulnerability: elevation, rainfall, the degree of damage to the permafrost, important ecological function areas and distance from water systems. Important ecological regions mainly include important ecological function areas and National Nature Reserves. Important ecological function areas are areas that undertake important ecosystem service functions such as water conservation, soil and water conservation, wind and sand fixation, and biodiversity conservation to ensure the national ecological security pattern. National Nature Reserves are special protection and management areas designated for the protection of typical natural ecosystems, habitats of rare and endangered wild animal and plant species, and natural relics. Thus, 10 km is the threshold range for the river ecological corridor effect [30]. In order to make the research results more reflective of the actual situation, we chose the Analytic Hierarchy Process (AHP) method to determine the index weight. The ecological vulnerability assessment index system is shown in Table 3.

Table 3. Table of ecological vulnerability assessment index system.

Target Layer	Level 1 Indicators	Weight	Level 2 Indicators	Weight
Ecological vulnerability	Elevation	0.15	Middle altitude (1000~3500 mi)	0.2
			High altitude (3500~5000 mu)	0.3
			Extremely high altitude (>5000 me)	0.5
	Rainfall	0.2	Arid zone (<200 mmo)	0.5
			Semi-arid area (200~400 mm)	0.3
			Semi-humid area (400~800 mmd)	0.2
	The degree of damage to the permafrost	0.2	Permafrost	0.7
			Seasonal permafrost	0.2
			Frozen soil free distribution	0.1
	Important ecological function areas	0.25	The overlap extent of important ecological functions area and national nature reserves	0.6
			Important ecological function areas/national nature reserves	0.3
			General area	0.1
	Distance from water system	0.2	10 km extent of the mainstream/1 km extent of water sources	0.6
			10 km extent of the main tributary	0.3
			More than 10 km away from the water system	0.1

2.3.6. Method of Zoning

The spatial weighted overlay method was used to analyze the weighted superposition of the stress of water conservation and biodiversity conservation ecological service functions and the ecological vulnerability assessment results. We used ArcGis' Natural Breaks method to divide the ecological risk of mining into five levels: high ecological risk area, comparatively high ecological risk area, general ecological risk area, comparatively low ecological risk area and low ecological risk area. Among these, we chose the Hot Spot analysis method to check the distribution and aggregation of the ecological risk characteristic values of mining in the study area. Hotspot areas are high characteristic values-concentrated areas.

3. Results

3.1. Ecological Stress of Mining

3.1.1. Characteristics of Mining and Ecosystem Damage

As of 2020, the ecosystem damaged area caused by mining in the source area of the Yellow River Basin was 14,874.80 hm^2. The methods of exploiting were mainly open-pit mining, and the excavation (stope), occupation (including transit site, solid waste, mine construction) and collapse pits caused by mining were 7052.61 hm^2, 7496.70 hm^2 and 325.49 hm^2, accounting for 47.41%, 50.40% and 2.19% of the total damaged area. The ecological negative effects caused by open-pit mining are about twice as much as underground mining [31]. The large number of open-pit mines stripped of rock and soil, excavated mineral resources and dumped solid waste caused serious damage to land resources and their overlying ecosystems, which are the main driving factors of the reduction of ecosystem service functions and ecological risk. The types of mines are mainly energy mines and non-metallic mines. The ecosystem areas damaged by energy mining, metal mining and non-metal mining were 5792.69 hm^2, 1167 hm^2 and 7915.11 hm^2, which accounted for 38.94%, 7.85% and 53.21%, respectively. The main types of mines are coal, construction sand, clay for bricks and tiles and copper mines, and the ecosystem damaged by mining accounts for 38.94%, 27.75%, 9.59% and 4.00%, respectively. The coal mines are mainly concentrated in the northern part of the study area, the southern edge of the Qilian Mountains, and the ecological function area of glacier and water conservation in the Qilian Mountains. Metal mines are mainly scattered in the eastern part of the study area, the transition area of the Qinghai-Tibet Plateau and the Loess Plateau, Xinghai County, Maqin County, Zhaling Lake and the northwest and north of Eling Lake. Non-metallic mines are widely distributed in the study area, but mainly distributed in the north-central region. Mining has caused serious ecological damage to national important ecological function areas and National Nature Reserves. The areas damaged by mining in national important ecological function areas, National Nature Reserves and the overlapping areas of the two areas were 7610.54 hm^2, 375.27 hm^2 and 236.77 hm^2, respectively, of which the damaged areas of grassland, forest and water bodies and wetlands were 5144.81 hm^2, 330.34 hm^2 and 225.28 hm^2. Alpine grassland ecosystems were the most severely damaged by mining, which accounted for 56.30% of the total area damaged by mining, and then followed settlement ecosystems, farmland ecosystems, forest ecosystems, water and wetland ecosystems, deserts and other ecosystems (Figure 4, Table 4).

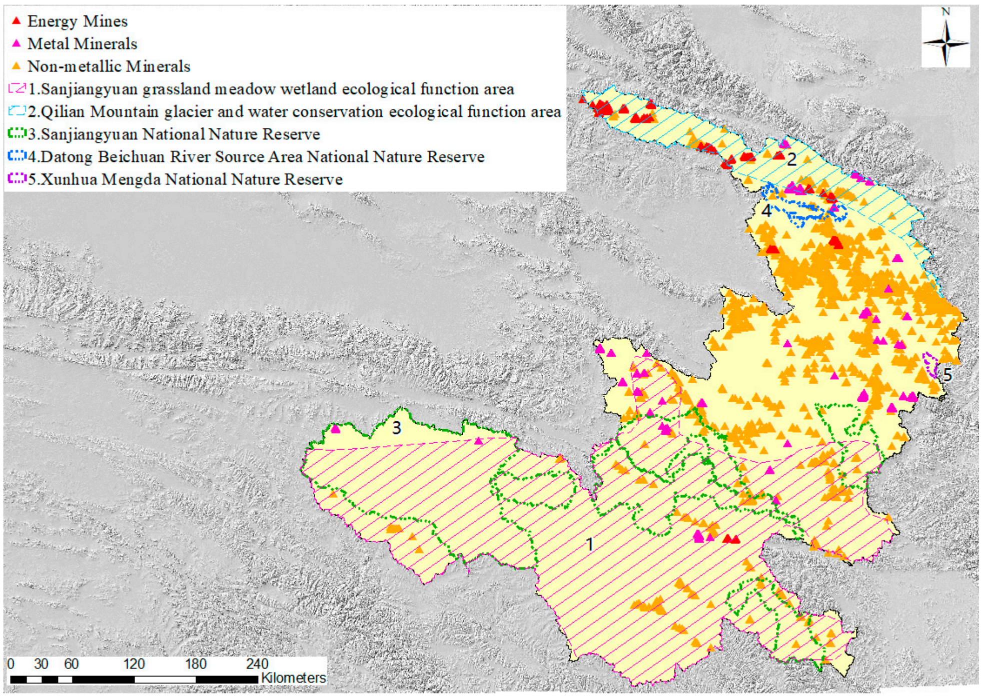

Figure 4. Distribution map of mines.

Table 4. Ecosystems damaged by mining.

	Stope	Transit Site	Solid Waste	Mine Construction	Mining Collapse	Total
Farmland ecosystem	4.81%	5.77%	0.70%	0.96%	0.00%	12.24%
Forest ecosystem	2.05%	0.71%	1.89%	0.54%	0.46%	5.66%
Grassland ecosystem	26.81%	9.57%	14.88%	3.38%	1.66%	56.30%
Settlement ecosystem	10.08%	1.87%	3.81%	1.49%	0.06%	17.31%
Water and wetland ecosystems	2.21%	0.74%	1.64%	0.21%	0.00%	4.80%
Desert ecosystem	0.03%	0.09%	0.11%	0.00%	0.00%	0.23%
Other ecosystem	1.42%	0.57%	1.40%	0.06%	0.00%	3.45%
Total	47.41%	19.32%	24.44%	6.64%	2.19%	100.00%

3.1.2. Stress Status of Water Conservation Ecosystem Service Function

The stress of the water conservation ecosystem service function caused by mining in the source area of the Yellow River Basin is shown in Figure 5. It can be seen that the highly stressed water conservation ecosystem service function areas are distributed in the eastern part of Tianjun County, the northern part of Gangcha County and the northwest of Ping'an District. Among them, the highly stressed water conservation ecosystem service function areas in the north of Tianjun County and the northern part of Gangcha County are located in the core area of the glacier and water conservation ecological function area of Qilian Mountain, which is the source of many important tributaries of the Yellow River Basin. Open-pit and underground mining of coal has caused large-scale destruction of high, medium and low coverage grassland, alpine meadow, swamp, wetland and flood land, that resulted in damage to the water conservation ecosystem service function. In the northwest of Ping'an District, the highly stressed water conservation ecosystem service function area is caused by concentrated, continuous mining of construction diorite, which destructed a large amount of medium and high coverage grassland. The comparatively highly stressed water conservation ecosystem service function areas are widely distributed in the study area, among which they are more concentrated in the Loess Plateau landform area and the Sanjiangyuan grassland meadow wetland ecological function areas. The stress was mainly caused by coal mines that damaged medium and low coverage grassland and other construction land and construction sand mining that damaged medium and low coverage grassland and other water conservation ecosystems, which resulted in damage to the water conservation ecosystem service functions. Moreover, there are 15 highly stressed water conservation ecosystem service function areas distributed in the surrounding area of the first-order stream. They are located in the upper reaches of Longyangxia Reservoir, the upstream and downstream of the Lijiaxia Reservoir and the main branch of the Yellow River, respectively. The types of mines mainly are construction sand and clay for bricks and tiles mines, which damaged medium and low coverage grassland, farmland, canals and flood land. Mineral development activities around the reservoir, especially sand mining along the river channel, more easily cause loose soil quality of river beaches, increasing the content of sediment in rivers, aggravating soil erosion, water pollution and other ecological problems.

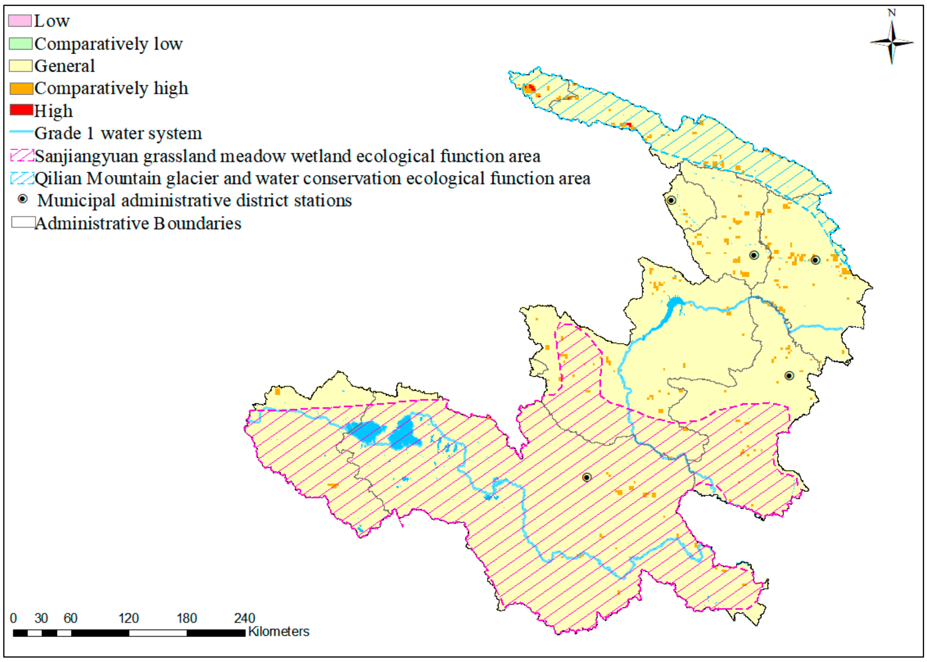

Figure 5. Distribution map of water conservation ecosystem service function stressed area.

3.1.3. Stress Status of Biodiversity Conservation Ecosystem Service Function

Using the Hot Spot analysis method, we obtained the distribution of the stressed biodiversity conservation ecosystem service function hotspot areas (Figure 6). Under the disturbance of mining, the hotspot areas are mainly distributed in Tianjun County, Gangcha County and Menyuan Hui Autonomous County, and other Qilian Mountain glacier and water conservation ecological function areas, as well as the areas bordering on Xining City and Haidong City, like Gonghe County, Guide County and Guinan County. These areas are the main human concentration area, an agricultural area and an animal husbandry area. Extensive human activities and the exploitation of mineral resources, like the mining of gypsum, limestone, limestone for cement, limestone for building stone, dolomite, quartzite, construction sand, clay for bricks and tiles, construction diorite, construction granite, cement marble and other construction materials and non-metallic minerals, as well as a small number of coal mines, iron ore mines, lead ore mines and metallurgical quartzite mines, have damaged large amounts of cultivated land and medium and low coverage grassland. The reduced vegetation cover and increased habitat fragmentation led to a decrease in habitat quality, destruction of livestock environments and living spaces and weakening of biodiversity conservation capacity. Additionally, they seriously disrupted the balance of the farmland cultivation layer and microbial ecosystem, which led to a decrease in the productivity of arable land. Then, we considered the ecological function areas of glacier and water conservation in Qilian Mountain. These areas are important habitats for rare, protected animals and plants in China, such as the wild yak (*Bos mutus*), Tibetan wild ass (*Equus kiang*), white-lipped deer (*Przewalskium albirostris*), snow leopard (*Panthera uncia*), rock sheep (*Pseudois nayaur*), cordyceps (*Cordyceps*), snow lotus (*Saussurea involucrata (Kar. et Kir.) Sch.-Bip.*), as well as marmots (*Marmota bobak*), eagles (*Hawk*), snow chickens (*Tetraogallus*) and other wild animals and a variety of plateau insects. Mineral development activities have caused large-scale destruction of high coverage, medium coverage and low coverage grasslands, flood lands and swamps, resulting in a decrease in habitat quality and a continuous encroachment on and destruction of living space and food, affecting the balance of biological chains and reducing the capacity for biodiversity conservation. The hotspot areas of stressed biodiversity conservation ecosystem functions are distributed in Gonghe, Guide and Gui'an counties, which are located around Longyangxia Reservoir and Lijiaxia Reservoir. The area is a habitat for a variety of trees, such as the white poplar (*Populus tomentosa Carr*), abies fargesii (*Abies fargesii Franch.*) and pinus armandi (*Pinus armandii Franch.*), the cormorant (*Phalacrocorax carbo*), tadorna ferruginea (*Tadorna ferruginea*), blue eared pheasant (*Crossoptilon auritum*) and other birds, the vulpes ferrilata (*Vulpes ferrilata*), wild wolves, bharal (*Pseudois nayaur*), orocapra gutturosa (*Procapra przewalskii*), wapiti (*Cervus canadensis*), otter (*Lutra lutra*), manul (*Otocolobus manul*), lynx (*Lynx lynx*) and other wild animals. The mining of construction sand and clay for bricks and tiles has caused the destruction of large-scale alpine grassland, forested land, arable land, flood land and other animal and plant habitats, and these ecological environmental impacts have expanded along a "point to line to surface" [32], and the actual ecological damage is much greater than the damaged area on the surface.

3.2. Mining Ecological Risk Spatial Zoning

We used the Natural Breaks method to divide the mining ecological risk areas into five levels: a high ecological risk area, comparatively high ecological risk area, general ecological risk area, comparatively low ecological risk area and low ecological risk area. The areas of high ecological risk area, comparatively high ecological risk area, general ecological risk area, comparatively low ecological risk area and low ecological risk area are 1,093,800 hm^2, 902,100 hm^2, 6,625,300 hm^2, 3,041,800 hm^2 and 3,380,100 hm^2, accounting for 7.27%, 6.00%, 26.63%, 20.22% and 22.47%, respectively (Figure 7). In general, the proportion of high ecological risk area and comparatively high ecological risk area in the study area are relatively high. It is urgent to eliminate the influencing factors of ecological risk through mine ecological restoration measures to reduce the ecological damage and ecological risk caused by mining.

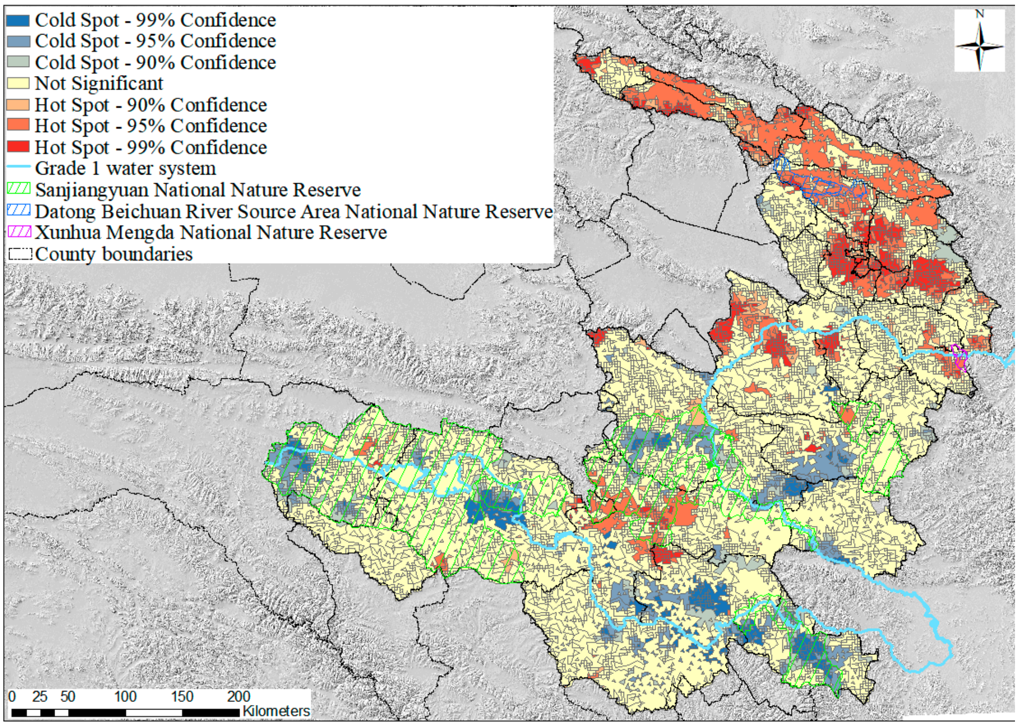

Figure 6. Distribution map of stressed hotspot areas of biodiversity conservation ecosystem service functions.

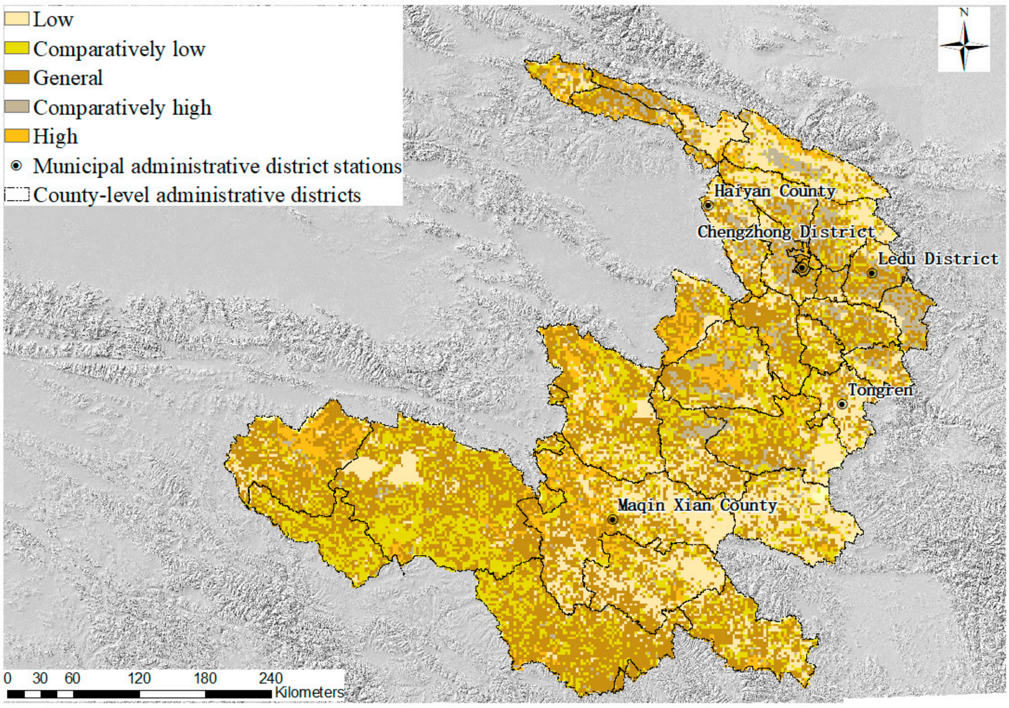

Figure 7. Distribution map of ecological risks of mining in the source area of the Yellow River Basin.

3.3. Distribution of Ecological Risk Hotspot Areas for Mining

We used the Hot Spot analysis tool to analyze the ecological risks of mining (Figure 8). It can be seen that the ecological risk hotspot areas are mainly distributed in Tianjun County, Gangcha County, Qilian County, Haiyan County, Huangzhong District, Chengbei District, Chengxi District, Chengzhong District, Chengdong District, Mutual Assistance Tu Autonomous County, Ping'an District, Ledu County, Gonghe County, Guinan, Guide

County, Xunhua Salar Autonomous County, Maqin County, Gander County and Qumalai County. Except for Tianjun County, Gangcha County and Datong Hui Tu Autonomous County, the ecological risks were mainly caused by the mining of coal. Other areas were mainly caused by the open-pit mining of non-metallic minerals, especially the non-metallic construction mines. According to the stress degree of the ecosystem service function and the natural ecological conditions, combined with relatively complete natural geographical ecological units such as mountain ranges, river and lake basins [33], we obtained four ecological risk hotspot areas: the ecological risk area of important water conservation ecosystem service function area of Qilian Mountain, Hehuang Valley Town ecological risk area, the ecological risk areas of river systems and water sources and the Sanjiangyuan ecological risk area.

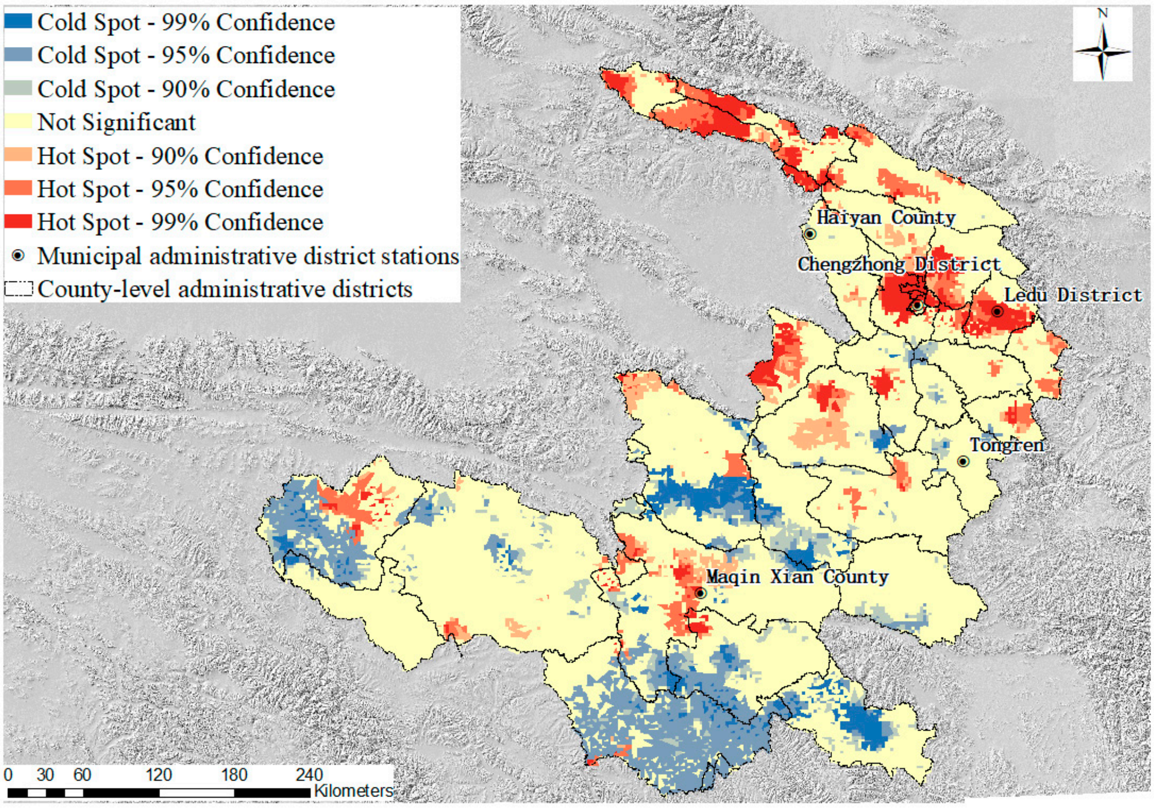

Figure 8. Distribution map of ecological risk hotspot areas of mining in the source area of the Yellow River Basin.

3.3.1. Ecological Risk Area of Important Water Conservation Ecosystem Service Function Area of Qilian Mountain

The ecological risk hotspot areas of important water conservation ecosystem service function area of Qilian Mountain are distributed in Tianjun County, Gangcha County, Qilian County and Haiyan Count. The open-pit and underground mining of coal mines that damaged the alpine grassland and other water conservation ecosystems are the main factors for the reduction of water conservation ecosystem function and the accumulation of high ecological risks. With an average altitude of 4000 m, this area, located in a semi-arid area with a fragile ecological condition, extensive development of plateau meadow swamps and continuous permafrost is an important water conservation ecological function area in the study area, and is the source of the Datong River, which is an important tributary of the Yellow River. The coal resource reserves in the region are small and the storage conditions are poor; the coal-bearing strata are roughly spread along the NW-SE direction, and the method of exploitation of coal mining is mainly open-pit or shallow well mining and the scale is generally large, such as the Muli Coal Mine and Jiangcang Coal Mine. Coal mines' open-pit mining stopes, dumps, gangue piles and so on damaged on a large scale alpine grasslands, alpine meadow wetlands and permafrost [34]. Alpine grasslands and alpine meadow wetlands are important water conservation carriers in the source area of the Yellow River Basin, and their large-scale damage has caused an increase in the evaporation of surface water and a decrease of the water conservation capacity. The destruction of the permafrost breaks the balance between the upper and lower aquifers of the frozen layer [35], turns groundwater into pit water, seriously affects the amount and quality of groundwater, and leads to ecological problems, such as reduced water conservation and water pollution. The large amount of spoil discharged at the dumping site not only causes regional topography and geomorphological changes, but also changes the surface stress, resulting in surface cracks, affecting surface runoff and aggravating soil erosion. Meanwhile, high altitude, cold and drought, soil reconstruction, vegetation restoration and other ecological restoration key technologies are not yet mature, resulting in a high cost and the difficulty of ecological restoration in this area, which increases the ecological risk level of the region.

3.3.2. Hehuang Valley Town Ecological Risk Area

The ecological risk hotspot areas are distributed in Huangzhong District, Chengbei District, Chengxi District, Chengzhong District, Chengdong District, Mutual Aid Tu Autonomous County, Ping'an District, Ledu County, Guide County and Xunhua Salar Autonomous County. The superposition and distribution of human activities such as mining, arable land reclamation and urban construction are the main factors causing the agglomeration of high characteristic values of ecological risk. This area belongs to the transition zone between the Qinghai-Tibet Plateau and the Loess Plateau, a sub-cold plateau zone and temperate semi-arid zone, with an average altitude of about 2200 m, which is a concentrated area of human activities and an extremely important agricultural area in the Huangshui Valley. As many as 61.01% of mines are distributed in the ecological risk area's 22.44% of the study area, mainly for construction sand, clay for bricks and tiles, granite, limestone, dolomite, diorite, basalt, gypsum, fluorite, quartzite, brick shale, cement marble and other construction materials and non-metallic ores. Thus, a small amount of coal mines are distributed in the southern part of Datong Hui Tu Autonomous County. The coal piles and gangue piles generated by the underground mining of coal damaged on a large scale medium coverage grassland and urban land, and the land collapse formed after hollowing out mineral resources destroyed a large area of medium coverage grassland and a small amount of thinned forest land, which seriously threatens the safety of the urban living environment. At the same time, small-scale, scattered and densely distributed non-metallic mines have seriously damaged the surface cover and arable land resources, which has aggravated ecological and environmental problems such as habitat fragmentation, desertification of the Loess Plateau, land desertification, soil erosion and so on. In severe desertification areas, sand has approached or even covered highways, posing a serious threat to traffic arteries and the safety of the human living environment. Habitat fragmentation has also led to poor connectivity of ecological patches, which reduced the living space of animals and plants, causing the reduction of biodiversity conservation ecosystem service function. This area is a habitat for a variety of important rare wild animals and plants such as cordyceps (*Ophiocordyceps sinensis (Berk.) G.H. Sung, J.M.Sung, Hywel-Jones & Spatafora*), white-lipped deer (*Przewalskium albirostris*), snow leopard (*Panthera uncia*), rock sheep (*Pseudois nayaur*), horse musk deer (*Moschus chrysogaster*), red deer (*Cervus canadensis*) and eagle owl (*Bubo bubo*), and human activities such as mining have seriously affected the range of animal activities and the species richness. Not only that, but mining has also dug up a large amount of cultivated land, stripped it of the original cultivation layer, and occupied the cultivated land by abandoning surrounding rock, ore piles and solid waste piles, resulting in the destruction of the cultivated layer of arable land, causing a decline in its production capacity, and even the serious loss of land production functions.

3.3.3. Sanjiangyuan Ecological Risk Area

The ecological risk hotspot areas in the Sanjiangyuan ecological risk area are mainly distributed in Gander County and Maduo County, which are located in the overlapping important ecological function area of the Sanjiangyuan grassland meadow wetland ecological function area and the Sanjiangyuan National Nature Reserve. Gander County is habitat to a variety of wild animals, like snow leopards (*Panthera uncia*), lynx (*Lynx lynx*), wild asses (*Equus hemionus*), yellow sheep (*Procapra przewalskii*), rock sheep (*Pseudois nayaur*), snowcocks (*Tetraogallus*), bears, deer, musk deer and so on. Maduo County is the core headwaters of the Yellow River and a key area for water conservation in the Yellow River Basin. The average altitudes of the two counties are all above 4000 m, and they are located at the foot of the Animaqing Mountain and Bayan Kara Mountain, respectively, which belong to the category of alpine landforms. Their natural ecological conditions are more fragile and sensitive due to the extremely high altitude, cold and drought, and mine ecological restoration is more difficult to carry out. Moreover, bare land, plateau desert, sandy land and low coverage of vegetation are the main factors that result in decrease of water conservation and biodiversity conservation ecosystem service functions, aggravating the ecological risk level in the region.

3.3.4. Other Ecological Risk Areas of River Systems and Water Sources

The ecological risk hotpot areas of the river systems and water sources in Gonghe County and Gui'nan County are located on the east and west sides of Longyangxia Reservoir, respectively. The hotspot areas are mainly caused by the mining of construction sand and clay for bricks and tiles that has damaged on a large scale alpine grassland and flood land. Thus, large areas of bare land and low coverage grassland surroundings jointly result in the concentration of high ecological risk characteristic values in the area. Moreover, a small amount of underground mining of copper in Guinan occupied medium coverage grassland, also exacerbating the ecological risk in the area. The mining of mineral resources around reservoirs and water sources not only destroyed large amounts of vegetation and damaged animal and plants' habitats, but also increased the risk of water pollution of water sources.

3.4. Ecological Restoration Model

Ecological restoration refers to the process of using engineering measures, biological measures and other technical means to assist degraded and damaged ecosystems to return to positive succession. For different ecological damage and ecological risk levels, we adopted a differentiated ecological restoration model to carry out mine ecological restoration and governance scientifically and reasonably, so as to avoid secondary damage to the ecosystem caused by excessive restoration and insufficient restoration measures that cannot help the damaged ecosystem achieve positive succession effects. Based on the results of the ecological risk analysis of mining in the study area, in accordance with the principle of "one mine, one policy", taking the same mining object as a unit, following the principle of natural restoration as the main and artificial restoration as the supplement, we proposed that 122, 48, 452, 22 and 853 of the 1497 mines in the study area adopt ecological reconstruction, artificial assistance + protection and conservation, artificial assistance, protection and conservation, and natural restoration and restoration 5 restoration modules, respectively (Figure 9, Table 5).

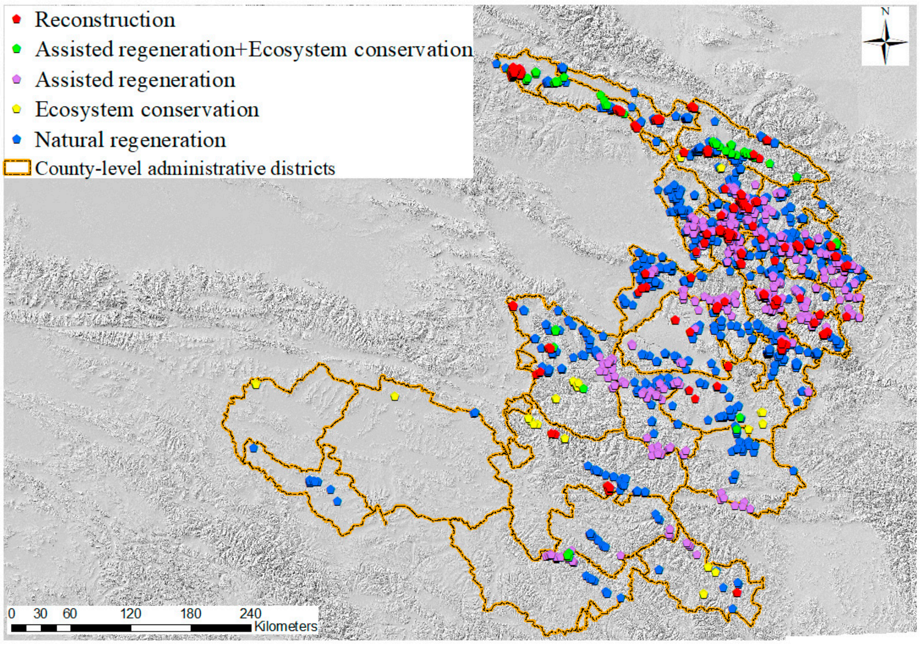

Figure 9. Distribution map of mines' ecological restoration models.

Table 5. Direction of mines' ecological restoration.

Ecological Risk Areas	Prominent Ecological and Environmental Issues	Ecological Restoration Direction
Ecological risk area of important water conservation ecosystem service function area of Qilian Mountain	Alpine grasslands, alpine meadows, wetlands, permafrost are destroyed, water conservation ecosystem service function reduced	Restore damaged terrain, vegetation and biological populations, maintain and improve the water conservation ecosystem service function
Hehuang Valley Town ecological risk area	Arable land destroyed, intensified desertification, soil erosion and danger to the living environment's security	Repair damaged arable land, eliminate hidden dangers of geological disasters, treat slopes of high and steep mining surfaces, and solidify water and soil
Sanjiangyuan ecological risk area	Sanjiangyuan ecological risk area	Sanjiangyuan ecological risk area
Ecological risk areas of river systems and water sources	Water and biodiversity conservation ecosystem service functions are reduced, ecological corridor effects are weakened, water pollution risks increased	Repair damaged river corridors and riparian flood land's vegetation, dredge river channels, eliminate hidden dangers of environmental pollution, strengthen water quality and water quality supervision, strengthen soil erosion control

4. Discussion

4.1. Analysis of the Factors Influencing the Spatial Difference of Mining Ecological Risk

Mining methods are closely related to mining ecological risks. According to the results of the analysis of mining development and ecosystem damage characteristics obtained by monitoring, it is found that the excavation loss and crushing of open-pit mining are the most important driving forces for ecological risk in the study area. The large-scale excavation loss caused by open-pit mining, as well as the stripping and pressing of surrounding rock and topsoil, caused damage to ecosystems with important ecological functions such as woodlands, grasslands, water areas and wetlands. This was the most important reason for the reduction of the ecosystem service functions of water conservation and biodiversity conservation in the study area, and aggravated the degree of ecological risk. This conclusion is consistent with Bernhardt; Lutz; et al. [36] proposed that open-pit mining changes surface cover, resulting in reduced water quality and water flow, and biomass damage; Yao; Yu; et al. [37] proposed that mine land excavation loss and solid waste occupation are the main causes of land degradation; and Gu; Xu; et al. [31] proposed that the ecological cost per unit of raw ore obtained by open-pit mining is about twice that of underground mining.

The stress degree of mining development and the spatial heterogeneity of the fragility of natural ecological conditions jointly affect the spatial differences of mining ecological risks. According to the diagnosis results of the mining ecological risk analysis, the hotspot areas were mainly distributed in the Qilian Mountains, Hehuang Valley, the Sanjiangyuan Water Source Conservation Ecological Function Area and other water systems and water source areas. This is basically consistent with the spatial distribution pattern of mining intensity and ecological fragility. The above four areas are typical ecologically fragile areas in the study area. The Qilian Mountains and Sanjiangyuan are important ecological function areas, ecosystems and plateau biodiversity conservation areas in the study area, with fragile natural ecological conditions and high sensitivity. Hehuang Valley is a key human activity area in the study area, and the cultivation of arable land and the expansion of urban construction land have reduced the quality of habitat in this area. Other water systems and water sources are sensitive areas for water resources environmental protection. From the spatial distribution of the stress degree of water conservation and biodiversity conservation ecosystem service functions caused by mining development, it can be seen that the highly stressed areas of the water conservation ecosystem service function and the hotspot stressed area of the biodiversity ecosystem service function are mainly distributed in the important water conservation ecological function area of Qilian Mountain, the Hehuang Valley and the Longyangxia Reservoir. In the above four regions, the distribution of the highly stressed areas of the two ecosystem service functions is highly overlapping, so it causes the agglomeration of high characteristic values of ecological risks. In addition, the ecological risk in the Sanjiangyuan area is mainly due to the concentration of contiguous low vegetation cover, coupled with the disturbance of mineral development activities. This conclusion is consistent with the conclusion reached by Wang; Cheng; et al. [38] and Zhao; Zhou; et al. [39] that grassland degradation and ecosystem service functions are reduced under the influence of human activities in the Sanjiangyuan area. It is of great significance to identify the status and distribution of ecological risks in the Qinghai section of the Yellow River Basin caused by mining development, and to improve the risk management level of the source area of the Yellow River Basin, as well as scientifically guide the ecological restoration of mines and the ecological protection and high-quality development of the Yellow River Basin.

4.2. Optimization of Mining Ecological Risk Assessment Methods

The development of reasonable assessment methods is a key prerequisite for scientifically diagnosing mining ecological risks. However, there are currently no clear criteria and diagnostic methods for the diagnosis of mining ecological risks. In previous studies, the mining ecological risk assessment was mostly carried out from a single angle and a single approach. Chang; Qiu; et al. [40] proposed a theoretical framework for mining ecological risk diagnosis based on land destruction. Wayne; Rea; et al. [41] propose to use ecosystem service functions as the evaluation endpoint, so as to improve the value of risk assessment for environmental decision-making. Vighi; Rico; et al. [23] elaborated on the need to introduce the concept of resilience into ecological risk assessment (ERA). In order to make the evaluation results more comprehensive and more in line with the actual situation, this study optimized the methodological framework of mining ecological risk assessment, and combined the stress effect of mining development with natural ecological vulnerability to jointly carry out ecological risk assessment. Firstly, the ecological stress index of water conservation based on local practice was used to characterize the stress degree of mining development on the water conservation ecosystem service function. We used habitat quality and habitat fragmentation, which characterize landscape patterns, to comprehensively evaluate the stress degree of mining development on biodiversity ecosystem service functions. Secondly, we carryied out the natural ecological vulnerability assessment by using five types of evaluation indicators: elevation, rainfall, types of damaged permafrost, types of important ecological regions, and distance from water system. Finally, the weighted superposition analysis of the two was carried out to perform the assessment of mining ecological risk more comprehensively. The optimized assessment method is more targeted and can diagnose the degree of ecological risk more scientifically.

4.3. Mine Ecological Restoration Policy Recommendations

Based on the characteristics of mining development and the ecological risks diagnosis results, the following policy suggestions for mine ecological restoration are proposed:

(1) Strengthen early warning and monitoring of mining ecological risks. Regularly carry out monitoring of the mining environment and ecological damage, and find out the changes in mining development and ecological damage. Formulate early warning standards for ecological risks in mining development, carry out early warning assessments of mining ecological risks, and dynamically adjust monitoring indicators and priorities according to actual conditions. Strengthen the frequency of monitoring and assessment in important areas and key ecological function areas promptly stop mining development activities in areas with high ecological risks, and strengthen the management and control of ecological risks.

(2) Carry out supervision of mining development by zoning classification. According to the early warning and monitoring of mining ecological risks, carry out zoning and classification supervision measures for different ecological protection needs and different degrees of ecological risk areas. For areas with high ecological risks, in principle, stop all human-made disturbance activities that aggravate ecological risks, such as mining development, and carry out ecological restoration and governance in a timely manner to control the trend of ecological deterioration. For medium- and low-risk areas, clarify the main responsibility for mine restoration and governance, strengthen the monitoring and management of production mines "while mining", and strengthen the comparison of previous monitoring results. If the ecological risk increases, the mine development enterprise shall be promptly required to strengthen protection and restoration, and the subsequent failure to improve or refuse to rectify shall result in its being punished or shut down.

(3) Increase policy support for mine restoration and governance. Research a tax super-deduction of the restoration and treatment costs of mine development enterprises, and provide financial subsidies for mine restoration and treatment projects in important ecological function areas. Encourage innovative ecological restoration governance models, and actively attract other capital to jointly manage and develop eligible mines into mining parks, industrial attractions, etc. Regularly organize and carry out the selection of mine restoration and governance cases, give financial and other rewards to mining enterprises with good restoration and governance effects, and promote their advanced experience and practices.

4.4. Shortcomings and Prospects

In this study, based on the current situation of mining development, we used high-resolution remote sensing technology to quickly and accurately identify the excavation loss, crushing, mining collapse, etc. caused by mining on a large scale. However, due to the limitation of satellite remote sensing image data, it was only possible to identify the damaged land with negative topographic crater-like morphology in high-resolution remote sensing images, rather than in the strict sense of the surface subsidence area, and its damage risk range assessment may be smaller than the actual situation. Furthermore, regarding the environmental pollution caused by mining, it is often expanded in the form of "point-line-surface-network" in practice, and the scope of pollution is often difficult to define. It is necessary to diagnose the pollution status based on field investigation sampling and analysis experiments. However, due to the huge workload of large-scale field investigation sampling and experiments, it is usually difficult to achieve in actual operation. Therefore, in future research, it is recommended to adopt the diagnostic method of macro plus micro, current situation and prediction, and the diagnosis method of multi-means and multi-data source integration to carry out an ecological risk assessment. For example, on the basis of satellite remote sensing image diagnosis, INSAR deposition data and hyperspectral pollution investigation data are added to comprehensively diagnose the ecological risk status, so that the diagnosis results are richer and more accurate, and the ecological risk status and evolution speed of mining development are more clearly and intuitively reflected.

5. Conclusions

Based on high-resolution remote sensing diagnosis technology, this study carried out the quantitative assessment of ecological risk caused by mining in the source area of the Yellow River Basin and proposed suitable ecological restoration models. The conclusions are as follows:

(1) Mining development caused damage to the ecosystem in the Qinghai section of the Yellow River Basin to 14,874.80 hm^2. Alpine grassland ecosystems were the most seriously damaged, and 66.77% of the total damaged areas were damaged ecosystems of forest lands, grasslands, waters and wetlands, which bear important water conservation and biodiversity conservation ecosystem service functions. A total of 35.29% were located within the national important water conservation ecological function area and National Nature Reserves. The damage to the important ecological function ecosystem caused the water conservation and biodiversity conservation ecosystem service functions in the study area to decrease, resulting in ecological risks. The types of mines in the research area are mainly energy minerals and non-metallic minerals. Mining excavation and occupation caused by open-pit mining are the main driving factors that cause ecological risk.

(2) According to the mining ecological risk, we divided the study area into five levels. The areas of high ecological risk and comparatively high ecological risk were 1,093,800 hm^2 and 902,100 hm^2, which accounted for 7.27% and 6.00% of the land area of the study area, respectively. It is urgent to carry out mine ecological restoration and maintain ecological security. According to the Hot Spot analysis results, the ecological risk hotspot areas are mainly distributed in the Qilian Mountains, Hehuang Valley, Sanjiangyuan and other water systems and water sources.

(3) Based on the results of the ecological risk diagnosis, and according to the principle of "one mine, one policy", and with natural restoration as the main focus, the 1497 mines in the study area were divided into 122, 48, 452, 22 and 853, which adopted ecological reconstruction, artificial assistance and protection and conservation, artificial assistance, protection and conservation, and natural restoration, respectively, and we proposed ecological restoration strategies according to the prominent ecological and environmental problems in each ecological risk area.

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