Land Ecological Security Evaluation of Underground Iron Mine Based on PSR Model

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Abstract. Iron ore mine provides an important strategic resource to the national economy while it also causes many serious ecological problems to the environment. The study summed up the characteristics of ecological environment problems of underground iron mine. Considering the mining process of underground iron mine, we analysis connections between mining production, resource, environment and economical background. The paper proposed a land ecological security evaluation system and method of underground iron mine based on Pressure-State-Response model. Our application in Chengchao iron mine proves its efficiency and promising guide on land ecological security evaluation.

1. Introduction
Land ecological safety is the core of the sustainable land use and a new research field in environmental impact assessment, which is highly connected with human’s survival and development [1]. Foreign studies mainly focus on ecological risk and ecosystem health while many domestic scholars aim at mechanism, warning and evaluation method of land ecological safety in special areas especially the ecological sensitive district [2]. They all largely enrich evaluation means and methods as well as enhance the awareness of land ecological security issues.

Steel is the most consumed metal in the world and Iron ore is the main raw materials in its production. With domestic open-pit mining facing an depletion, underground iron mining is becoming more and more popular, so it’s high time we carry out study aims at land ecological safety issues of underground iron mine. They are typical ecological sensitive districts, researchers have obtained much achievements on some aspects: the vulnerability, stability and health assessment of ecosystem, the ecological civilization and the ecological risk assessment and etc [3-6]. But the deficiencies are as follows: (1) Different types of mine own unique resources, mining technology, characteristics and social background with relatively great difference in ecological safety issues. Current studies are
mainly generalized evaluation or only suitable for coal mine. (2) The evaluation result is not comparable for its evaluation indexes and standards are limited to a special location thus restricting its application.

2. Land Ecological Safety Problems of Underground Iron Mine

2.1. Characteristic
A fuzzy indication between risk source and damage. There are many kinds of risks during mining process jeopardizing ecological system via different ways, which results that one kind of problem derives from varied sources and one source accompanies more than one problems [7].

Concealment and hysteresis. The underground producing activity of mining has less obvious effect and damage on ecological environment compared with open-pit mining. In addition, risks such as surface subsidence resulted from roadway and empty area collapse belongs to the kind of accumulative and permanent damage, which will progress as time goes by.

Mutual interaction and feedback effect. On the one hand, The mining force is assumed to be source of ecological safety issues, whose ecological effects are subjected to local environment. On the other hand, the destructed geological environment will affect the choice of mining technique and process in underground iron ore, which may influence investment and social cost during production.

2.2. Associated Patterns
Considering the mining process of underground iron mine, we analysis the emergence and development of ecological security problems, then put up with a causal association patterns between ecological safety, mining process, resource, environment and economical background (figure 1).

Figure 1. The causal association pattern based on mining process
3. Evaluation Process and the Method

3.1. Evaluation Index System
The PSR model is a widely used model based on "pressure - state - response" index system and was established by the United Nations agency for economic cooperation development. Pressure index reflects the load caused by human activities to the system. State index shows natural resources and the environment quality condition of ecosystem. Response index characterizes human countermeasures on ecological safety issues. So PSR model has a clear causal relationship with systematicness [8]. So this paper presents a modified PSR model(table 1), considering the natural and human pressure rather than human pressure alone.

Table 1. The evaluation index system of the land ecological security

| First level index | Second level index | Third level index |
|-------------------|--------------------|------------------|
| Pressure (P)      |                    |                  |
| Natural pressure(P1) | Geomorphological and geological conditions:P11 Climate condition:P12 Ore grade:P13 Occurrence of ore body:P14 |
| Mining pressure(P2) | Mining intensity:P21 Technology modernization:P22 Condition of equipment:P23 |
| Economical pressure(P1) | Per capita output:P31 Roe:P32 Ton ore mining costs:P33 Per capita income:P34 |
| State of geological hazard (S1) | Disaster area ratio:S11 Risk level of tailings:S12 Comprehensive risk in mine-out area:S13 Comprehensive risk of waste rock:S14 |
| State of Water Resources(S2) | Environmental quality of surface water:S21 Environmental quality of underground water:S22 Groundwater level:S23 |
| Landscape ecological state (S3) | Ratio of soil erosion area:S31 Biological diversity:S32 Landscape fragmentation:S33 |
| Soil environmental state(S4) | Green coverage:S41 Land reclamation rate:S42 Soil environmental quality:S43 |
| Management technology response(R1) | “Three wastes” emission compliance rate:R11 Comprehensive utilization rate of waste rock:R12 “Three simultaneous” implementation:R13 |
| Institutional policy response(R2) | Governance funds proportion:R21 Science and technology investment:R22 |

3.2. Evaluation Methods and Steps
This paper employ AHP to determine the weight of each index to set up fuzzy comprehensive evaluation mathematics model so as to study this complex ecotope issues.

Weighing index: a judgment matrix is used to identify importance with other indexes in the same level, importance numbers are judged by a certain criterion comes from the standard of its dominant level.

\[
(A)_{n \times n} = \begin{bmatrix}
\alpha_{11} & \cdots & \alpha_{1n} \\
\vdots & \ddots & \vdots \\
\alpha_{n1} & \cdots & \alpha_{nn}
\end{bmatrix}
\]  

(1)
The weight of each index is obtained by the greatest characteristic root and characteristic vector of judgment matrix.

Evaluations: we grade the land ecological safety into four ranks: extremely low, low, medium and high and the evaluation set are built as $V = \{\text{extremely low, low, medium, high}\}$.

Index classification standard: the quantifiable indexes are referred to national standards and criteria as table 2.

**Table 2.** The classification standards of quantitative indexes

| Index            | Standard and reference | Index        | Standard and reference |
|------------------|------------------------|--------------|------------------------|
| Ore grade        | %                      | <25          | 0-2.5                  |
|                  |                        | 25-35        | 2.5-5                  |
|                  |                        | 35-45        | 5-7.5                  |
|                  |                        | >45          | 7.5-10                 |
| Mining intensity | 10t/a                  | >50          | 0-2.5                  |
|                  |                        | 30-50        | 2.5-5                  |
|                  |                        | 20-30        | 5-7.5                  |
|                  |                        | <20          | 7.5-10                 |
| Per capita output| 10t                    | <15          | 0-2.5                  |
|                  |                        | 15-25        | 2.5-5                  |
|                  |                        | 25-30        | 5-7.5                  |
|                  |                        | >30          | 7.5-10                 |
| Roe              | %                      | <0           | 0-2.5                  |
|                  |                        | 0-6          | 2.5-5                  |
|                  |                        | 6-15         | 5-7.5                  |
|                  |                        | >15          | 7.5-10                 |
| Ton ore mining   | yuan/t                 | >200         | 0-2.5                  |
| costs            |                        | 160-200      | 2.5-5                  |
|                  |                        | 120-160      | 5-7.5                  |
|                  |                        | <120         | 7.5-10                 |
| Per capita income| 10t                    | <1.5         | 0-2.5                  |
|                  |                        | 1.5-2.5      | 2.5-5                  |
|                  |                        | 5           | 5-7.5                  |
|                  |                        | >3.5         | 7.5-10                 |
| Disaster area ratio | %                      | >12          | 0-2.5                  |
|                  |                        | 8-12         | 2.5-5                  |
|                  |                        | 4-8          | 5-7.5                  |
|                  |                        | <4          | 7.5-10                 |
| Environmental quality of surface water | / | V | IV | III | aboveII |
|                  |                        | Governance funds proportion | % | <1 | 2.3 | >3 |
| Environmental quality of underground water | / | V | IV | III | aboveII |
| Ratio of soil erosion area | % | >30 | 0-2.5 | 2.5-5 | 5-7.5 | 7.5-10 |

For other qualitative indexes, we establish a index classification basis(table 3)based on its major
influence and characteristics on ecological safety issues. So different descriptive definitions is used to provide reference for the expert scoring that are matched with evaluation set \( V = \{ \text{extremely low, low, medium, high} \} \).

### Table 3. The classification basis

| Index                          | Basis                                                                 |
|--------------------------------|-----------------------------------------------------------------------|
| Geomorphological geological and conditions | Degree of tectonic activities; Joint fracture development; Hydrogeological conditions; Geomorphic type; Elevation and cutting conditions |
| Climatic conditions           | Annual rainfall; Intensity of heavy rain; Matching condition of light, warmth and water |
| Occurrence of ore body        | Depth, thickness and dip angle of the orebodies; Continuity degree of the orebodies; Rock types and strata conditions of the roof rock |
| Technology modernization      | Scientificity in development and utilization; Green method in mining; Environmental protection in ore dressing; Completeness in six system |
| Condition of equipment       | Advanced level of production equipment; Exist of environmental protection equipment |
| Risk level of tailings        | Land use; Engineering geological conditions; Condition of the dam; Damage if collapse |
| Comprehensive risk in mined - out area | Accumulation degree and scale; Geological condition of surrounding rock; Stability of its structure and support; Ecological damage |
| Comprehensive risk of waste rock | Land use; Terrain and formation characteristics; Physical properties of waste rock; Impacted objects and scope |
| Groundwater level             | Development and burial depth of underground water; Water intake and water gushing in mining area; Influence of ground disaster on groundwater recharge channels |

Membership function: The membership function is the basis and a key point in a reasonable fuzzy evaluation. Quantifiable indexes in table 2 are divided into classification index and numerical index. Classification indexes are determined by the lowest category amid monitoring samples. As for numerical index, we apply a improved distribution function to a avoid subjectivity in evaluation. Membership function is as follows:

\[
\mu_C(c) = \begin{cases} 
1 & \frac{c - (a_1 + a_2)}{a_2 - a_1} \\
\frac{-c + (a_1 + a_2)}{a_1 - a_2} & \frac{c - (a_1 + a_2)}{a_2 - a_1} \\
0 & \frac{-c + (a_1 + a_2)}{a_1 - a_2} 
\end{cases}
\]

(2)

C represents real value of the quantitative index, \( a_1 \) is the lower threshold of grade interval where \( c \) belongs to and \( a_2 \) is the upper threshold. When there is no concrete upper threshold or lower one, we calculate the interval span to add or plus. For other qualitative indexes in table 3, we take a average of expert scoring as \( c \) to calculate.

### Table 4. The standard value and range of score

| \( V_1 \) (extremely low) | \( V_2 \) (low) | \( V_3 \) (medium) | \( V_4 \) (high) |
|----------------------------|----------------|-------------------|-----------------|
| Standard values            | Score interval | Standard values   | Score interval  |
| c                          | 1              | 2                 | 3               | 4               |
| 0-2                        | 1-3            | 2-4               | 3-5             |

Membership of \( c \) in table3 is derived from a trapezoidal distribution function.
Fuzzy comprehensive evaluation: we aim at getting a membership vector of four evaluations for land ecological safety in studying area. Calculation starts from lowest index level with function (2) and (3) to get the membership degree to the four evaluations. Then the fuzzy relation matrices of upper level index is built by calculated membership, we multiply the fuzzy relation matrices by its weight to get another fuzzy relation matrices of further upper level. In this way, we can have a final membership of four evaluations.

A fuzzy relation matrix:

\[
\begin{bmatrix}
\mu_{m1} & \cdots & \mu_{mn} \\
\vdots & \ddots & \vdots \\
\mu_{m1} & \cdots & \mu_{mn}
\end{bmatrix}
\]  

(4)

M is index numbers in next level, n is 4 (number of evaluations), r is the membership value.

4. Empirical Test
Chengchao iron mine is a integrated mining founded in 1958 with mainly pillarless caving method whose production scale ranks third among iron mine around China, thus being an important source of Wuhan Iron and Steel. The evaluation data mainly come from geological topographic map of Chengchao iron ore, geological report of Chengchao iron ore, statistical report of Chengchao iron ore, environmental quality report of Ezhou, remote sensing image of mining area and field survey data.

Here are the results:

The general score of land ecological security in Chengchao Iron Mine is (0.158, 0.385, 0.354, 0.103), mainly lies in the range between "low" and "medium", whose final result is lower in land ecological security.

Score in stress is (0.126, 0.302, 0.425, 0.147), close to "medium", which due to the complex geological conditions, strong tectonic movement, high mining intensity and caving mining that brings about great ecological security pressure. Meanwhile, the advanced mining equipment with lower cost favorable income of workers reduce the mine land ecological security pressure in turn.

Score in state is (0.276, 0.412, 0.229, 0.083), belongs to "low" and had a tendency to "extremely low", which is related to the frequent occurrence of geological disaster, massive large mine-out areas with poor support, serious soil pollution, low biodiversity, and landscape fragmentation in Chengchao iron mine. Although the greening coverage of mining area is high, soil and water loss is managed to a certain extent, but it is still not enough to alter the "low" state in land ecological security.

Score in response is (0.033, 0.432, 0.450, 0.085), lies in the range between "low" and "medium" and prior to "medium", which is connected with the economic benefits, increased governance funds, science and technical investment.

The whole evaluation results reflect the actual situation and main contradiction of land ecological security in Chengchao iron mine, which point the direction in management and regulation for mine land ecological safety issues.
5. Discussions
This paper aims at underground iron mine and based on the analysis of potential causal connections between safety and mining activities, resources, environment and economic background, attempting to establish a universal evaluation index system and method of land ecological safety for underground mines. We apply it in Chengchao iron ore, then achieve a good result.

Land ecological safety is a relative concept consists of not only the relativity of region (space), but also the relativity of development stage (time). Therefore, the evaluation needs reflecting the relative difference of land ecological security among the same type of mines to make comparisons, and provide the basis for further classification management of a certain type mine in the country or region. Besides, the evaluation on pixel or plaque level based on the special local and spatial heterogeneity of land ecological security reserves further research.

6. References
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