The Evaluation of Land Ecological Safety of Chengchao Iron Mine Based on PSR and MEM

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Abstract. Land ecological security is of vital importance to local security and sustainable development of mining activities. The study has analyzed the potential causal chains between the land ecological security of Iron Mine mining environment, mine resource and the social-economic background. On the base of Pressure-State-Response model, the paper set up a matter element evaluation model of land ecological security, and applies it in Chengchao iron mine. The evaluation result proves to be effective in land ecological evaluation.

1. Introduction
Land ecological security is vital to human’s daily life and development and is the core of sustainable use of land resource. Mine area is the typical ecological fragile zone, whose ecological environment and land ecological security problem has attracted the attention of researchers. The evaluation of land ecological quality of mine¹,², ecosystem stability³, vulnerability⁴ and health assessment⁵, mine ecological civilization⁶ and ecological risk assessment⁷ made a series of research results. However, the existing research objects are mostly aimed at coal mines, lacking evaluation of underground iron mines. Due to different types of mine resources, mining technology, technical characteristics and social economic background are different. The main ecological environmental problems varies⁸. It demands distinctions between different types of mine to carry out targeted research. Chengchao Iron Mine was founded in 1958, it is a typical integrated underground mines. The mine has the most abundant mineral resources and owns largest production in South Central China. It has made a great contribution to the rapid development of local economy. But at the same time, long-term iron ore mining also brings geological disasters, environmental pollution, ecological destruction and a series of land ecological environment problems, so it is necessary to carry out land ecological security research.
2. Basic Understanding and Evaluation Index System of Land Ecological Security in Chengchao Iron Mine

2.1. Basic Understanding of Land Ecological Security in Chengchao Iron Mine
The source power of the land ecological security of ChengChao iron mine is the mining production activities, including mining, row rock, ore dressing and tailings processing four main production procedures. The mining exploration, mining quasi, cutting, ventilation in the mining process, and the transportation, waste rock stacking in rock dumping, and the crushing, grinding, separation in mineral processing, these links will have an impact on the ecological environment. They will act directly or indirectly on the atmosphere, soil, hydrology, rocks, landforms, vegetation and other elements of land ecological environment. As time goes on, these factors will eventually lead to the secondary geological disaster, destruction of water resources, landscape and ecological destruction, soil occupation and destruction and other ecological environment effects. In this process, mine resources and environment system, social economic system play an extremely important role. What’s more, the main form and degree of land destruction of the ecological environment have an extremely close relationship with the occurrence of ore bodies, mining scale, mining method and process, geological environment conditions and their sensitivity, social economic background conditions. On the other hand, mining production activities, the background of mine resources and environment, socioeconomic background of the three together determine the land ecological security situation and trend of Chengchao Iron mine.

2.2. The Evaluation Index System of Land Ecological Safety of Chengchao Iron Mine Based on PSR
We uses PSR model to construct the evaluation index system of land ecological security in Chengchao Iron Mine. The contents are shown in figure 1.

![Diagram of P-S-R model for Chengchao Iron Mine](image)

**Figure.1** The associated patterns between P-S-R of Chenchao Iron Mine

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When the specific index is selected, aiming at the actual situation of the main problems in Chengchao Iron Mine and land ecological security. The index weight is obtained by expert consultation and analytic hierarchy process (AHP). The index weight of project layer and index layer is in Table 1, and the index weight of Index layer is in Table 3.

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

| project | Factor | Index |
|---------|--------|-------|
| Pressure | Natural endowment pressure (0.184) | Geomorphic conditions P1, Climatic conditions P2, Ore grade P3, Occurrence of ore bodies P4 |
| Mining activity pressure (0.184) | Mining intensity P21, Degree of technological modernization P22, Equipment advanced degree P23 |
| Social economic (0.061) | per-capita output value P31, Return on net assets P32, The cost of mining tons of ore P33, Income per worker P34 |
| Geological disasters (0.223) | Disaster area ratio S1, Risk of tailings Banks S2, Comprehensive risk of goaf S3, Waste rock field comprehensive risk S4 |
| Water resources environment | Surface water quality S5, Groundwater environment quality S6, The influence of groundwater level S7 |
| Landscape ecology (0.034) | Soil erosion area ratio S8, Biodiversity index S9, Landscape fragmentation index S10 |
| soil environment (0.086) | green coverage ratio S11, Land reclamation rate S12, Soil environmental quality index S13 |
| reponse | Management technology (0.071) | "Three wastes" emission rate index R1, Waste rock comprehensive utilization ratio R2, Implementation of "three simultaneous" R3 |
| System policy (0.071) | The proportion of management funds to sales revenue R4, Science and technology investment accounts for profit ratio R5 |

Note: 1. The mining intensity is expressed in tons of ore mined each year; 2. Index of surface water environmental quality \( I_w = \left( \frac{\sum_{i=1}^{n} f(x_i)}{n} \right) \), referring to the literature [9] and [10] for details; 3. Groundwater environmental quality index \( F = \left( \frac{\sum_{i=1}^{n} F_i/n}{2} \right) \), referring to the literature [8] for details; 4. Shannon-Wiener index formula is used to calculate; 5. Landscape fragmentation index \( Ft = \left( \frac{Nt-1}{Nc} \right) \), Nt is total number of landscape patches, Nc is the ratio of the total area to the minimum patch area was evaluated; 6. The soil environmental quality index calculated by Nemerow index method, referring to the literature [10] for details; 7. Discharge standard rate of "three wastes" \( P = \sqrt{C1 * C2 * C3} \), C1, C2, C3 are the discharge rate of wastewater, waste gas and waste residue are standard respectively.

3. The Evaluation Model of Land Ecological Safety in Chengchao Iron Mine

The evaluation of mine land ecological security involves many indexes, and the results of single index evaluation are incompatibility. Matter-element model combine objects, features and their eigenvalues to study the possibility and development law of things in a formalized model. This can be used to solve complex problems that are incompatible. Therefore, this research establishes the matter-element model of the land ecological safety in chengchao iron mine, and the evaluation process is as follows.

3.1. Construct the Land Ecological Security Matter-Element

According to the evaluation index system which is determined by Table 1, the evaluation object M(Land ecological security), feature vector c(the evaluation index) and characteristics of the value x(Parameter values) can build the land ecological security matter-element R=(M, c, x). The land ecological security element of chengchao iron mine is expressed as:
3.2. Determine the Classical Domain and the Matrix of Joint Domain

The classical domain matrix can be expressed as:

$$ R = (M, c, x) = \begin{bmatrix} M_{o_1} & c_{o_1} & x_{o_1} \\ c_{o_2} & x_{o_2} \\ \vdots & \vdots \\ c_{o_n} & x_{o_n} \end{bmatrix} \quad (1) $$

$$ R_{oj} = (M_{oj}, C_{oj}, X_{oj}) = \begin{bmatrix} M_{oj} & c_{oj1} & x_{oj1} \\ c_{oj2} & x_{oj2} \\ \vdots & \vdots \\ c_{ojn} & x_{ojn} \end{bmatrix} = \begin{bmatrix} M_{oj} & c_{oj1} & (a_{oj1}, b_{oj1}) \\ c_{oj2} & (a_{oj2}, b_{oj2}) \\ \vdots & \vdots \\ c_{ojn} & (a_{ojn}, b_{ojn}) \end{bmatrix} \quad (2) $$

In the formula: $ R_{oj} $ is --- Classical domain element; $ M_{oj} $ is ---The evaluation level of $ j $th rank. This evaluation ranks four grades. They are relative safe, not so safe, unsafe, dangerous; $ c_{ojj} $ is ---The $ i $th index of land ecological security at the $ j $ level. In this study $ i \in (1, 2, \ldots, 29) $; $ x_{ojj} = (a_{ojj}, b_{ojj}) $ ---means evaluation index $ c_{ojj} $ is the range of magnitude in the rank of $ j $ which is the classical domain matrix.

Node matter element matrix can be expressed as:

$$ R_p = (M_p, C_{pi}, X_{pi}) = \begin{bmatrix} M_p & c_{p1} & x_{p1} \\ c_{p2} & x_{p2} \\ \vdots & \vdots \\ c_{pn} & x_{pn} \end{bmatrix} = \begin{bmatrix} M_p & c_{p1} & (a_{pi1}, b_{pi1}) \\ c_{p2} & (a_{pi2}, b_{pi2}) \\ \vdots & \vdots \\ c_{pn} & (a_{pni}, b_{pni}) \end{bmatrix} \quad (3) $$

In the formula: $ R_p $ is ---node matter element; $ M_p $ is ---land ecological security of the object to be evaluated; $ c_{pi} $ is the $ i $th evaluation index of Land ecological security; $ x_{pi} = (a_{pi}, b_{pi}) $ is evaluation range of rank $ c_{pi} $ on all levels which is the corresponding value range of land ecological security evaluation index.

3.3. Determine the Actual Value of Each Index of Chengchao Iron Mine and Establish an Evaluation Element

Obtaining the actual value of each evaluation index of Chengchao iron mine and establishing an evaluation element $ R_o $:

$$ R_o = (M_o, C_{oi}, X_{oi}) = \begin{bmatrix} M_o & c_{o1} & x_{o1} \\ c_{o2} & x_{o2} \\ \vdots & \vdots \\ c_{on} & x_{on} \end{bmatrix} \quad (4) $$

For quantitative indicators, the main data is from the geological topographic map of Chengchao iron mine, the geological report of Chengchao iron mine, the statistics report of Chengchao iron mine, the remote sensing image and field survey data in mining area. For the indicators that cannot be quantified, we can establish index classification table(Table 2) from the index that can reflect the main fea-
tures of the land ecological security status or have the leading role of land ecological safety aspects. We can also establish index classification table (Table 2) from the index which have a relationship with land ecological safety of underground iron mine. From the index classification table (Table 2), we can set up the description language of relative safe (75-100 points), not so safe (50-75 points), unsafe (25-50 points) and dangerous (0-25 points), these four levels for expert scoring reference, and take the arithmetic mean of experts scoring as the index value.

Table 2. The classification basis of the qualitative indexes quantitative indexes

| Index                                | Classification basis                                                                 |
|--------------------------------------|---------------------------------------------------------------------------------------|
| Geological and geomorphic conditions | Degree of tectogenesis; Fracture joint development degree; Hydrogeological condition; Geomorphic types; Elevation and cutting conditions |
| Climatic conditions                  | Annual rainfall; Storm intensity; Matching condition of light and warm water          |
| Occurrence of ore bodies             | Buried depth of ore body; Thickness and dip angle; Continuity of ore body; Roof rock types and formation conditions |
| Degree of technological modernization| Scientific development and utilization plan; Green situation of mining methods; Environmental protection degree of mineral processing technology; Completeness of six systems |
| Equipment advanced degree            | Advanced level of production equipment; Popularization of environmental protection equipment |
| Tailings reservoir risk              | Land occupation scale; Engineering geological condition; Dam condition; Ecological loss size of dam break |
| Comprehensive risk of mined out area | Degree and scale of aggregation; Geological conditions of surrounding rock; The stability of its structure and support; Accident ecological loss size |
| Comprehensive risk of waste rock yard| floor area; Topography and stratigraphic characteristics; Physical properties of waste rock; Influence object and scope |
| Influence of groundwater level       | Groundwater development and burial depth; Mining water intake and roadway water inflow; Effects of land disasters on groundwater recharge channels |

3.4. Calculation of Correlation Degree and Land Ecological Security Grade Determination

3.4.1. Determine the Correlation Function of Index Layer. Provided \( k_j(x_{oi}) \) is the correlation degree of rank \( j \) in index layer \( i \), we define \( k_j(x_{oi}) \) as follows:

\[
k_j(x_{oi}) = \begin{cases} \frac{\rho(X_{oi}, X_{oji})}{\rho(X_{oi}, X_{pi}) - \rho(X_{oi}, X_{oji})} & \text{if } \rho(X_{oi}, X_{pi}) - \rho(X_{oi}, X_{oji}) \neq 0; \\ - \rho(X_{oi}, X_{oji}) - 1 & \text{if } \rho(X_{oi}, X_{pi}) - \rho(X_{oi}, X_{oji}) = 0; \end{cases}
\] (5)

In the formula:

\[
\rho(X_{oi}, X_{oji}) = x_{oi} - \frac{1}{2}(a_{oji} + b_{oji}) - \frac{1}{2}(b_{oji} - a_{oji})
\] (6)

\[
\rho(X_{oi}, X_{pi}) = x_{oi} - \frac{1}{2}(a_{pi} + b_{pi}) - \frac{1}{2}(b_{pi} - a_{pi})
\] (7)

Among them, \( \rho(X_{oi}, X_{oji}) \) and \( \rho(X_{oi}, X_{pi}) \) are respectively the distance from index \( x_{oi} \) to the classical field area \( x_{oji} = (a_{oji}, b_{oji}) \) and Joint domain range \( x_{pi} = (a_{pi}, b_{pi}) \).
3.4.2. Computing Comprehensive Association Degree Layer by Layer. According to the hierarchy of evaluation indicators determined by Table 1, the comprehensive correlation degree of each level index is calculated layer by layer and start from the bottom one.

Calculation formula:

\[ K_j(X_{ol}) = \sum_{i=1}^{m} (\omega_i \cdot k_j(x_{oi})) \times (j = 1, 2, 3, 4) \]  

(8)

In the formula: \( K_j(X_{ol}) \) is comprehensive correlation of index \( X_{ol} \) of rank \( j \); \( k_j(x_{oi}) \) is single correlation degree of rank \( j \) in every lower index among \( X_{ol} \); \( m \) is the index numbers of \( X_{ol} \); \( \omega_i \) is weight of index \( X_{oi} \).

We calculate layer by layer, until get the comprehensive correlation grade \( K_j(M_o) \) of \( M_o \) (land ecological security) in rank \( j \).

3.4.3. Grade Assessment and Development Trend Judgment. Provided \( K_j(X_{ol}) = \max \{K_1(X_{ol}), K_2(X_{ol}), K_3(X_{ol}), K_4(X_{ol})\} \), the index \( X_{ol} \) belongs to the standard level of land ecological security, referred as \( j \). Provided \( K_j(M_o) = \max \{K_1(M_o), K_2(M_o), K_3(M_o), K_4(M_o)\} \), then object to be evaluated here in \( M_o \) of standard level in land ecological security is \( J \). When \( K_j(x) \geq 1.0 \), it indicates the evaluated object \( M_o \) exceeds the limit, the bigger the number is, the greater potential it has. When \( 0 \leq K_j(x) < 1 \), it indicates the evaluated object is in accordance with \( J \) standard, and the bigger the value is, the better the match degree is, which is more close to the upper limit of ranks; When \( -1 \leq K_j(x) < 0 \) it indicates the evaluated object is not in rank \( J \), but it chance to be transformed into rank \( j \) and the bigger the number is, the more chance it has. When \( K_j(x) < -1.0 \) it indicates the the evaluated object is not in rank \( J \), and it has no chance to be transformed into rank \( j \).

4. Evaluation Results and Analysis of the Land Ecological Safety of Chengchao Iron Mine

4.1. Data Sources

Matter-element model of land ecological security evaluation whose classical domain and joint field are refer to “Cleaner production standard(Iron ore mining),” “Surface water environmental quality standard,” “Groundwater environmental quality standard,” “Soil environmental quality standard,” “Evaluation conditions of state level green mine pilot units by Ministry of land and resources,” “Standards for ecological protection and restoration of mining(Draft for Soliciting Opinions)” and other national standards and norms, and ”China Mining Yearbook (2013)” and other statistical data and related research literature. The actual value of Chengchao Iron Mine evaluation index is determined by the above methods described in this paper(Table 3).

Table 3. The evaluation index's actual value and weight of Chengchao Iron Mine

| Index | \( P_{11} \) | \( P_{12} \) | \( P_{13} \) | \( P_{14} \) | \( P_{21} \) | \( P_{22} \) | \( P_{23} \) | \( P_{31} \) | \( P_{32} \) | \( P_{33} \) |
|-------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Index | \( P_{41} \) | \( S_{11} \) | \( S_{12} \) | \( S_{13} \) | \( S_{14} \) | \( S_{21} \) | \( S_{22} \) | \( S_{23} \) | \( S_{31} \) | \( S_{32} \) |
| Index | 3.4 | 16 | 56 | 38 | 63 | 0.68 | 1.94 | 63 | 12 | 1.1 |
| Weight | 0.016 | 0.087 | 0.034 | 0.087 | 0.015 | 0.052 | 0.017 | 0.017 | 0.021 | 0.008 |
| Index | \( S_{31} \) | \( S_{32} \) | \( S_{33} \) | \( R_{11} \) | \( R_{12} \) | \( R_{13} \) | \( R_{21} \) | \( R_{22} \) | \( R_{23} \) | \( R_{31} \) |
| Index | 0.33 | 72 | 23 | 2.2 | 85 | 37 | 88 | 1.6 | 12 |
| Weight | 0.005 | 0.008 | 0.021 | 0.058 | 0.043 | 0.014 | 0.014 | 0.018 | 0.054 |
4.2. Evaluation Results and Analysis

According to formula 5-8, the comprehensive correlation degree of each level index is calculated (Table 4). Evaluation results show as follows:

Table 4. The results of comprehensive evaluation on ecological security of land in Chengchao Iron Mine

| All levels of indicators | Comprehensive correlation | Security level |
|--------------------------|---------------------------|----------------|
|                          | K1   | K2   | K3   | K4   |               |
| Natural endowment pressure | -0.045 | 0.016 | -0.021 | -0.074 | not so safe |
| Mining activity pressure  | -0.038 | 0.043 | -0.058 | -0.079 | not so safe |
| Social economic pressure  | 0.057  | 0.014 | 0.030  | -3.599 | relative safe|
| Pressure synthesis        | -0.012 | 0.012 | -0.013 | -0.249 | not so safe |
| Geological disaster state | 0.041  | 0.033 | 0.050  | -3.074 | unsafe       |
| State of water resources   | -0.008 | 0.030 | -0.002 | -0.145 | not so safe |
| Landscape ecological status| 0.002  | 0.003 | 0.012  | -1.036 | not so safe |
| Soil environmental state   | -0.184 | 0.109 | 0.068  | 0.025  | not so safe |
| State synthesis            | -0.007 | 0.020 | 0.017  | -0.730 | not so safe |
| Management technology response | -0.009 | 0.022 | -0.021 | -0.043 | not so safe |
| Institutional policy response | -0.015 | 0.012 | -0.009 | -0.025 | not so safe |
| Response synthesis         | -0.002 | 0.002 | -0.002 | -0.005 | not so safe |

The general situation of land ecological security in Chengchao iron mine is (-0.009, 0.014, 0.002, -0.420), Belongs to “not so safe”, but have “unsafe” features, and also shows the greater potential turn to “relative safe”.

The general situation of land ecological safety pressure (P) in Chengchao Iron Mine is (-0.012, 0.012, -0.013, -0.249), belongs to “relative safe”. The geological conditions in Chengchao iron mine is very complicated, the degree of tectonic movement here is stronger than any other iron ore. What’s more, many factories use caving method to mining. These factors put great pressure on the ecological safety of mine land. But on the other hand, the mining equipments in these factories are very advanced. Ore mining costs are low. The economic benefits of these factories are good, and the workers’ income in these factories are good. All these factors to some extent alleviate the pressure of mine land ecological security. However, with the depth of iron ore mining increases, and iron ore mining costs increase, especially the lower price of iron ore market. The pressure of mine land ecological security is increasing.

The general situation of the land ecological security state (S) of Chengchao iron mine is (-0.007, 0.020, 0.017, -0.730), belongs to “not so safe”, but have “unsafe” features, and also shows the greater potential turn to “unsafe”. Chengchao iron mine has been mining for years. Ecological environment pollution and landscape ecological destruction have not been timely managed, especially a large number of goaf which is made by caving method to mining that used by the factories here. Tailings, waste rock and other hidden dangers make mine geologic hazard happen frequently, so the Geologic hazard state here belongs to “unsafe”.

(4) The general situation of the land ecological security response (R) of Chengchao iron mine is (-0.002, 0.002, -0.002, -0.005), Belongs to “not so safe”. It has relationship with the mine economic benefits, governance funds, science and technology capital investment increased and gradually improve the corresponding management system in recent years. However, the relevant policy measures need to be further implemented, a large number of comprehensive utilization of waste rock remains to be resolved.
5. Conclusion
Because of the different types of mine resource endowment, mining technology, technical characteristics and socio-economic background, the ecological environment problems which we faced have much difference. This paper focuses on the potential causal chain of the land ecological security and mining activities, mine resource environment and socio-economic background of chengchao iron mine, by establishing the evaluation model of ecological security of mine land which is based on PSR, and good application results have been obtained.

We have reviewed a large number of relevant specifications, standards, statistics and previous research results in this research to determine the threshold value of the classical domain of matter element model. However, by the relevant information is incomplete, there are still some threshold value with the subjective, and need to be further improved and perfected.

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