GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2023 Volume 39 Issue 4 Pages 23–48

DOI: 10.24425/gsm.2023.148160

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Mineral investment risk assessment of host countries based on a cloud matter-element model

Introduction

The concept of overseas investment emerged in the nineteen-sixties and has evolved significantly over the past fifty years (Buckley 1976). As the global economic landscape has changed, researchers have also adapted their investment strategies accordingly. By promoting foreign investments by businesses, countries can indirectly access essential services and valuable local resources from the host nation. This enables them to effectively adjust and optimize their domestic industrial structure while bolstering their own competitive edge.

Mineral resources are finite, and no country can solely depend on its own resources to meet its development requirements. As economic and social development accelerates, the disparity between the supply and demand of resource becomes increasingly evident.

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Over the long term, it becomes necessary to rely on imports to bridge this gap. Consequently, investing in overseas mineral resources has become an inevitable choice (Huang et al. 2020).

Investments in mineral resources possess several distinctive features (Hussain et al. 2020). Firstly, they typically require substantial financial outlays due to the large scale of operations involved. Secondly, the construction period for such projects tends to be lengthy. Additionally, mineral investments entail numerous factors that must be taken into account, making project decision-making complex. Lastly, these investments carry higher levels of uncertainty and risk compared to other types of investment (Botín et al. 2011).

Overseas investment primarily involves investing in another economy with the intention of obtaining long-term benefits (Brennan and Schwartz 1985). Such investments often carry a significant level of risk but also offer the potential for high returns. Currently, there is no standardized and established set of specialized procedures for selecting, investing in and managing overseas projects. As a result, companies face numerous risks when engaging in overseas investments (Scammacca et al. 2021).

Investing in foreign countries poses various uncertainties due to differences in political, legal, economic and cultural aspects, as well as due to the volatile international situation. These uncertainties increase the likelihood of encountering adverse events during the investment process, leading to investment risks for enterprises. In addition to the common characteristics of risk such as objectivity, contingency, controllability and predictability, investment risks also exhibit complexity and diversity, making them challenging to manage effectively (Foo et al. 2018; Tubis et al. 2020).

To maximize returns on investments, enterprises must conduct a thorough evaluation of the potential risks associated with overseas investments. These risks encompass political, economic, environmental, natural resource potential and investment environment factors. One approach to tackling investment risks involves scholars analyzing the origins of these risks, establishing an index system for evaluating them, and employing qualitative or quantitative methods to estimate their level of risk.

There are two main categories of risk sources in mining projects: sources of uncertainty and sources of hazards. Sources of uncertainty include factors like insufficient and inaccurate information, as well as fluctuations in mineral prices and demand. Sources of hazards in mining projects include the project's location, environmental control measures, geological conditions and potential regulatory changes (Shahabi et al. 2022).

Mining projects should be mindful of various risk sources, such as environmental issues, geological conditions, production technology, market environment, social conditions, and policies and regulations. The management of these risks greatly influences whether a given mining project would be able to achieve its expected level of profitability.

In Ghana, a study identified the top five risk factors that significantly impact mining projects (Amoatey et al. 2017). These factors include volatile commodity prices, inflation and exchange rate fluctuations, land degradation, high costs of living and government bureaucracy associated with obtaining licenses. These risks have been identified as the most critical and should be closely monitored and managed for the successful execution of mining projects in Ghana.

To select the optimal investment solution, Sobczyk (Sobczyk et al. 2017) introduced a hierarchical model that considered five key categories: geological and mining conditions, technical condition of the mine plant, environmental impact assessment, required investment expenditures, and social and political factors. This comprehensive model aims to ensure a well-informed decision-making process by evaluating various aspects of the investment and prioritizing each category accordingly. By taking into account these crucial factors, Sobczyk's hierarchical model provides a systematic approach to identify the most suitable investment solution.

Meldrum (Meldrum 2000) divided national risk into six categories: economic risk, transfer risk, exchange rate risk, location or neighborhood risk, sovereign risk and political risk. Al Khattab et al. (Al Khattab et al. 2007) noted that the risks in international investment projects mainly include natural, financial, cultural and political risks. Yujing (Xiang et al. 2022) established a six-dimension investment evaluation indicator system to comprehensively assess mineral resources, including political, economic, social, resource potential, environmental risks and China factors – fifty countries were studied.

After conducting extensive research and analysis of various investigations and data, Jamal identified and extracted thirty-six indicators from reliable sources such as World Development Indicators (WDI), Worldwide Governance Indicators (WGI), and the International Country Risk Guide (ICRG) database. These indicators were carefully selected to develop a novel system for evaluating investment risks and natural resource potential. The indicator system encompasses four key aspects: economic foundation, political stability, environmental risk and resource potential. By considering these indicators, Jamal successfully created a comprehensive assessment tool to support informed decision-making in evaluating investment opportunities and natural resources (Hussain et al. 2020).

The factors that influence risk in overseas mining investments are extensive, possess a complex structure and exhibit a degree of uncertainty. Evaluating these risks involves a multi-level, multi-element, multi-objective and complex system approach.

In recent times, the utilization of multi-index evaluation has led to the integration of knowledge from various fields in order to enhance the existing comprehensive evaluation methods. Through qualitative research, the quantification of risk index allows decision-makers to gain a clear and direct understanding of investment risks. The scientific weighting of indices plays a vital role in evaluating environmental risks associated with overseas mining investments, consequently impacting the accuracy of the results.

At present, the main methods for evaluating the risk of overseas mining investment include the analytic hierarchy process (AHP), data envelopment analysis (DEA), artificial neural network (ANN) analysis, support vector machine (SVM), the fuzzy comprehensive evaluation method, the gray evaluation method, sensitivity analysis, the entropy method, the particle swarm algorithm and the BP neural network (Banda 2019; He et al. 2021, 2022; Ke et al. 2012; Khalili-Damghani et al. 2016; Memon et al. 2015).

However, these methods have limitations. The entropy method can determine the weights for different evaluation methods such as the analytic hierarchy process (AHP), grey system theory, and fuzzy evaluation. However, the AHP may not be suitable for solving multi-objective problems due to the high computational workload and subjective weight allocation. In contrast, the grey system theory only reflects positive correlations among data columns and fails to account for negative correlations.

The fuzzy comprehensive evaluation method typically utilizes a linear weighted-average model to generate the evaluation set. However, this approach often leads to distorted, failed, homogenized, and inconsistent evaluation results, making the evaluation process complex. The grey evaluation method effectively captures the uncertainty of overseas mining investment systems but is hindered by its low resolution. In comparison, artificial neural network (ANN) analysis exhibits characteristics similar to human evaluation and offers the advantages of speed and objectivity. Nevertheless, when dealing with samples that lack coordination, the evaluation results obtained through ANN analysis are prone to homogenization.

At present, the majority of research conducted on evaluation models primarily focuses on the simplistic categorization of risk levels, overlooking the inherent unpredictability and ambiguity of risk. Meanwhile, the cloud matter-element model has the capacity to not only quantitatively analyze risk but also effectively consider the uncertainty and randomness associated with delineating boundaries for risk levels.

Aimed at the fuzziness and randomness during the evaluation process, Ruan (Ruan et al. 2018) constructed a fuzzy comprehensive evaluation method based on a cloud model. Cloud model theory has a strong ability to express knowledge and information. The comment sets and membership functions improved by a cloud model could effectively reflect the uniformity of ambiguity and randomness.

Due to the complicated risk factors, incomplete quantitative indexes and the uncertainty of overseas mining investment, the cloud matter-element model can be used to fully evaluate the impact of uncertainty during risk assessment (Lima and Suslick 2006).

Based on the research findings of foreign scholars, we have found that foreign research on the risks of mining investment started early, and the theory has become mature. The research tends to focus on evaluating the current situation. Generally, risk factors are identified from various aspects such as politics, the economy, society, geological conditions and other factors. An investment risk evaluation indicator system is established, and the investment environment is assessed using certain evaluation methods. The evaluation mainly involves subjective scoring and weighted calculation of composite indices, focusing on qualitative analysis with some quantitative calculations. However, the quantitative analysis methods used are often simple and tend to overlook the interaction and connection between the connotations of regional mining investment risks and risk factors.

There have been fruitful research results on the identification of overseas mining investment risks for Chinese enterprises, and the selection of investment locations has also received increasing attention from scholars. However, there remain problems and deficiencies in research on the risks faced by host countries during overseas investment activities.

These include the insufficient refinement of evaluation indicators, a lack of research from an industry perspective, and inadequate use of quantitative indicators. In terms of evaluation methods, many scholars tend to use a single evaluation method, often overlooking the fuzziness and randomness of the evaluation process.

This study focuses on the risks faced by host countries in mineral investment activities. By refining the evaluation indicators, quantifying each indicator, and utilizing research methods such as the analytic hierarchy process, the entropy method, the cloud model, and the matter-element theory, the risks faced by host countries in mineral investment activities are evaluated.

1. The construction of risk evaluation index system for mineral investment

1.1. The identification of the risk of mineral investment in the host country

Mineral resources investment risks can be divided into the following categories:

- From the perspective of the nature of investment, it can be divided into geological, social, political, and economic risks. It can be divided into external and internal business risks from the perspective of business operation. In the context of the controllability of risks, it can be divided into predictable and controllable risks and uncontrollable risks. From the perspective of the host country, risk could be divided into political and legal risks, social and cultural risks, economic and financial risks, and natural risks.
- From the political and legal point of view, the political stability and perfection of the legal system of the host country both have a direct impact on the investment activities of investors. from the social and cultural point of view, the risks of infrastructure construction and cultural conflicts affect the normal operation of transnational investment enterprises. From the perspective of economy and finance, the unstable economic development of the host country brings risks to investment and affects the investment income of transnational investment enterprises. From the natural risk point of view, the resource endowment conditions and the stability of the natural environment of the host country affects the attractiveness of the foreign investment entry.

Therefore, the risks faced by mineral investment activities in the host country are summarized as political and legal risks, social and cultural risks, economic and financial risks, and natural risks.

1.2. The construction of the evaluation index system

The hierarchical analysis method (AHP) is used to classify the mineral investment host country risk evaluation indicators into multiple layers, and the mineral investment host country risk evaluation indicator system is shown in Table 1.

Table 1. Risk evaluation index system of mineral investment in the host country

Tabela 1. System wskaźników oceny ryzyka inwestycji w surowce mineralne w kraju przyjmującym

First level index	Second level index
Political and legal risk (I_1)	Political risk (I_{11})
	Level of government corruption (I_{12})
	Perfection of the legal system (I_{13})
Sociocultural risk (I_2)	Risk of social unrest (I_{21})
	Labor risk (I_{22})
	Infrastructure risk (I_{23})
	Cultural conflict risk (I_{24})
Economic and financial risk (I_3)	Exchange rate risk (I_{31})
	Inflation risk (I_{32})
	Economic development level (I_{33})
	External debt liabilities (I_{34})
Natural risk (I_4)	Ore quality risk (I_{41})
	Natural disaster risk (I_{42})

1.3. Evaluation index analysis and assignment basis

1.3.1. Political and legal risk

Political and legal risk refers to the uncertainty of business performance and other objectives caused by changes in the investment environment due to political instability or discontinuity of laws and regulations in the host country. Specifically, it includes three aspects (political risk, government corruption degree, legal perfection degree) and mining legal policy risk. Table 2 shows the evaluation criteria of each index in political and legal risk.

1. Political risk. Typical risk events of political risk include frequent regime change, civil unrest, revolution and terrorist attack in the host country, which are unavoidable

Table 2. Evaluation criteria of each index in political and legal risk

Tabela 2. Kryteria oceny poszczególnych wskaźników ryzyka politycznego i prawnego

Second level index	Assignment basis	Index value range
Political risk (I_{11})	Political stability index in WGI	[–2.5, 2.5]
Level of government corruption (I_{12})	Control of corruption index in WGI	[–2.5, 2.5]
Perfection of legal system (I_{13})	Index of laws and regulations in WGI	[–2.5, 2.5]

* The value range of indicators is derived from *Worldwide Governance Indicators* (WGI).

risks for mineral investment and operation. In the specific project evaluation, the political stability governance performance of each country in *WGI* is used to evaluate the political risk of the host country. The higher the score, the more stable the political situation will be.

2. Level of government corruption. In investment activities, government corruption not only seriously damages the fairness of investment policies, but also hinders the smooth implementation of investment management activities. In the specific project evaluation, the governance performance of each country in *WGI* was used to evaluate the corruption status of the host government. The higher the score, the lower the degree of government corruption.
3. Perfection of the legal system. The degree of perfection of the rule of law includes the degree of perfection of the legal system, the strength of law enforcement, and the degree of judicial independence. In the specific project evaluation, the governance performance of *WGI*'s laws and regulations index is used to assess the political stability risk of the host country. The higher the score, the higher the degree of legal perfection.

1.3.2. Sociocultural risk

The social and cultural risks of mineral investment are mainly manifested in the following aspects: whether the infrastructure is complete, whether the people resist, whether the cultural consciousness will arouse the striking behavior, etc. This includes social unrest risk, labor risk, social infrastructure risk and cultural conflict risk. The evaluation criteria of each index in social and cultural risk are shown in Table 3.

1. Risk of social unrest. Indicators of social unrest risk include the occurrence of organized crime, murders, terrorism and the adequacy of dispute resolution laws. The higher the country's score, the lower the risk of social unrest.
2. Labor risk. Cooperative labor relations, the ease of hiring labor, and productivity in the host country are all important factors affecting labor risk. In specific project eval-

Table 3. Evaluation criteria of each index in social and cultural risk

Tabela 3. Kryteria oceny poszczególnych wskaźników ryzyka społecznego i kulturowego

Second level index	Assignment basis	Index value range
Risk of social unrest (I_{21})	Social institutions and governance index in the GCI	[0, 100]
Labor risk (I_{22})	Labor market index in GCI	[0, 100]
Infrastructure risk (I_{23})	Infrastructure index in GCI	[0, 100]
Cultural conflict risk (I_{24})	Hofstede six-dimensional cultural difference index The sum of the absolute cultural gap with the investment country	(0, 500]

* The value range of the index is derived from the *Global Competitiveness Index* (GCI) and Hofstede's cultural dimensions theory.

uation, the labor market index ranking in *GCI* is used to quantify this indicator. The higher the score of the country, the lower the labor risk.

3. Infrastructure risk. The infrastructure of the society mainly includes communication conditions, water and power supply conditions, port conditions, transportation conditions, etc. In the specific project evaluation, the infrastructure ranking of the region where the mine is located in the *GCI* is quantified, and the higher the country score, the lower the infrastructure risk of the country.
4. Culture conflict risk. In investment activities, culture clash risk refers to the differences due to cultural background as well as cultural awareness, including spirituality, language, religious beliefs, working styles and cooperation patterns. In the specific project evaluation, the sum of the absolute value of the six-dimensional cultural difference index of Hofstede in the host country and the gap with the investment country is used for calculations; the larger the difference, the higher the risk of cultural conflict; conversely, the lower the risk of cultural conflict.

1.3.3. Economic and financial risk

The economic and financial situation of the host country is an important influence on outward foreign direct investment (OFDI). The unstable economic development of the host country will bring risks to investment and affect the return of OFDI. Specifically, it includes exchange rate risk, inflation risk, interest rate fluctuation risk, economic development level, and foreign debt indebtedness. The assignment criteria of each indicator in economic and financial risk are shown in Table 4.

1. Exchange rate risk. Exchange rate risk refers to the possibility of increased operational risk due to changes in the currency exchange rates of the host country. Exchange rate risk is a key factor that cannot be ignored in enterprise investment and manage-

Table 4. Assignment criteria for each indicator in economic and financial risks

Tabela 4. Kryteria przypisania dla poszczególnych wskaźników ryzyka ekonomiczno-finansowego

Second level index	Assignment basis	Index value range
Exchange rate risk (I_{31})	Exchange rate stability ranking in ICRG	(0, 100]
Inflation risk (I_{32})	Inflation index in GCI	[0, 100]
Economic development level (I_{33})	GDP per capita index in WDI	(0, 190]
External debt liabilities (I_{34})	Debt Status Index in GCI	[0, 100]

* Index value range is derived from the *International Country Risk Guide* (ICRG), *Global Competitiveness Index* (GCI), and *World Development Indicators* (WDI).

ment. This index is quantified by the ranking of exchange rate stability in *ICRG*. The higher the ranking, the lower the exchange rate risk.

2. Inflation risk. Inflation may cause a significant increase in wages and price levels in the host country, resulting in higher operating costs and a significant impact on the financial viability of the project. In the specific project evaluation, the inflation index in *GCI* is used to quantify this indicator, and the higher the country score, the lower the inflation risk.
3. Level of economic development. The level of economic development refers to the scale, speed and level of economic development of a country. The stable economic development of the host country can create a good investment environment, which is conducive to mineral investment activities. In the specific project evaluation, the index is quantified by using the GDP per capita index in *WDI*. The higher the ranking of the country, the higher the level of economic development.
4. External debt liabilities. External debt indebtedness refers to the indebtedness of a country to foreign countries and is used to measure the dependence of a country on external debt for economic growth, the overall risk of the external debt of a country and its international creditworthiness. In the specific project evaluation, the debt status index in the *GCI* is used for calculations; the higher the country score, the lower the overall risk of external debt liabilities.

1.3.4. Natural risk

Natural risk refers to the risk of a certain impact on mineral investments due to phenomena arising from irregular changes in natural forces, specifically including ore quality risk as well as natural disaster risk. The assignment criteria of each index in natural risk are shown in Table 5.

Table 5. Evaluation criteria of each index in natural risk

Tabela 5. Kryteria oceny poszczególnych wskaźników ryzyka naturalnego

Second level index	Assignment basis	Index value range
Ore quality risk (I_{41})	Comprehensive rating of reserves and ore grades	[0,100]
Natural disaster risk (I_{42})	Natural disaster risk index in GRR	[0,10%]

* The value range of the index is derived from the *Global Risk Report 2023* (GRR).

1. Ore quality risk. In the evaluation of mineral investment activities, the natural risk should consider the ore quality risk, including the host country's reserves and ore grade. In the specific project evaluation, the comprehensive score of reserves and ore grade is used to quantify the index. The higher the score, the lower the ore quality risk.
2. Natural disaster risk. Natural disaster risk refers to the risk created by natural and physical factors and other material phenomena, such as earthquakes, floods, typhoons, mudslides, etc., which can have a serious impact on mineral companies. In the specific project evaluation, the natural disaster risk index in *GRR* is used; the higher the value, the lower the natural disaster risk.

1.4. Evaluation index weights determination

The weight determination methods are mainly divided into three categories: subjective assignment method, objective assignment method, and combined subjective and objective assignment method. The subjective assignment method is simple, but the human factor is too strong, and the objective assignment method is completely dependent on the sample data, so the combined assignment method is adopted to ensure the accuracy and comprehensiveness of the assignment results.

1.4.1. The determination of subjective weights

A flow chart for determining the weights of each indicator of the evaluation index system using AHP is shown in Figure 1.

The opinions of experts from colleges, universities, design institutes and mining enterprises are widely collected using a questionnaire survey. The questionnaire adopts the 1–9 scale method, and each indicator is compared with the importance of the previous level in pairs, as shown in Table 6.

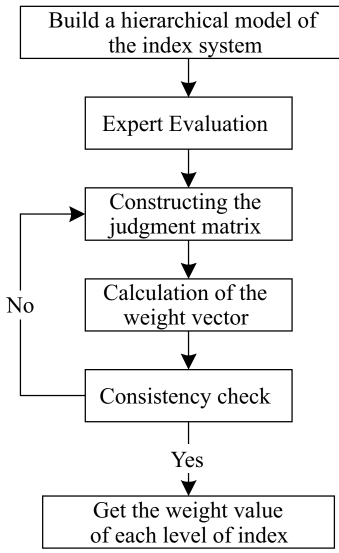

Fig. 1. Flowchart of calculating subjective weights based on AHP

Rys. 1. Schemat obliczania wag subiektywnych na podstawie AHP

Table 6. 9-level importance rating scale of AHP

Tabela 6. Dziewięciostopniowa skala oceny ważności AHP

Scale	Description
1	Two goals are equally important compared to each other
3	One goal is slightly more important than the other
5	One goal is significantly more important than the other
7	One goal is strongly more important than the other
9	One goal is more extremely important than the other
2, 4, 6, 8	The middle value of the above two adjacent comparisons

The 1–9 scale method is usually used to describe the importance between elements, and the judgment matrix is established as follows:

$$A = (a_{ij})_{n \cdot m} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (1)$$

The weight values of each indicator wi are calculated according to Equation 2 and 3.

$$b_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n} \tag{2}$$

$$w_i = \frac{b_i}{\sum_{i=1}^{n} b_i} \tag{3}$$

For the obtained judgment matrix, the eigenvalue λ_{max} is calculated according to Formula 4. To ensure the consistency of the comparison results and the objectivity and accuracy of the results, a consistency test should be performed. The consistency index *CI* should be calculated according to Equation 5.

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} w_i}{b_i} \tag{4}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{5}$$

When *CI* equals 0, the judgment matrix has complete consistency. The consistency of the judgment matrix is worse when the value of CI is larger. When CI is less than 0.1, the judgment matrix is considered to have satisfactory consistency. If this is not the case, the judgment matrix needs to be adjusted.

1.4.2. Objective weight determination

The basic idea of the entropy weighting method is to determine the objective weights according to the variability of indicators. Generally speaking, if the information entropy E_j of an indicator is smaller, it means that the degree of variability of the indicator value is greater. The more information it provides, the greater the role it can play in the comprehensive evaluation and the greater its weight.

Assuming that the index system contains n samples and m indicators, the original matrix can be expressed as:

$$B = (b_{ij})_{n \cdot m} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{bmatrix} \tag{6}$$

The original matrix is normalized according to Equations 7, 8 and 9 to obtain the matrix $C = (c_{ij})_{n \cdot m}$.

$$c_{ij} = \frac{b_{ij} - b_i^{\min}}{b_i^{\max} - b_i^{\min}} \tag{7}$$

$$b_i^{\max} = \max\left\{b_{1j}, b_{2j}, ..., b_{mj}\right\}, \quad j = 1, ..., m \tag{8}$$

$$b_i^{\min} = \min\left\{b_{1j}, b_{2j}, ..., b_{mj}\right\}, \quad j = 1, ..., m \tag{9}$$

The information entropy E_j is calculated according to Equations 10 and 11.

$$D_{ij} = \frac{1 + c_{ij}}{\sum_{i=1}^{m}(1 + c_{ij})} \tag{10}$$

$$E_j = \frac{-\left(\sum_{i=1}^{m} D_{ij} \ln D_{ij}\right)}{\ln n} \tag{11}$$

According to Equation 12, the objective weight w_j is calculated.

$$w_j = \frac{1 - E_j}{m - \sum_{i=1}^{m} E_j} \tag{12}$$

1.4.3. Combination weight determination

To avoid the phenomenon of a single weighting method causing the loss of some important information, the combined weighting method is adopted in this paper. The formula is as follows:

$$\overline{\omega}_i = \alpha \cdot \alpha_i + (1 - \alpha)\beta_i, \quad (i = 1, 2, 3, ..., n) \tag{13}$$

In the equation, α_i is the subjective weight. β_i is the objective weight. $\overline{\omega}_i$ is the combined weight. α is the adjustment coefficient and 0.5 is adopted in this model.

2. Construction of a risk assessment model for mineral investment in the host country

The risks faced by mineral investment in the host country are diverse, and the classification of risk levels is fuzzy and random. Therefore, the cloud model and matter-element theory are combined to construct the risk assessment model of mineral investment in the host country based on the cloud matter-element model. The cloud matter-element model is used to evaluate the risk of the host country. The specific steps are as follows:

The interval division method is used to classify the value ranges of indexes listed in Tables 2, 3, 4 and 5. Table 7 shows the quantification of the second-level indexes.

Each first-level indicator is regarded as the matter element of the indicator layer, and the representation of the matter element of the indicator layer is as follows:

Table 7. Graded quantification of second-level indexes

Tabela 7. Stopniowa kwantyfikacja wskaźników drugiego poziomu

Risk	Low		Relatively low		General		Relatively high		High	
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
I_{11}	(2, 2.5]	(1.5, 2]	(1, 1.5]	(0.5, 1]	(0, 0.5]	(–0.5, 0]	(–1, –0.5]	(–1.5, –1]	(–2, –1.5]	[–2.5, –2]
I_{12}	(2, 2.5]	(1.5, 2]	(1, 1.5]	(0.5, 1]	(0, 0.5]	(–0.5, 0]	(–1, –0.5]	(–1.5, –1]	(–2, –1.5]	[–2.5, –2]
I_{13}	(2, 2.5]	(1.5, 2]	(1, 1.5]	(0.5, 1]	(0, 0.5]	(–0.5, 0]	(–1, –0.5]	(–1.5, –1]	(–2, –1.5]	[–2.5, –2]
I_{21}	(90, 100]	(80, 90]	(70, 80]	(60, 70]	(50, 60]	(40, 50]	(30, 40]	(20, 30]	(10, 20]	[0, 10]
I_{22}	(90, 100]	(80, 90]	(70, 80]	(60, 70]	(50, 60]	(40, 50]	(30, 40]	(20, 30]	(10, 20]	[0, 10]
I_{23}	(90, 100]	(80, 90]	(70, 80]	(60, 70]	(50, 60]	(40, 50]	(30, 40]	(20, 30]	(10, 20]	[0, 10]
I_{24}	(0, 50]	(50, 100]	(100, 150]	(150, 200]	(200, 250]	(250, 300]	(300, 350]	(350, 400]	(400, 450]	(450, 500]
I_{31}	(0, 15]	(15, 30]	(30, 45]	(45, 60]	(60, 75]	(75, 90]	(90, 105]	(105, 120]	(120, 135]	(135, 150]
I_{32}	(90, 100]	(80, 90]	(70, 80]	(60, 70]	(50, 60]	(40, 50]	(30, 40]	(20, 30]	(10, 20]	[0, 10]
I_{33}	(0, 19]	(19, 38]	(38, 57]	(57, 76]	(76, 95]	(95, 114]	(114, 133]	(133, 152]	(152, 171]	(171, 190]
I_{34}	(90, 100]	(80, 90]	(70, 80]	(60, 70]	(50, 60]	(40, 50]	(30, 40]	(20, 30]	(10, 20]	(0, 10]
I_{41}	(90, 100]	(80, 90]	(70, 80]	(60, 70]	(50, 60]	(40, 50]	(30, 40]	(20, 30]	(10, 20]	(0, 10]
I_{42}	(9%, 10%]	(8%, 9%]	(7%, 8%]	(6%, 7%]	(5%, 6%]	(4%, 5%]	(3%, 4%]	(2%, 3%]	(1%, 2%]	(0, 1%]

$$R_i = \left(I_i, I_{ip}, V_{ip}\right) = \begin{bmatrix} I_i & I_{i1} & V_{i1} \\ & I_{i2} & V_{i2} \\ & \vdots & \vdots \\ & I_{in} & V_{in} \end{bmatrix} \tag{14}$$

In the equation, I_i is the first-level index layer of the matter element to be evaluated. I_{ip} is the p^{th} index corresponding to the second level I_i. V_{ip} indicates the quantity of I_{ip}.

The classical domain and section domain are divided according to the definition of the classical domain and section domain, as shown in Table 8.

Table 8. Division of the classical domain and the section domain

Tabela 8. Podział domeny klasycznej i domeny sekcji

Risk level	Low	Relatively low	General	Relatively high	High
Classical domain	(0, 0.2)	(0.2, 0.4)	(0.4, 0.6)	(0.6, 0.8)	(0.8, 1)
Section domain	(0, 1)				

The numerical characteristics of the cloud matter-element model are expressed as follows:

$$R_0 = \begin{bmatrix} U & u_1 & u_2 & u_3 & u_4 & u_5 \\ I_{i1} & (0.1, 0.085, 0.007) & (0.3, 0.085, 0.007) & (0.5, 0.085, 0.007) & (0.7, 0.085, 0.007) & (0.9, 0.085, 0.007) \\ I_{i2} & (0.1, 0.085, 0.007) & (0.3, 0.085, 0.007) & (0.5, 0.085, 0.007) & (0.7, 0.085, 0.007) & (0.9, 0.085, 0.007) \\ I_{i3} & (0.1, 0.085, 0.007) & (0.3, 0.085, 0.007) & (0.5, 0.085, 0.007) & (0.7, 0.085, 0.007) & (0.9, 0.085, 0.007) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ I_{in} & (0.1, 0.085, 0.007) & (0.3, 0.085, 0.007) & (0.5, 0.085, 0.007) & (0.7, 0.085, 0.007) & (0.9, 0.085, 0.007) \end{bmatrix}$$

In the equation, u_i is the risk level (i = 1, 2, …, 5). I_{in} is the n^{th} index of second-level corresponding to the i^{th} matter element.

Each risk value corresponds to the membership degree of each risk level, which is calculated as shown in Table 9.

The membership degree of first-level indicators to risk level j is determined by

$$\mu_j(R_i) = \sum_{i=1}^{n} \omega_{ip} \mu_j(Rip)$$

Table 9. Membership degree of each risk value corresponding to each risk level

Tabela 9. Stopień przynależności do każdej wartości ryzyka odpowiadający każdemu poziomowi ryzyka

Risk level	Low	Relatively low	General	Relatively high	High
0.1	1.0000	0.1353	0.0003	0.0000	0.0000
0.2	0.6065	0.6065	0.0111	0.0000	0.0000
0.3	0.1353	1.0000	0.1353	0.0003	0.0000
0.4	0.0111	0.6065	0.6065	0.0111	0.0000
0.5	0.0003	0.1353	1.0000	0.1353	0.0003
0.6	0.0000	0.0111	0.6065	0.6065	0.0111
0.7	0.0000	0.0003	0.1353	1.0000	0.1353
0.8	0.0000	0.0000	0.0111	0.6065	0.6065
0.9	0.0000	0.0000	0.0003	0.1353	1.0000
1.0	0.0000	0.0000	0.0000	0.0111	0.6065

The membership degree of target matter element to risk level j is determined by

$$\mu_j(R) = \sum_{i=1}^{4} \omega_i \mu_j(R_i)$$

The risk level of each element is determined by

$$\mu_j(R) = \max_{j \in \{low, relatively\ low, general, relatively\ high, high\}} \mu_j(R)$$

3. The risk assessment of mineral investment in the host country

3.1. Weights determination

The opinions of experts from universities, research institutes and mining enterprises were widely collected using a questionnaire survey. Thirty copies of questionnaires were sent out and twenty-three were collected in total. Table 10 shows the collection of questionnaires.

Table 10. Questionnaire collection

Tabela 10. Zbiór kwestionariuszy

Quantity	Expert Sources	Areas of expertise
8	Universities	Mining engineering
7	Research institutes	Mining engineering
8	Mining enterprises	Mining engineering

Table 11 shows the subjective weight of the risk assessment index system of mineral investment in the host country.

Eight countries were selected as the evaluation samples, and the objective weights w_j were calculated according to Equation 12. The objective weights of the host country risk evaluation index system for mineral investment are shown in Table 12.

According to the combined weighting method, the final combined weight of risk indexes is obtained, as shown in Table 13.

Table 11. Subjective weights of risk indicators

Tabela 11. Subiektywne wagi wskaźników ryzyka

First level index		Second level index	
Indexes	Weights	Indexes	Weights
Political and legal risk (I_1)	0.343	Political risk (I_{11})	0.451
		Level of government corruption (I_{12})	0.244
		Perfection of legal system (I_{13})	0.305
Sociocultural risk (I_2)	0.212	Risk of social unrest (I_{21})	0.320
		Labor risk (I_{22})	0.119
		Infrastructure risk (I_{23})	0.236
		Cultural conflict risk (I_{24})	0.325
Economic and financial risk (I_3)	0.335	Exchange rate risk (I_{31})	0.314
		Inflation risk (I_{32})	0.282
		Economic development level (I_{33})	0.205
		External debt liabilities (I_{34})	0.199
Natural risk (I_4)	0.111	Ore quality risk (I_{41})	0.715
		Natural disaster risk (I_{42})	0.285

Table 12. Objective weights of risk indexes

Tabela 12. Obiektywne wagi wskaźników ryzyka

First level index		Second level index	
First level index	Second level index	First level index	Second level index
Political and legal risk (I_1)	0.230	Political risk (I_{11})	0.329
		Level of government corruption (I_{12})	0.336
		Perfection of legal system (I_{13})	0.335
Sociocultural risk (I_2)	0.307	Risk of social unrest (I_{21})	0.247
		Labor risk (I_{22})	0.247
		Infrastructure risk (I_{23})	0.249
		Cultural conflict risk (I_{24})	0.257
Economic and financial risk (I_3)	0.308	Exchange rate risk (I_{31})	0.248
		Inflation risk (I_{32})	0.250
		Economic development level (I_{33})	0.248
		External debt liabilities (I_{34})	0.254
Natural risk (I_4)	0.154	Ore quality risk (I_{41})	0.504
		Natural disaster risk (I_{42})	0.496

Table 13. Combined weight of risk indexes

Tabela 13. Łączna waga wskaźników ryzyka

First level index		Second level index	
First level index	Second level index	First level index	Second level index
Political and legal risk (I_1)	0.287	Political risk (I_{11})	0.390
		Level of government corruption (I_{12})	0.290
		Perfection of legal system (I_{13})	0.320
Sociocultural risk (I_2)	0.260	Risk of social unrest (I_{21})	0.283
		Labor risk (I_{22})	0.183
		Infrastructure risk (I_{23})	0.243
		Cultural conflict risk (I_{24})	0.291
Economic and financial risk (I_3)	0.321	Exchange rate risk (I_{31})	0.281
		Inflation risk (I_{32})	0.266
		Economic development level (I_{33})	0.226
		External debt liabilities (I_{34})	0.227
Natural risk (I_4)	0.132	Ore quality risk (I_{41})	0.610
		Natural disaster risk (I_{42})	0.390

3.2. Risk assessment

Australia, South Africa, Canada, Suriname, Kyrgyzstan, Ethiopia, the Democratic Republic of the Congo and Tajikistan are the countries with the highest overseas investment in gold minerals in China. These eight countries that are relatively rich in minerals and have a large number of investment projects have been selected for the practical application of the constructed model to evaluate the host country's risks in mineral investment activities.

Taking the country of Australia as an example, the risk of the host country in mineral investment activities is evaluated. The political-legal, socio-cultural, economic-financial and mineral resource endowment of Australia are analyzed and the relevant data are collected to determine the risk degree value of each second-level index. The index value and risk value of each second-level index of the country of Australia are shown in Table 14. Each element to be evaluated is determined according to Table 14:

$$R_1 = \begin{bmatrix} I_1 & I_{11} & 0.4 \\ & I_{12} & 0.2 \\ & I_{13} & 0.2 \end{bmatrix}; \quad R_2 = \begin{bmatrix} I_2 & I_{21} & 0.3 \\ & I_{22} & 0.4 \\ & I_{23} & 0.3 \\ & I_{24} & 0.6 \end{bmatrix}; \quad R_3 = \begin{bmatrix} I_3 & I_{31} & 0.1 \\ & I_{32} & 0.1 \\ & I_{33} & 0.1 \\ & I_{34} & 0.1 \end{bmatrix}; \quad R_4 = \begin{bmatrix} I_4 & I_{41} & 0.1 \\ & I_{42} & 0.7 \end{bmatrix}.$$

Table 14. Mineral risk assessment indexes of Australia

Tabela 14. Wskaźniki oceny ryzyka mineralnego w Australii

Index code	Index name	Index value	Risk value
I_{11}	Political risk	0.98	0.4
I_{12}	Level of government corruption	1.81	0.2
I_{13}	Perfection of legal system	1.72	0.2
I_{21}	Risk of social unrest	73.6	0.3
I_{22}	Labor risk	68.5	0.4
I_{23}	Infrastructure risk	73.6	0.3
I_{24}	Cultural conflict risk	251	0.6
I_{31}	Exchange rate risk	4	0.1
I_{32}	Inflation risk	100	0.1
I_{33}	Economic development level	10	0.1
I_{34}	External debt liabilities	100	0.1
I_{41}	Ore quality risk	91	0.1
I_{42}	Natural disaster risk	117	0.7

Table 15. Membership of second-level indexes to risk levels

Tabela 15. Przynależność wskaźników drugiego poziomu do poziomów ryzyka

Risk level	Low	Relatively low	General	Relatively high	High
I_{11}	0.0111	0.6065	0.6065	0.0111	0
I_{12}	0.6065	0.6065	0.0111	0	0
I_{13}	0.6065	0.6065	0.0111	0	0
I_{21}	0.1353	1	0.1353	0.0003	0
I_{22}	0.0111	0.6065	0.6065	0.0111	0
I_{23}	0.1353	1	0.1353	0.0003	0
I_{24}	0	0.0111	0.6065	0.6065	0.0111
I_{31}	1	0.1353	0.0003	0	0
I_{32}	1	0.1353	0.0003	0	0
I_{33}	1	0.1353	0.0003	0	0
I_{34}	1	0.1353	0.0003	0	0
I_{41}	1	0.1353	0.0003	0	0
I_{42}	0	0.0003	0.1353	1	0.1353

The membership degree of each second-level index to each risk level is determined as follows (Table 15).

The membership degree of the first-level indexes to be evaluated for each risk level was calculated, and the risk level of each first-level indicator was obtained according to the principle of maximum membership degree:

$$\mu_j(R_1) = (0.3827, 0.3852, 0.2034, 0.0001, 0.0000) = \mu_{relatively\ low}(R_1)$$

$$\mu_j(R_2) = (0.0714, 0.6145, 0.3644, 0.1989, 0.0036) = \mu_{relatively\ low}(R_2)$$

$$\mu_j(R_3) = (1.0000, 0.1354, 0.0003, 0.0000, 0.0000) = \mu_{low}(R_3)$$

$$\mu_j(R_3) = (0.6070, 0.0822, 0.0535, 0.3940, 0.0533) = \mu_{low}(R_3)$$

The risk level of each category is obtained according to the maximum membership principle:

$$\mu_j(R_1) = (0.4663, 0.3199, 0.1560, 0.0998, 0.0076) = \mu_{low}(R)$$

On the whole, the risk level of mineral resources in country A is low. As can be seen from Figure 2, the index values of political and legal risks and socio-cultural risks are between

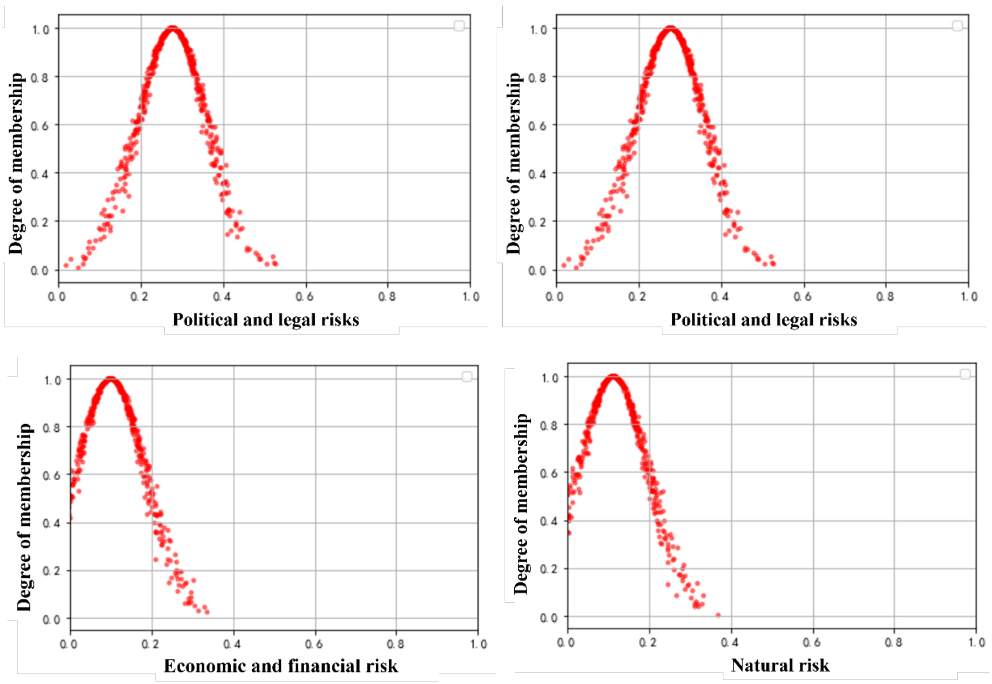

Fig. 2. Cloud map of different risk levels of minerals in Country A

Rys. 2. Mapa chmury przedstawiająca różne poziomy ryzyka związanego z minerałami w kraju A

Table 16. Risk evaluation level of mineral resources investment in each country

Tabela 16. Poziom oceny ryzyka inwestycji w surowce mineralne w poszczególnych krajach

No.	Country	Risk level
1	Australia	Low
2	South Africa	Low
3	Canada	Low
4	Suriname	General
5	Kyrgyzstan	Relatively low
6	Ethiopia	Relatively low
7	The Democratic Republic of the Congo	General
8	Tajikistan	General

0.2 and 0.4, which are at a low level. The index values of economic and financial risks and natural risks are between 0 and 0.2, which is at a low level.

In accordance with the above steps, the investment risks of eight countries are evaluated. The evaluation results are shown in Table 16.

Discussion

A new evaluation indicator system for risks faced by host countries in overseas mining investment activities has been developed based on the characteristics of such investments in comparison to previous research. The system consists of four main indicators: political and legal risks, socio-cultural risks, economic and financial risks, and natural risks. Furthermore, there are thirteen secondary indicators included in this system. Whenever possible, indicators that can be directly quantified were selected during the process of choosing evaluation indicators.

To collect data, survey questionnaires were distributed to industry experts and scholars in the field, which were then processed to determine subjective weights. Additionally, the entropy method was utilized to determine objective weights. Ultimately, the subjective and objective weights were combined to obtain a comprehensive set of scientifically accurate combined weights.

In this study, the cloud model was introduced into the theory of matter-element, resulting in the construction of a risk assessment model for host countries in overseas mineral investment activities. This model enables the quantitative evaluation of the risk level associated with each country and indicator, providing a theoretical basis and decision-making reference for mineral enterprises engaging in overseas investments.

The research not only expands the application of the cloud matter-element model but also enhances the methods of risk evaluation in the mining industry. The proposed methodology can be applied to similar evaluations and is both scientifically grounded and scalable.

Conclusion

Scientific identification and evaluation and the prevention of risk are important issues facing mineral investment. Risk in this paper is defined as the host country's risk faced in mineral investment activities. To evaluate the risk scientifically, the cloud matter-element model was introduced to construct the risk assessment model of the host country in mineral investment activities. Risk evaluation and application verification was performed for eight countries with more concentrated investment and richer mineral resources as cases.

In accordance with the characteristics of mineral investment, a risk evaluation index system of the host country in mineral investment activities has been established, which includes four first-level indexes including political and legal risk, social and cultural risk, economic and financial risk, and natural risk, and thirteen second-level indexes. The index system can scientifically, systematically and objectively summarize the risk environment of the host country faced by overseas mineral investment. The subjective weight was determined by sending questionnaires to experts and scholars in the industry and conducting data processing. The entropy method was used to determine the objective weight. Finally, the subjective weight and the objective weight were combined to obtain a group of scientific and accurate combined weights.

The research results show that the weights of each level of indicator in the risk evaluation of mineral investment host countries are economic and financial risk, political and legal risk, socio-cultural risk, and natural risk in descending order, among which, political and legal risk should focus on political bureau risk. Socio-cultural risk needs to be alert to the risk of cultural conflict. Economic and financial risk has the highest proportion of exchange rate risk, and ore quality risk seriously affects natural risk. However, the impact of natural disaster risk on natural risk should not be ignored.

The cloud model is introduced into matter-element theory to construct the risk assessment model of the host country in mineral investment activities. The model can not only quantitatively evaluate the risk level of each country and each index but also comprehensively consider the randomness and fuzziness of risk assessment, which can provide the corresponding theoretical basis and decision-making method for mineral enterprise investment. Eight countries with concentrated investment and rich mineral resources are selected as sample countries to verify the model.

This research was supported by the National Key R&D Program of China (no. 3592022YFC2903905) and the National Natural Science Foundation of China (no. 52074022).

REFERENCES

Al Khattab et al. 2007 – Al Khattab, A., Anchor, J. and Davies, E. 2007. Managerial perceptions of political risk in international projects. *International Journal of Project Management* 25(7), pp. 734–743, DOI: 10.1016/j.ijproman.2007.03.006.

Amoatey et al. 2017 – Amoatey, C.T., Famiyeh, S. and Andoh, P. 2017. Risk assessment of mining projects in Ghana. *Journal of Quality in Maintenance Engineering* 23(1), pp. 22–38, DOI: 10.1108/JQME-09-2015-0044.

Buckley, P., and Casson, M. 1976. The Future of Multinational Enterprises. London: Macmillan.

Banda, W. 2019. An integrated framework comprising of AHP, expert questionnaire survey and sensitivity analysis for risk assessment in mining projects. *International Journal of Management Science and Engineering Management* 14(3), pp. 180–192, DOI: 10.1080/17509653.2018.1516577.

Botín et al. 2011 – Botín, J.A., Guzmán, R.R. and Smith, M.L. 2011. A methodological model to assist in the optimization and risk management of mining investment decisions. *Dyna* 78(170), pp. 221–226.

Brennan, M.J. and Schwartz, E.S. 1985. Evaluating natural resource investments. *The Journal of Business* 58(2), pp. 135–157.

Foo et al. 2018 – Foo, N., Bloch, H. and Salim, R. 2018. The optimisation rule for investment in mining projects. *Resources Policy* 55, pp. 123–132, DOI: 10.1016/j.resourpol.2017.11.005.

He et al. 2021 – He, H., Xing, R., Han, K. and Yang, J. 2021. Environmental risk evaluation of overseas mining investment based on game theory and an extension matter element model. *Scientific Reports* 11(1), DOI: 10.1038/s41598-021-95910-x.

He et al. 2022 – He, H., Zhao, Y., Tian, H. and Li, W. 2022. Risk Evaluation of Overseas Mining Investment Based on a Support Vector Machine. *Sustainability* 15(1), DOI: 10.3390/su15010240.

Huang et al. 2020 – Huang, J., Liu, J., Zhang, H. and Guo, Y. 2020. Sustainable risk analysis of China's overseas investment in iron ore. *Resources Policy* 68, DOI: 10.1016/j.resourpol.2020.101771.

Hussain et al. 2020 – Hussain, J., Zhou, K., Guo, S. and Khan, A. 2020. Investment risk and natural resource potential in "Belt and Road Initiative" countries: A multi-criteria decision-making approach. *Science of the Total Environment* 723, DOI: 10.1016/j.scitotenv.2020.137981.

Ke et al. 2012 – Ke, L., Xiaoliu, S., Zhongfu, T. and Wenyan, G. 2012. Grey clustering analysis method for overseas energy project investment risk decision. *Systems Engineering Procedia* 3, pp. 55–62, DOI: 10.1016/j.sepro.2011.11.008.

Khalili-Damghani et al. 2016 – Khalili-Damghani, K., Tavana, M. and Santos-Arteaga, F.J. 2016. A comprehensive fuzzy DEA model for emerging market assessment and selection decisions. *Applied Soft Computing* 38, pp. 676–702, DOI: 10.1016/j.asoc.2015.09.048.

Lima, G.A.C. and Suslick, S.B. 2006. Estimating the volatility of mining projects considering price and operating cost uncertainties. *Resources Policy* 31(2), pp. 86–94, DOI: 10.1016/j.resourpol.2006.07.002.

Meldrum, D. 2000. Country risk and foreign direct investment. *Business economics* 35(1), pp. 33–40.

Memon et al. 2015 – Memon, M.S., Lee, Y.H. and Mari, S.I. 2015. Group multi-criteria supplier selection using combined grey systems theory and uncertainty theory. *Expert Systems with Applications* 42(21), pp. 7951–7959, DOI: 10.1016/j.eswa.2015.06.018.

Ruan et al. 2018 – Ruan, J., Chen, Y., Xiao, X., Yong, G., Huang, R. and Miao, Z. 2018. Fuzzy comprehensive evaluation of ecological risk based on cloud model: taking Chengchao Iron mine as example. IOP Conference Series: Earth and Environmental Science,

Scammacca et al. 2021 – Scammacca, O., Gunzburger, Y. and Mehdizadeh, R. 2021. Gold mining in French Guiana: A multi-criteria classification of mining projects for risk assessment at the territorial scale. *The Extractive Industries and Society* 8(1), pp. 32–43, DOI: 10.1016/j.exis.2020.06.020.

Shahabi et al. 2022 – Shahabi, R.S., Basiri, M.H., Qarahasanlou, A.N., Mottahedi, A. and Dehghani, F. 2022. Fuzzy MADM-based model for prioritization of investment risk in Iran's mining projects. *International Journal of Fuzzy Systems* 24(7), pp. 3189–3207, DOI: 10.1007/s40815-022-01331-x.

Sobczyk et al. 2017 – Sobczyk, E.J., Kicki, J., Sobczyk, W. and Szuwarzyński, M. 2017. Support of mining investment choice decisions with the use of multi-criteria method. *Resources Policy* 51, pp. 94–99, DOI: 10.1016/j.resourpol.2016.11.012.

Tubis et al. 2020 – Tubis, A., Werbińska-Wojciechowska, S. and Wroblewski, A. 2020. Risk assessment methods in mining industry – A systematic review. *Applied Sciences* 10(15), DOI: 10.3390/app10155172.

Xiang et al. 2022 – Xiang, Y., Zhang, Q., Wang, D. and Wu, S. 2022. Mining Investment Risk Assessment for Nations along the Belt and Road Initiative. *Land* 11(8), DOI: 10.3390/land11081287.

MINERAL INVESTMENT RISK ASSESSMENT OF HOST COUNTRIES BASED ON A CLOUD MATTER-ELEMENT MODEL

Keywords

mineral investment, cloud matter-element model, investment risk, risk assessment

Abstract

The rapid development of the global economy has led to an increasing demand for resources. The disparity between the supply and demand of resources continues to be prominent and shows a situation of short supply. Resource investment projects with large amounts and long construction periods face many risks due to various unpredictable factors. Cultural, legal, economic and other environments vary between different countries. Therefore, comprehensive risk identification, understanding, evaluation, and analysis are important prerequisites for the success of mineral investment. In this paper, the risk of mineral resources investment in host countries is identified. A risk evaluation index system is established to objectively evaluate the risk environment of the host country. The risk evaluation index system includes four first-level indexes: political and legal risk, social and cultural risk, economic and financial risk, and natural risk. The subjective weight was determined by sending questionnaires to experts and scholars in the industry and conducting data processing. The entropy method was used to determine the objective weight. Finally, the subjective weight and the objective weight were combined to obtain a group of scientific and accurate combined weights. The matter-element theory was introduced into the cloud model and a risk assessment model based on the cloud matter-element theory was constructed with comprehensive consideration of the fuzziness and randomness of risks. Eight countries with relatively rich mineral resources were taken as cases to verify the model application. The research results provide a theoretical basis and decision-making methods for mineral enterprise investment.

OCENA RYZYKA INWESTYCJI W MINERAŁY W KRAJACH PRZYJMUJĄCYCH W OPARCIU O MODEL CHMURY MATERII I PIERWIASTKA

Słowa kluczowe

inwestycje w surowce mineralne, model materii-chmury, ryzyko inwestycyjne, ocena ryzyka

Streszczenie

Szybki rozwój gospodarki światowej doprowadził do rosnącego zapotrzebowania na surowce. Rozbieżność między podażą a popytem na zasoby jest w dalszym ciągu wyraźna i świadczy o niedoborze podaży. Projekty inwestycyjne dotyczące zasobów, obejmujące duże kwoty i długie okresy budowy, są narażone na wiele zagrożeń ze względu na różne nieprzewidywalne czynniki. Środowiska kulturowe, prawne, gospodarcze i inne różnią się w poszczególnych krajach. Dlatego kompleksowa identyfikacja, zrozumienie, ocena i analiza ryzyka są ważnymi warunkami wstępnymi powodzenia inwestycji w surowce mineralne. W artykule zidentyfikowano ryzyko inwestycji w surowce mineralne w krajach przyjmujących. Ustanawia się system wskaźników oceny ryzyka w celu obiektywnej oceny środowiska ryzyka w kraju przyjmującym. System wskaźników oceny ryzyka obejmuje cztery wskaźniki pierwszego stopnia: ryzyko polityczne i prawne, ryzyko społeczne i kulturowe, ryzyko ekonomiczne i finansowe oraz ryzyko naturalne. Subiektywna waga została określona poprzez wysyłanie kwestionariuszy do ekspertów i naukowców z branży oraz przeprowadzenie przetwarzania danych. Do wyznaczenia wagi obiektywnej wykorzystano metodę entropii. Na koniec połączono wagę subiektywną i wagę obiektywną, aby uzyskać grupę naukowych i dokładnych połączonych wag. Teoria elementów materii została wprowadzona do modelu chmury, a model oceny ryzyka oparty na teorii elementów materii chmury został skonstruowany z kompleksowym uwzględnieniem rozmytości i losowości ryzyka. Do weryfikacji zastosowania modelu wzięto osiem krajów o stosunkowo bogatych zasobach mineralnych. Wyniki badań zapewniają podstawy teoretyczne i metody podejmowania decyzji w zakresie inwestycji przedsiębiorstw z branży wydobywczej.