閉鎖鉱山再生に関する評価結果とその指標システム

特　　　集

Effect Assessing for Closed Mine Reclamation and Its Index System

Changhua LIU *, Lei ZHANG *, Shidong WANG * and Xin ZHAO *

The systematic theoretic study on quantitative evaluation of mine closure is still blank, although some experts and scholars have taken unceasing efforts to the research of assessing theories and methods, and achieved some successes. Effect assessing index for closed mine reclamation are direct reflection of implementation of mine closure planning and relevant circumstances, being used to describe feature values of overall quantity and quality of the planning contents. The principles to establish the index system are made. The classification and contents of the index system are discussed. According to the values range of various index, and contrasting to background value related to quality index, the result grades of elements assessing can be divided. The whole result grade of assessing can be taken. This is the basic of mine closure planning, being applied to the course of whole reclamation scheme formulation and its implementation, taking great significances to closed mine reclamation.

Keywords : Effect assessing, Mine closure, Closed mine reclamation, Index system

1 INTRODUCTION

Each mining enterprise has to suffer the responsibility of various impacts as its mining activities until the end, which can not be drawn with the ended termination of that. The destroyed mine environment must be restored, with the land reclaimed to be stable in [1] production capacity for local communities and public administrative authorities [1,2]. Mine should be properly shut down with effective measurements to the pre-and after-treatment. As a result, how to supervise and manage mine closure affairs and evaluate the renovating effectiveness, has become one key issue of current domestic and foreign mine renovating.

Mine closure relates to multi-discipline and multi-sector including environment, biology, physics, chemistry, geography, geology, economic etc. The solution schemes deal with pollution and disaster prevention, land and ecological environment rehabilitation, long-term division of mining responsibilities, socio-economic problems, the disposal or switch of the original facilities, staffs arrangements, keeping of the file information, cost estimates, the assets settlement and so on.

In the past, many mining enterprises took the mine closure as accidental things in non-plan. However, long-term mineral development practices put the thinking of sustainable development strategy deeply into the hearts of the people. Currently, if mining companies can not be proved to be good for their duties in environment protection, they may be punished or even be prosecuted for one's criminal liability [3]. People in mining industry will cognize increasingly the essentiality to take effect assessing for closed mine reclamation and establish the

*School of Surveying & Land Information Engineering, Henan Polytechnic University, Jiaozuo 454100, Henan, P. R. China.

corresponding scientific index system.

2 SUMMARY OF EFFECT ASSESSING OF CLOSED MINE RECLAMATION

2.1 Theory and Methods of Assessing

The systematic theoretic study on quantitative evaluation of mine closure is still blank in domestic and foreign, although some experts and scholars have taken unceasing efforts to the research of assessing theories and methods, and achieved some successes.

The relevant theories and methods to effect assessing of closed mines remediation can be broadly summarized into three categories. The first one links to theories and methods based on mathematics, which takes rigorous quantitative description and calculation for assessing system based on mathematical theory and analytical methods. The second relates to statistical-based theories and methods, which takes statistical data to establish assessing model for projects that only is done through feel not accurately measure. The third connects to the theories and methods of decision support [4].

2.2 Completion criteria of mine closure

Completion criteria of mine closure means the agreed standards or effect index to indicate that the mine is closed successfully. Before the completion criteria of mine closure is drafted, the post-mining land use must be consulted by all related parties and recorded explicitly in document in detail.

Generally, post-mining land use is basically to restore its original one in order to maintain natural ecosystems. However, post-mining land use may include grazing, agriculture, aquaculture, forestry, industry and other purposes, also leisure land or reservoir etc. Correspondingly, the effectiveness index should be formulated not only in line with the specific conditions of the mining area but also to achieve the completion of a comprehensive mine closure standards before lease lifting.

The completion criteria should be made as document in the beginning period as possible, and involve climate, geological conditions, and the chemical and physical properties of minerals[2].

Various issues should be taken into account as follows.
(1) Restore the land to the agreed conditions.
(2) Restore the land to the state in accordance with aesthetic view point.
(3) Remove all abandoned or unused buildings and structures.
(4) Adopt approachs of taking out or burying to deal with all scrap metal, broken bricks and stones, garbage and other wastes.
(5) To prevent water erosion and pollution.
(6) The treatment and disposal of sewage.
(7) To prevent and control air pollution.
(8) To restore the original special tree species.
(9) The establishment of animal communities, and so on.

All the above criteria should have their specific effect indicators, which can do quantitative assessment to the achieved effect in case of subjective evaluation. Each effect indicator should be clear, specific and measurable, also achievable.

Completion criteria of mine closure can be used to guide the required work that achieves all targets of mine closure, and to prove that the work has been successfully implemented. The completion criteria, which is definited from quality and quantity, should be able to objectively evaluate mine closure and post-remediation results being good or bad.

The development of criteria will help the entire industry to achieve consistency in the development of mine closure planning standards, which bring significant benefits to shareholders of mining companies. For example, they can more firmly implement the government-set standards, and thus more easily adjust the mine reclamation and accept the monitoring of the relevant departments. This also provides a good activities space for mining enterprises, because mining enterprises can get the local community greater confidence from that.

The diversity of mining activities requires formulating appropriate different closure criteria for different mining areas, because it is still a very difficult task to precisely definite mine's overall situation and its specific attributes despite that many mines have some similarities. It can be said that mining activitiy in every mining area is unique, which are all carried out under special economic and social environment. Therefore, it is necessary to establish a set of completion criteria of mine closure not only having general characteristics but also being suitable to a specific mine, in order to be applicable to a wider variety of mining enterprises with eliminating the contradiction between the various indicators.

The work of assessment and monitoring should strictly abide by the completion criteria of mine closure of mine closure, including the specific regional characteristics for the mine. Finally, the assessment and monitoring should be submitted to the relevant departments with detailed evaluation report.

Completion assessment of mine closure and lease relinquishment shows as Fig. 1.

2.3 Analysis to mining-land use planning

As land is the fundamental part of a mine, to research mining-land use planning and mine closure's economical efficiency takes quite important significance to play fully effects of mine closure investment and mining land conservation. Technical and economic analysis to mine closure planning generally include land use analysis, technical and economic indicators, and effect assessment of mine

economic coditions of the location and man-made materialized labor inputs at different sections, land quality and land revenue are also different. Thus, by analyzing the location of land, investment, natural conditions, the extent and frequency of economic activities and so on, the land quality and land revenue differences can be revealed so that better land is used well when worse one used clever in mine closure planning, in order to reasonably determine the use nature and intensity of different sections, laying an important foundation for regulating land use with economic means to improve use efficiency.

when planning mine closure, land use balance table need be made. The roles of that are to make comparative analysis to the status of land use as one of the basis for the mine site and planning, to compare the programs for testing the economy and rationality of the allocation of mine land as one of the bases for mine closure planning and design programs. The model table of mining land use balance shows as Table 1.

Table 1 Balance table of mining-land use

Using type of the land	Actuality		Programming	
	Area（ha）	Proportion（%）	Area（ha）	Proportion（%）
Agriculture				
Mining				
Building				
Road and ditch				
Others				

The data in land use balance table are the main indicators to land use control in mine closure planning, being the most important data to measure the reasonableness of land allocated. By adopting the spatial measurement and statistical functions of GIS, the land balance state of this area can be calculated out.

(2) Rationality analysis to land-occupied proportion in different period

Mining-land use structure displays as not only different spatial combined relations and for the space different combinations of relations and constitute pattern, but also temporal evolution and process, which is impacted by various mining activities in the course of its formation and development.

When the role intensity of various natural factors and human factors reaches a certain level, or the role time reach certain period, the mining land system will happen fluctuation, which means the land attributes will change resulting in the land structure succession.

Mine closure planning at all stages must be reasonable to adjust the ratio of various mining land types. If the land imbalance, it will bring adversely affect to normal production activities of mining enterprises. Mine is a particular geographical area. In the early stages of mining, the proportion of mine land
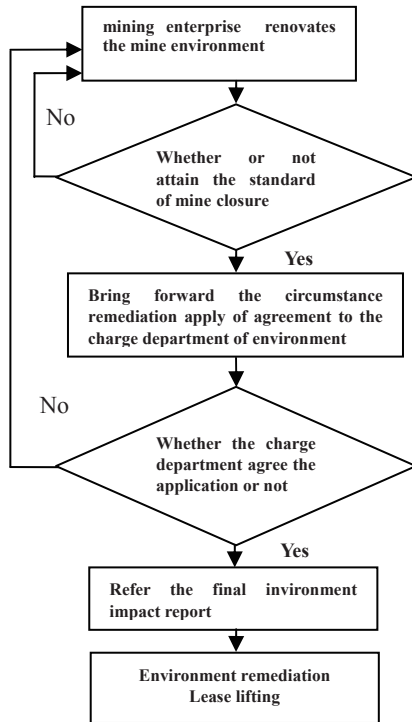

Fig.1 Flowchart of mine closure completion assessment & lease relinquishment

closure, etc.
(1) Mine land evolvement and economical characteristics

Mining land environment is an open system that includes static and dynamic time, space and other factors in constraints associated with each other, having the general nature of other systems. It has more characteristics in the dynamic changes and spatial structure. The former has relatively large magnitude and scope, such as extraction of mineral resources→surface subsidence→land destruction→remediation, restore or abandon. The later has intuitive spatial variation structure with continuously variable from underground to surface[5]. In addition, coal mining is a long process, in which there are more influence factors in wide scope, and broad prospect, with quick change in land use types and very complicate evolution of ecological system. To study the evolution laws of mining land and its economy, can give land reclamation and ecological system specific content combining with various characteristics in different stages of the mine development, so that the evolution of the land and ecosystems is put in virtuous circle state from the beginning, in order to ensure sustainable land use in mining area. That has important scientific and practical significance to study the use and protection of land resources at all stages of of mine closure planning, and remediation programming.

In mining area, due to the differences in natural and

for construction purposes is a smaller, with unlarge land destruction. However, with ongoing mining activities, the areas of construction land, surface subsidence, and other covering accounts increase sharply. If not taking certain measures, the proportion of mining sites will become more unreasonable. Land reclamation is an effective way to change this situation. In ongoing process of mining activities, it is very important to reclaim timely the destroyed land, which can be reclaimed as construction land or agricultural land so as to maintain the dynamic balance of mine land. It is also an important composed part of mine closure planning.

3   BUILDUP OF EFFECT ASSESSING INDEX SYSTEM FOR MINE CLOSURE

Effect assessing indicators for mine closure are the basis for mine closure planning, which will be applied to the formulation and implementation process of that. To make scientific plan for mine closure work, implement accurate control, adjustment and feedback in order to achieve coordinated development in society, economy and environment, it is very necessary to draft a set of index system, which is scientific and can reflect the regional environmental quality status of closed mine area and socio-economic development etc. Nevertheless, to build such a set of index system is extremely complex, as it involves almost all aspects of human activity in the mining area.

Effect assessment index or factor of mine closure is the feature value that directly reflects mine closure planning and implementation as well as relevant circumstances, being used to describe the content of the overall quantity and quality. It includes two meanings. The first is the part to express the connotation and the scope of the content of the assessing index, being the name of that. The second is value of the quantity and quality characteristics of the assessing index, being the data obtained through survey and compiling in summary.

Following extensive research and in-depth analysis, the index system of effect assessing for mine closure is gotten as fig. 2. The building process of that are described below.

3.1   Principles to build up index system of effect assessing for mine closure

To build up index system of effect assessing for mine closure, is to give a series of indicators that can reflect the phenomena, features and contents linking to all the aspects of closed mine reclamation work. In order

(1) Integrity principle

The index system should be integrated and comprehensive, having not only environmental indicators reflecting the remediation effect of a closed mine, but also ones of sciety and economy and other

used in the course of mine closure planning and implementation.

(2) Scientific principle

The index system should be established following scientific methods, as only according to scientific assessing index can the mine closure planning be done scientifically and the targets be realized.

(3) Normativeness principle

Effect assessing index system for mine closure is a system composed of a number of indicators. Because the nature and characteristics of these indicators are not quite similar, every assessment indicators should be classified and processed with normativeness in order to have unity for their meaning, scope, dimension and calculation methods. Moreover, they should remain unchanged over an extended period to ensure the accuracy and comparability of the effect assessing indicators for mine closure.

(4) Feasibility principle

Effect assessing index system for closed mine reclamation must be set up based on mine closure planning requirements, determined depending on the contents of a closed mine planning, having feasibility in the design and implementation of mine closure planning programs.

(5) Adaptivity principle

Effect assessing index system for closed mine reclamation, needs to adapt to the mine closure planning requirements on the one hand, also those of the mine daily work on the other hand, while take into account of the actual possible conditions. If the intact of indicators is emphasized in the one-sided, it will bound to increase the workload of indicators statistics, which beyonds the capacity of the statistics department in labor, finance, and material, and bring more adverse effects to effect assessing index system for closed mine reclamation

(6) Selectivity principle

The effect assessing index system for closed mine reclamation should pay attetion to select those indicators with a realistic, independence and necessity, particularly ones of comprehensive remediation with the representativeness and comparability, truly reflecting the comprehensive remediation level of closed mine area and make it to be objective and accurate assessment.

3.2   The classification and contents of effect assessing index system for mine closure

(1) Index model

Closed mine area is a complex system with multi-variable, multi-objective and multi-level. To establish effects assessment model for mine closure, the systematic remediation model should be build up at first in order to test and describe the interactional quantitive relations among the various elements of mine remediation, as well as the various quality parameters or the relements of the various elements.

On this basis, the index model of effect assessing for mine closure is then established. Commonly used indicator models are as follows. 1) Remediation pressure - remediation state - countermeasure model; 2) Driving force - state - response model; 3) Completely mixed model, etc. [6]

(2) Index types

1) Individual indicator. Individual indicators focus on the description of the basic conditions, the data integrated is in the lowest level, with the features in a large list or menu for indicators, whose quantity is more.

2) Thematic index. Thematic index is based on integrity and simplified requirements. The role things are selected in each theme. Based on principles of comparable weight, a unit is built up as to establish of effectiveness as effect assessment criteria and thematic equivalent for mine closure, which are further re-integrated internally into assessment equivalent. Such indicators are more easy to be operated than the individual indicators, but it is difficult to select the more applicable thematic equivalent and evaluation weight[7].

3) Systematic indicators. Systematic indicators are the ones that large number of related information are synthesized and integrated in a certain framework to form clear meaning. They are similar to exponent for information's integrated level. The difference is that the exponents are taken from simple weighting to similar exponent in low-level.

3.3 Effect assessing factors for mine closure

The key to assess the effect of mine closure is to determine the assessment factors that can represent various remediation elements. Assessment factor is a multi-unit, multi-type, multi-variable, multi-level complex mixture, being impacted by the assessing object, purpose, requirements, environmental conditions and monitoring technologies and other reasons, which depend on the specific circumstances. From the study, the effect assessing factors are summarized as five main categories in first grade index, part of which are as follows.

(1) To determin assessment factors

1) Physical-chemical indicators include 2-level ones: soil erosion control rate (%), surface subsidence, soil pollution, compliance rate of mine waste treatment (%), compliance rate of heavy metal ions treatment (%), geological environment, etc. These include in detail: atmosphere, such as sulfur dioxide, carbon dioxide, carbon monoxide, particulate matter, soot, dust, etc.; water bodies, such as the hydrological water quality, surface or bottom of water, PH value, heavy metals, etc.; soil, such as soil degradation, soil erosion, soil pollution, soil saline sand-based, ground softening corrosion; geology, such as surface water, dewatering, ground subsidence, landscape damage, landslides, mudslides, and other geological disasters, etc.; noise, such as the sound source, sound intensity, mode of transmission, noise disasters etc.

2) Eco-environmental indicators include 2-level ones: re-vegetation, wildlife conservation, mine ecological landscape construction, human health, etc. That specifically include green area, plant and animal diversity, radiological effects, agriculture, forestry, animal husbandry and fishery conditions, local residents' disease status.

3) Resource utilization indicators: the amount of the remaining minerals, the resource utilization of remaining mine facilities (%), mine resource utilization after mine closure (%), resource utilization of mine water (%), that of waste rock and tailings(%), etc.

4) Socio-economic indicators: revenue of mining enterprises (million yuan), per capita GDP in mining area (yuan), natural population growth rate in mining area (%), investments proportion of fiscal revenue accounted for mine closure, etc.

5) Implementation and management indicators: comprehensive remediation rate of mine environment (%), land reclamation rate (%), investment progress, mine closure monitoring, and public satisfaction rate (%), etc.

(2) To determin factors weights

In a specific region of closed mine, the various elements have different impactions or reflections to mine closure effect, whose importance can be expressed with weight value. With regards to this, the weight-determinating methods system towards various elements has to be established to determin the weight value of different factors in different levels.

To the abstract assessment factor, expert scoring method or survey one are used to determine the weight value. To the concrete and micro-factors assessment factor, we should try our best to use objective quantitative data as weight-determinating factors. To do that can also apply sequences integrated, formula, artificial neural network and simulation and other advanced technological methods.

3.4 Quality classification of the effect assessing for closed mine reclamation

Quality of every elements are classified at first. According to the values range of various elements
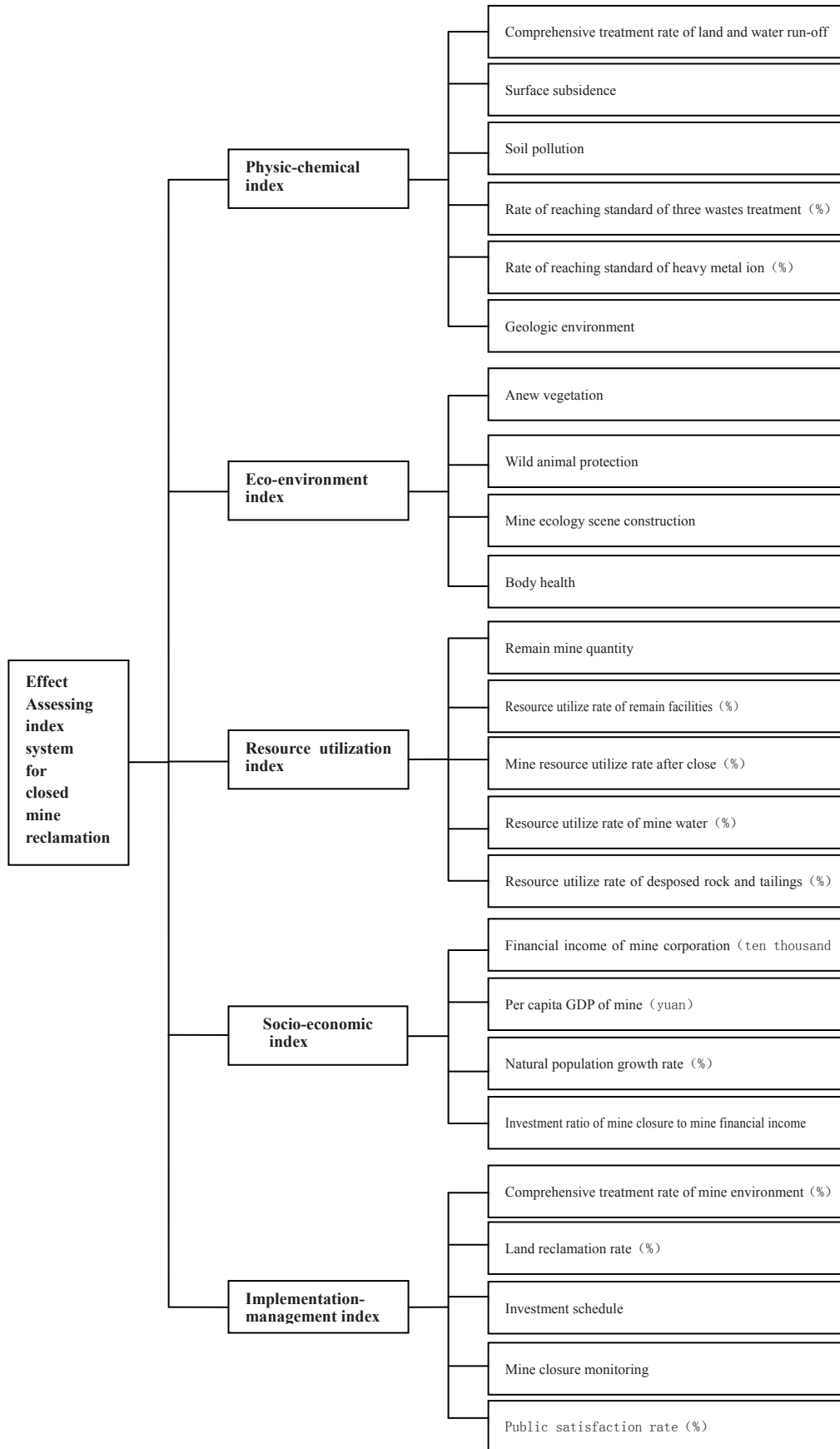
Fig.2 Index system of effects assessing for closed mine reclamation

index, and contrasting to background value related to quality index, the result grades of elements assessing can be divided. Based on single element of the quality classification, with the same principles and methods, the whole result grade of effect assessing for closed mine reclamation can be taken.

4 CONCLUSION

Effect assessing index system for closed mine reclamation is build up for the first time, which bases on discussing the elements for drafting completion criterion of mine closure and analysing the characteristics of mining land-use planning. The first level indicators include physical and chemical ones, eco-environmental ones, resource utilization ones, socio-economic ones, implementation and management ones. This index system is the basis for the planning of mine closure, which will be applied to the whole process of formulation and implementation of mine closure planning, taking a great significance in mine-closure remediation work.

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閉鎖鉱山再生に関する評価結果とその指標システム

Changhua LIU *, Lei ZHANG *, Shidong WANG *, Xin ZHAO *

概要
鉱山閉鎖の定量的な評価に関する組織的な理論研究はまだなされていない。けれども数人の専門家や研究者は評価理論と方法の研究に絶え間ぬ努力をしており、2,3 の成果もある。閉鎖鉱山の再生についての評価指標は鉱山閉鎖計画や適切な状況の履行の直接的反映であり、それは計画内容全体の質と量についての特徴的値を記述するために用いられる。指標システムを確立するための原理が作られ、指標システムの分類と内容が議論される。さまざまな指標値の範囲に従い、そして質的指標と関連する背景値を対比させ、評価要素の等級結果が分類されることが出来る。全体の評価等級結果がなされることが出来る。これは鉱山閉鎖計画の基本であり、全体の再生計画の公式化や履行方針に応用され、閉鎖鉱山再生に大きな意義を与える。

Keywords: Effect assessing, Mine closure, Closed mine reclamation, Index system

*School of Surveying & Land Information Engineering, Henan Polytechnic University, Jiaozuo 454100, Henan, P. R. China.