Available online at www.sciencedirect.com
SCIENCE DIRECT
Resources Policy 30 (2005) 7–19
RESOURCES POLICY
www.elsevier.com/locate/resourpol

A quantitative integrated evaluation of sustainable development of mineral resources of a mining city: a case study of Huangshi, Eastern China

Jing Yu[a,b,*], Shuzhen Yao[c], Rongqiu Chen[a], Kejun Zhu[b], Liandi Yu[b]

[a]School of Management, Huazhong University of Science and Technology, Wuhan 430074, People's Republic of China
[b]School of Management, China University of Geosciences, Wuhan 430074, People's Republic of China
[c]Faculty of Earth Resources, China University of Geosciences, Wuhan 430074, People's Republic of China

Received 25 January 2004; received in revised form 10 August 2004; accepted 25 August 2004

Abstract

It is generally considered that the non-renewable nature of mineral resources will make them gradually depleted over time. However, in the perspective of development availability of mineral resources in a long-term depends not only on their currently available amounts but also on future potential mineral resources (e.g. those undiscovered and low-grade ores) and substitutive renewable resources. In addition, it is influenced by factors like technology and capital. These factors interact with each other. As a result, it is possible to make the sustainable development of mineral resources by appropriate coordination between these factors. A new concept of Degree of Sustainable Development of Mineral Resources (DSDMR) and its conceptual model are proposed in this paper in the viewpoints of system science and sustainable development to evaluate the ability of sustainable development of mineral resources for a mining city. DSDMR refers to the ability of meeting needs of present and future generations for mineral resources by their logical distribution and substitution. An indicator system and a fuzzy integrated judgment model, which involve factors of resources, economy, society, environments and intelligence, are presented. They are used to evaluate DSDMR of Huangshi city, which is the most ancient and yet one of the most important mining cities producing iron and copper in China.

Keywords: Mineral resources; Degree of Sustainable Development of Mineral Resources (DSDMR); Fuzzy integrated judgment model; Huangshi city

Introduction

Compared to renewable resources like water and lands, the scarcity and non-renewable nature of mineral resources make them gradually depleted over time. However, economy of many developing countries like China and particularly their mining cities heavily depends on mineral resources (Mikesell, 1997; Aryee, 2001). Accordingly, it is crucial for a mining city to make sustainable use of its mineral resources. This requires evaluation of its ability of sustainable development of mineral resources.

Current evaluation theories and methods of sustainable development mainly focus on evaluation of ability of sustainable development on a national or large regional scale (Bossel, 1999; UNDSD, 1999; Bond et al., 2001; UNDESA, 2001; López-Ridaura et al., 2002; Malkina-Pykh, 2002; Ronchi et al., 2002). Research on sustainable development of resources and especially mineral resources is still in its infancy (Santos and Zaratan, 1997; Hilson and Murck, 2000). In the statistic sense most of the present evaluation indicators of mineral resources are either quantitative or static and are difficult to reflect the quality and trend of sustainable development of mineral resources. Economically they emphasize growth (i.e. changes in quantity (e.g. gross, size and rate)) and neglect development (i.e. change in both quantity and quality (e.g. structural change and ability improvement)) (Wang et al., 2001;

* Corresponding author. Address: School of Management, Huazhong University of Science and Technology, Wuhan 430074, People's Republic of China. Tel.: +86 27 6788 4145; fax: +86 27 8743 6107.
E-mail address: yujing1990@vip.sina.com (J. Yu).

0301-4207/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.resourpol.2004.08.006

Yang and Hong, 2001). In a real evaluation of sustainable development of mineral resources, both quantity and quality are important.

In this study we propose a new concept of Degree of Sustainable Development of Mineral Resources (DSDMR) in the viewpoints of system science and sustainable development and construct a corresponding system of evaluation indicators and a fuzzy integrated judgment model. We attempt to combine factors of resources, economy, society, environments and intelligence into the system, take into account dynamic and substitutive features of DSDMR, and finally use Huangshi as an example to evaluate its DSDMR. Huangshi is the most ancient and yet one of the most important mining cities producing iron and copper in China. The results are expected to form a basis for decision-making in mineral exploration and investments on a mine of a mining city, regional planning of sustainable development of mining industries, and strategic planning of mineral resources in a nation's economy.

Conceptual model of DSDMR

Degree of Sustainable Development of Mineral Resources refers to the ability of meeting needs of present and future generations for mineral resources by their logical distribution and substitution (Yu and Yao, 2002). It reflects the ability of sustainable development of mineral resources to contribute to human development. Logical distribution means that limited mineral resources are optimally distributed between present and future generations in order to maximize benefits to society. In other words, they are developed and mined in such a way that maximizing the income over time generated from mining (and thus the benefits to society) is subject to the constraints that (a) degradation of the natural environment is kept to socially acceptable levels and (b) social disruptions caused by mining also are kept to socially acceptable levels. Substitution refers to replacement of present mineral resources by future potential mineral resources and renewable resources. It also refers to decreasing consumption of mineral resources and a higher efficiency of their use resulting from technology and capital. For example, application of new geochemical and geophysical technologies for mineral exploration will lead to discovery of deeply buried ore deposits, which cannot be found by conventional methods.

The conceptual model (Yu and Yao, 2002) of DSDMR can be expressed as

$$\mathrm{DSDMR} = f(u_1, u_2)$$

where u_1 is development degree and u_2 is coordination degree.

In the viewpoints of system science and sustainable development (Clayton and Radcliffe, 1996), the DSDMR system consists of such subsystems as mineral resources, economy, society, environments and intelligence. DSDMR depends not only on factor structure and state of subsystems, but also on their interconnection and interaction. These two aspects represent development and coordination functions of the DSDMR system, respectively, which are defined as development degree and coordination degree. Development degree indicates the ability of mineral resources and other subsystem factors (see Table 1) to contribute to human development. It is reflected by resources abundance and mining conditions (u_{11}), economic development and benefits (u_{12}), social development and life quality (u_{13}), environmental impacts (u_{14}), and intelligence level (u_{15}). Coordination degree represents the ability of the subsystem factors to contribute to human development by their appropriate interconnection and interaction. It is reflected by conversion efficiency of resources (u_{21}) and coordination degrees of economy (u_{22}), society (u_{23}), environments (u_{24}), and intelligence (u_{25}). Measures of all these factors are shown in Table 1. Accordingly we formulate the development and coordination degrees as

$$u_1 = f(u_{11}, u_{12}, u_{13}, u_{14}, u_{15}); \quad \text{and}$$

$$u_2 = f(u_{21}, u_{22}, u_{23}, u_{24}, u_{25})$$

DSDMR is characterized by its dynamic and substitutive features. In connotation mineral resources include not only traditional ones which can be mined profitably using current techniques, but also non-traditional ones of potential value in future (Eggert, 1995; Zhao and Chen, 2000). Moreover, changes in many factors like technology, other determinants of resources production and use have effects on DSDMR. These decide its dynamic feature. The economic essence of DSDMR is an issue of optimizing exhaustion, which includes logical distribution of mineral resources between present and future generations and their substitution by alternative resources (Yu, 2004). The substitution may involve substitution by future potential mineral resources and renewable resources and more effective production and use of mineral resources as a result of technology and capital.

An indicator system and a fuzzy integrated judgment model

Table 1 presents the indicator system of evaluating DSDMR on the basis of the above described conceptual model and features of DSDMR (Yu, 2004).

Based on fuzzy characteristics (Cornelissen et al., 2001) of the DSDMR system, a fuzzy integrated judgment model is constructed from the principle of fuzzy integrated judgment (Zadeh, 1965; Zimmerman, 1994). The fuzzy integrated judgment is based on fuzzy mapping and maximizing membership degree. It yields an integrated decision to a concerned issue which is influenced by multi-factors in a fuzzy environment. The judgment consists of constructing