Research on the concept and evaluation method of geo-ecological security

L Shengping, A Lavrusevich, M Slesarev, and V Stepanov

1 Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: doptaganka@yandex.ru

Abstract Geo-ecological security can be understood as the geo-ecological environment (natural-social-production system) in a certain area is not subject to the threat of geological disasters caused by active technogenesis, such as engineering construction and agricultural production. This article elaborates on the relationship between the geo-ecological security and related concepts, reviews and summarizes the current index system and methods of the geo-ecological security evaluation, and puts forward suggestions for using 3S technology in combination with landscape ecological theory to study geo-ecological security.

1. Introduction

The geo-ecological environment is composed of the lithosphere, pedosphere, hydrosphere, biosphere, atmosphere, and anthrosphere on the earth's surface. It is the whole of organic interaction between geological environment, ecological environment, and socio-economic environment. Among them, the lithosphere includes the development and evolution of stratigraphic, geomorphology (river, mountains, plains, etc.), mineral resources, and various geological phenomena. The hydrosphere and atmosphere contain climatic elements such as rainfall, temperature, humidity, wind, solar radiation, freeze-thaw, etc., as well as the circulation and movement of surface water and groundwater. The biosphere includes the distribution and evolution of animals, plants and microorganisms in nature, and the ecological balance and constraints between them. At the same time, the geo-ecological environment also includes humans and related activities, such as engineering construction and agricultural production.

Therefore, the geo-ecological environment has resources and catastrophic characteristics [1]. On the one hand, the geo-ecological environment is the basic condition for human survival (terrain, topography, climate, soil layers, water bodies, etc.). Mineral resources, hydropower, wind power, solar energy, water resources, etc. provided by the geo-ecological environment is the material basis of human
social and economic activities. On the other hand, disasters caused by the evolution of itself and the impact of human activities in the geo-ecological environment, such as soil erosion, earthquakes, mudslides, landslides, floods, subsidence, etc., bring huge threats and losses to human social and economic security.

2. Geo-ecological security and its correlative concepts

Geo-ecological security can be understood as the environment for human survival and development in a certain area is not subject to the threat of geological disasters caused by active technogenesis, such as engineering construction and agricultural production. According to related research results [2-7], there is an interaction between geo-ecological security and ecological value, geo-ecological environment vulnerability, geo-ecological environment carrying capacity, geo-ecological risk, geo-ecological health, and sustainable development, as shown in Figure 1.

![Figure 1](image-url)  

**Figure 1.** Interaction between geo-ecological security and its correlative concepts.

Ecological value refers to the renewal, succession, and regeneration of geo-ecosystems and their natural materials, which provide sufficient material and energy for the survival and reproduction of living organisms, and obtain economic value through the social reproduction of natural materials by people.[8]. Ecological value is the basic attribute of geo-ecological environment. The study of combining ecological value with geo-ecological security can provide a basis for socio-economic development and landscape environmental planning.

Geo-ecological environment carrying capacity refers to the harmonious, symbiotic and interactive relationship between human and geo-ecological environment analyzed from the perspective of supply and demand [9]. When the threat or damage to the geo-ecological environment does not exceed its self-sustainment and self-regulation capabilities, the ecosystem is within the carrying capacity and does not appear to be insecure.

The geo-ecological environment vulnerability exists objectively. When large-scale human activities or severe geological disasters act on the geo-ecological environment, the geo-ecological environment shows an unsafe state.
Geo-ecological health represents the stability of a region's geo-ecosystem—not only can maintain its structure and function, but also can automatically recover from a damaged state after a period of time. Geo-ecological health reflects the integrity, stability, and sustainability of the development process, as well as the landscape heterogeneity and state of vitality and resilience of the geological and ecological environment [10].

Geo-ecological risk refers to the potential threat of geological disasters caused by active technogenesis to the geo-ecological environment. Therefore, an undamaged geo-ecological environment cannot be considered safe, especially for landscape functions.

Sustainable development emphasizes the balance between geo-ecological security and socio-economic development. Geo-ecological security is both a sustainable development goal and a guarantee for achieving the sustainable development goal.

Based on this, we can endow the concept of geo-ecological security, as exhibited in Figure 2. Geo-ecological security refers to the fact that the components in the natural-social-production system system in a certain area are not threatened or destroyed by adverse factors, and present a whole state of health and sustainable development.

![Figure 2. Connotation of geo-ecological security.](image)

This understanding contains three connotations: 1) the research object is the natural-social-production system in a certain area; 2) The complex geo-ecological environment system includes natural ecosystems and socioeconomic systems, the former providing service functions and the latter providing positive responses; 3) Natural ecosystems and socioeconomic systems restrict each other, threaten and destroy.

To carry out geo-ecological security evaluation research, we must first understand its conceptual connotation and make full use of relevant theories, technologies, methods and experiences. The
evaluation of geo-ecological security is based on the selected evaluation index system and evaluation standards, and appropriate evaluation methods. Many scholars have done a lot of exploration on evaluation index and methods.

3. Evaluation method of geo-ecological security

3.1 Evaluation index system
The research on evaluation index system of the geo-ecological security has gone through the process from simple to comprehensive development [4, 11-13]. Statistical index is often applied in early geo-ecological security evaluation because the index data is easy to obtain. With the development of landscape ecology theory and the application of 3S technology, the integration of the landscape index obtained through RS, GIS and GPS into the geo-ecological security evaluation index system can meet the scientific and reliability requirements of the evaluation index data.

In general, the establishment of the index system for geo-ecological security evaluation can be divided into single factor index and multi-factor comprehensive index.

Among them, the single factor index method uses measured data and standard comparative classification to assess the risk of geo-ecological environment pollution and certain geological disasters. It is generally applicable to the evaluation of small-scale ecosystems. For example, Ye Sutao et al [14] compared the single factor pollution index calculated from the standardization value of the dispersion of the heavy metal pollution concentrations in the region with the heavy metal pollution degree classification table, and established a soil heavy metal pollution model.

The multi-factor comprehensive index method simultaneously uses different categories of evaluation index, including not only biological, resource or environmental, but also index of the role of geological ecosystems on socioeconomic and human health. From the perspective of resource security, Zhang Lei [15] comprehensively selected 6 factors including cultivated land resources, mineral resources, energy minerals, forest resources, and CO2 to calculate safety factors for 10 large population countries, and explained China's degree of security of resources and environment through numerical and category comparisons.

The establishment of a multi-factor comprehensive index system is usually based on a series of conceptual frameworks, such as the pressure-state-response (P-S-R) framework proposed by The Organization for Economic Co-operation and Development (OECD). With the goal of sustainable development of regional land resources, Liu Yong [16] constructed an index system including natural ecological security of land, ecological security of land economy, and ecological security of land society, and selected 20 index factors for a comprehensive evaluation of the security of land resources in Jiaxing, China from 1991 to 1997.

3.2 Evaluation method
For the time being, geo-ecological security evaluation methods are mostly transplanted from adjacent disciplines. The evaluation models can be summarized into four categories: mathematical models, ecological models, landscape ecological models, and digital terrain models [17]. As shown in Table 1.

Table 1. Basic methods for geo-ecological security evaluation.
The mathematical model is divided into three groups: quantification of index data, determination of index weights, and comprehensive calculation of multiple index. Quantification of index data is the basis for successful evaluation work; determination of index weights is the key to ensuring reasonable evaluation results; comprehensive calculation of multiple index is a model for overall evaluation of objects. The sub-class methods in these three groups are based on various mathematical and statistical methods, and usually need to be integrated in the actual evaluation process. For example, the analytic hierarchy process is often only used to establish an index system and determine the index weights; the synthetical index method cannot reflect the gradual and transitional characteristics of geo-ecological security because the factor classification and factor weight are too rigid. Therefore, based on the advantages of the above methods, many scholars have developed a composite evaluation model combining multiple methods, such as the Geological Ecological Security Evaluation Method based on the principle of fuzzy decision analysis (FDA). The basic principle is to combine the fuzzy evaluation method with the analytic hierarchy process (AHP), establish the AHP hierarchy through the principal component analysis (PCA) method, and complete the evaluation by the AHP.

The biggest advantage of the FDA method is that it makes the evaluation process completely quantitative and optimizes the classification of evaluation index, and makes the evaluation results objective and credible. Other composite evaluation models such as multi-level fuzzy comprehensive evaluation—gray correlation advantage analysis model, analytic hierarchy—variable weight—fuzzy—gray correlation composite model, etc. also came into being in the actual evaluation.

Landscape ecology is an emerging branch of modern ecology, so landscape ecological models are classified under ecological models. The sub-class methods of ecological models are independent of each other, and they are suitable for evaluation tasks at a specific scale. The landscape ecological model comprehensively evaluates the types of landscape units starting from the structure of the geo-ecological system and has become an important method for geo-ecological security research in recent years. For example, The landscape spatial adjacency index analyzes the damage degree of each landscape type.

| Evaluation model               | Sub-class methods                          | Representative method                                |
|--------------------------------|--------------------------------------------|-----------------------------------------------------|
| Mathematical models           | Quantification of index data               | Range classification; Delphi method; Standard trade-off |
|                               | Determination of index weights             | Expert determination method; Analytic Hierarchy Process; Principal Component Analysis; Grey Relational Analysis; Fuzzy Comprehension Evaluation Method |
|                               | Comprehensive calculation of multiple index | Single model; Synthetical index method; Variable weight model; Matter-element evaluation; principal component projection |
|                               |                                            | Composite model; Additive-multiplicative model; Multi-level blurring - gray correlation model; Fuzzy - variable weight model |
| Ecological models             | Landscape ecological model                 | Landscape spatial adjacent feature model; Landscape pattern index |
|                               | Individual population scale model          | Nontoxic effect analysis model; Habitat regional scale model |
|                               | Habitat regional scale model               | LERAM model |
|                               | Ecosystem scale model                      | Habitat Stability Index Model; Ecological footprint model |
| Digital terrain models        |                                            | Using 3S technology |
(such as cultivated land, grassland, and woodland) by constructing a function of the spatial adjacency length ratio, the spatial adjacency number ratio, and the spatial adjacency area ratio. [18].

The digital terrain model, reflecting the characteristics of regional geo-ecological safety, is the product of the combination of remote sensing information extraction technology and computer simulation software and hardware technology[19], which can make full use of remote sensing technologies to provide rapid, micro-to-macro information advantages of various forms of data. The powerful data management and spatial analysis functions of GIS in this model can systematically integrate regional factors to form a complete analysis system for comprehensive evaluation of regional geo-ecological environment security, and establish vector data or raster data. Combining this model with GPS can form a geo-ecological security model with evaluation, prediction and early warning functions on a regional scale.

4. Conclusion

The evaluation of geo-ecological security is a long-term and complex task, and all links of the evaluation will affect the evaluation process and the quality of the results. Therefore, combining advanced theoretical techniques and improving the evaluation method is an important basis for improving the study of geo-ecological security.

The combination of landscape ecology theory and the related spatial heterogeneity theory, spatial scale theory, and ecological security has been applied to the study of geo-ecological security pattern [20-22]. Its characteristics are that through the study of the relationship between landscape structure and function, a series of thresholds and security levels of natural ecological processes can be determined, and the maintenance and control of the spatial-temporal pattern of geo-ecological processes are proposed for the planning and design of a reasonable and safe landscape spatial pattern.

Consequently, using the landscape ecology theory is of great significance to the design of regional geo-ecological security pattern and the guarantee of geo-ecological security With the widespread application of satellite remote sensing technology, the quantity and quality of collected data will be improved, and the combination of landscape ecology theory and geo-ecological security will likely become a new field for future research.

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