

Research Review on Land Ecological Security Evaluation and Its Influencing Factors

Peirong Zhao

*School of Humanity and Law, Northeastern University, Shenyang, China
1100001565528960@qq.com*

Abstract. With the rapid advancement of urbanization and the continuous intensification of land development, conflicts between humans and land have become increasingly prominent, and issues such as land ecosystem degradation and weakened ecological functions occur frequently. Land ecological security has thus become a core issue for regional sustainable development and ecological civilization construction. To systematically sort out the research evolution and cutting-edge findings concerning land ecological security, this paper centers on four core dimensions: evaluation systems, research scales, technical methodologies and driving mechanisms of land ecological security, and conducts a systematic review of domestic and international literature via literature induction. This paper summarizes land ecological security evaluation systems from economic, social, and natural dimensions, delineates three research scales: watershed, provincial, and municipal levels, reviews the application scenarios of evaluation models such as PSR and DPSIR, combination weighting methods, and various spatial analysis techniques, and categorizes the three core influencing factors—land use, socio-economic conditions, and industrial structure—along with their quantitative identification methods. The study finds that the academic community has currently established a multi-scale, multi-model, and multi-dimensional land ecological security evaluation system, but there are still shortcomings such as insufficient empirical research and weak regional specificity.

Keywords: Land Ecological Security, Public Policy, Human-Land Relationship, Sustainable Land Utilization, ESG

1. Introduction

Research on land ecological security assessment has expanded rapidly in recent years, yet prominent drawbacks persist: fragmented evaluation frameworks, scale studies lacking targeted design, shallow analyses of driving mechanisms, and disconnection between research outputs and ecological governance policies. In addition, systematic, comprehensive review papers on this topic remain scarce [1]. Based on this, this paper adopts research methods of literature review and comparative induction, integrates the latest research findings from both domestic and international sources, systematically defines the core connotations of land ecological security, summarizes multidimensional evaluation perspectives and multi-regional research scales, categorizes and reviews mainstream evaluation models, weighting methods, and spatial analysis techniques, and

outlines the key influencing factors and quantitative analysis approaches for land ecological security. This study aims to clarify the research framework and development trajectory in this field, address the shortcomings of systematization in existing review studies, accurately identify current research limitations and future research directions, provide theoretical support for national spatial planning, ecological risk prevention and control, and differentiated ecological governance policy formulation, while also promoting the coordination of human-land relationships and the long-term sustainable use of land resources.

2. The connotation of land ecological security

Land ecological security constitutes an indispensable component of national security and serves as the practical extension of ecological security concepts in land science research. Therefore, it possesses two core characteristics: maintaining the health and integrity of the ecosystem itself, and ensuring that human production and daily life are not threatened by environmental deterioration [1]. Accordingly, its connotation can be defined as a status confined to specific spatial and temporal boundaries: the land ecosystem retains sound structural and functional stability, boasts robust resistance and resilience, delivers sustained ecosystem services for human survival and development, sustains harmonious human-land interactions, and keeps ecological risks under effective control.

3. Perspectives of land ecological security evaluation

3.1. Economic perspective

The status of land ecological security mirrors the health and sustainable development capacity of terrestrial ecosystems; accordingly, land ecological security is closely intertwined with economic growth. Studying the coupling relationship between the two helps optimize resource allocation, improve resource utilization efficiency, and achieve a win-win situation for both economic and ecological benefits [2]. Under current levels of productivity, science, and technology, economic development will inevitably impact the land ecological environment and threaten land ecological security. From an economic perspective, examining land pollution, cropland productivity decline, disrupted ecological equilibrium and biodiversity losses induced by economic expansion provides critical evidence for advancing sustainable development, securing national ecological safety and informing land-related policymaking.

3.2. Social perspective

Land ecological security is critically important for identifying latent ecological hazards, evaluating real-time eco-security status, and informing regional territorial spatial planning. When land ecological security is threatened, it leads to a series of social problems, such as increasingly sharp contradictions between humans and land, the continuous squeezing of ecological space, and threats to social order [3]. Accordingly, from a sociological viewpoint, land ecological security extends far beyond a purely natural concern; instead, it constitutes an integrated systemic issue covering social pressure, developmental status, social feedback, social equity, social governance and social sustainability. Its evaluation must embed a social dimension and focus on human-land relationships, urban-rural relationships, regional relationships, governance relationships, and people's well-being

in order to truly reflect the essence of land ecological security and serve sustainable development and ecological civilization construction.

3.3. Natural perspective

Rapid urbanization has intensified the contradiction between land utilization and ecological protection. The disorderly expansion of construction land encroaches on biological habitats, fragments landscape patterns, and disrupts ecological processes such as material cycling, energy flow, and information transmission, thereby threatening ecosystem stability [4]. Accordingly, exploring land ecological security from a natural perspective provides a fundamental basis for preserving woodlands and grasslands, sustaining soil fertility, conserving biodiversity, reconnecting fragmented land patches, and improving ecosystem resilience. The natural perspective of land ecological security evaluation is primarily composed of four dimensions: the land natural background dimension (topographic, soil, climatic, and precipitation factors); the ecosystem structure dimension (vegetation coverage, forest coverage, and biodiversity); the ecological function vitality dimension (net primary productivity, soil organic carbon dynamics, and water conservation capacity); and the ecological environment stability dimension (soil erosion sensitivity, ecological degradation risk index, etc.).

4. Scales of land ecological security evaluation

4.1. Watershed landscape scale

This research scale typically targets the integrated natural-social composite landscape across multiple provincial and municipal administrative units within a complete river watershed as its research object. It comprehensively evaluates the land ecological security status within the region from four dimensions: ecological, social, spatial, and temporal. Taking the Chishui River Basin as a case study—which originates in Yudong Township, Zhenxiong County, Zhaotong City, Yunnan Province, and flows through Yunnan's Zhaotong, Guizhou's Bijie and Zunyi, and Sichuan's Luzhou—this evaluation prioritizes watershed-scale ecological security based on its unique landscape features, including karst landforms, evergreen broad-leaved forests and river network corridors. It emphasizes the integrated functional evaluation of upstream-midstream-downstream ecological linkage, and water conservation-soil conservation-biological corridor integration. Meanwhile, because the upstream and downstream elevation gradients and ecological vulnerabilities of the Chishui River Basin vary, it is necessary to conduct continuous, phased, and dynamic evaluations of the related industries suitable for development in various areas within the basin and their impact on land ecological security based on long-term factor inputs [5].

4.2. Provincial scale

This scale typically takes a provincial administrative region contained within a watershed landscape as the research scope. In general, provincial administrative units delineated by mountain and river boundaries exhibit highly homogeneous land resource endowments. Research at this scale focuses more on the impacts of land use types—such as agricultural land, industrial land, and construction land—on land ecological security alongside economic development. Taking Hubei Province as an example, over the past 15 years, the land ecological security score (DPSIR model index) of Hubei's core Yangtze River zone climbed from 0.60 (representing a critical state) to 0.83, showing a

significant improvement in security levels. In 2020, the score declined slightly, a trend largely attributable to the socioeconomic disturbances caused by pandemic-related lockdown policies in Hubei. From 2021 to 2022, Hubei's economy recovered rapidly, driving the rebound of the regional ecological security level. Hubei Province's "14th Five-Year Plan" introduced relevant measures to strengthen ecological security guarantees in the middle reaches of the Yangtze River, with the core goal of shifting the focus of development from rapid economic growth to sustainable, eco-friendly development. By narrowing the development gap between cities and deepening regional collaborative cooperation, Hubei Province can gradually resolve various challenges faced by land use ecological security [6].

4.3. Municipal scale

This research scale regards prefecture-level cities or municipalities directly under the Central Government and their subordinate counties and towns as integrated research units, which feature homogeneous natural land endowments and tight socioeconomic linkages. This scale serves as the primary implementation target for territorial spatial development strategy patterns and the integration of ecological civilization into economic development construction. Therefore, land ecological security research at the municipal scale exhibits a strong orientation toward sustainable development concepts and problem-solving to alleviate human-land contradictions. Taking Beijing as a case study, the region exhibits a prominent northwest–southeast topographic gradient, where high-elevation northwestern terrain gradually transitions to low-lying southeastern plains. The climate of the areas surrounding Beijing belongs to a temperate semi-humid and semi-arid continental monsoon climate, with four distinct seasons, a significant temperature difference between summer and winter, concentrated precipitation, and sharp wet-dry contrasts. As a crucial region for China's ecological civilization construction, this area has experienced rapid economic growth, continuous increases in energy consumption, and accelerating urbanization. These factors have led to an imbalance in the land ecosystem and a decline in ecological functions, posing a serious threat to the ecological environment. Adopting geographically weighted regression and other analytical methods, this study identifies key influencing factors of land ecological security in Beijing and its surroundings, including land economic density, per-unit land fixed asset investment, and GDP growth rate, thereby supporting the formulation of localized and differentiated development strategies [7].

5. Methods of land ecological security evaluation

5.1. Index model evaluation methods

1. PSR (Pressure-State-Response) Model: Taking the causal chain of 'human activities exert pressure on the ecosystem, trigger changes in ecosystem states, and humans take targeted responsive restoration measures' as its core logic, this model divides evaluation into three major dimensions. It can systematically portray the complete process of human-land interaction and is widely used to construct evaluation systems at meso-scales, such as watersheds and urban agglomerations [3]. Among them, the P dimension quantifies the ecological stress imposed by human activities on terrestrial ecosystems; the S dimension reflects the inherent health and functional status of land ecosystems; and the R dimension characterizes human governance capacity in response to ecological degradation.

2. DPSIR (Driving Force-Pressure-State-Impact-Response) Model: As an extended version of the PSR framework, this model incorporates two additional dimensions: Driving Force (underlying socioeconomic drivers) and Impact (socioeconomic feedback induced by ecological changes) [8]. This further refines the causal logic and more comprehensively portrays the interaction process of the social-ecological system. Based on the progressive relationship of 'root drive -> direct pressure -> realistic state -> comprehensive impact -> regulatory response,' the model systematically reveals the dynamic mechanism of the human society-natural ecology composite system, covering all dimensions of 'cause-process-result-feedback'. Compared to the PSR model, it includes two additional factors: driving force (D) and impact (I). The D dimension represents underlying socioeconomic and natural baseline elements that dominate eco-environmental changes and constitute the fundamental causes of ecological problems, including macro drivers such as population scale and structure, economic development level, industrial composition, technological advancement, urbanization, and climate variability. I refers to the direct and indirect effects exerted on the ecosystem itself, human health, and socio-economic systems after the ecosystem state changes; it represents the consequential feedback of state changes, including comprehensive impacts such as intensified land degradation, biodiversity loss, declined ecological service functions, food production capacity fluctuations, regional economic losses, and human settlement health risks.

3. DPSIRM (Driving Force-Pressure-State-Impact-Response-Management) Model: As an upgraded framework of DPSIR, this model adds a 'Management (M)' dimension to the original structure, distinguishing between passive ecological restoration responses and active institutional governance regulation. This completes the closed loop of 'risk-feedback-governance,' making it better suited for evaluation in refined governance scenarios such as county levels. The newly added M dimension refers to active institutional intervention, full-process control, and long-term governance implemented by governments and management departments [9]. It represents proactive pre-emptive/in-process regulation over 'driving force-pressure-state,' including indicators such as land-use planning, ecological red-line control, resource quota management, ecological compensation mechanisms, regulatory enforcement intensity, and governance funding investment.

4. Ecological Security Index (ESI) Evaluation System: This system serves as a quantitative assessment framework tailored for ecological security pattern research. It can comprehensively quantify the security levels of ecological sources, corridors, and nodes, supporting the dynamic assessment of ecological security patterns [10]. Grounding on theories of ecological security, human-land coordination and sustainable development, the system screens core indicators to characterize ecosystem structure, functions, external stress, ecological resilience and social regulatory capacity. It constructs a multi-dimensional, quantifiable, and comparable comprehensive evaluation framework used to quantitatively characterize the security level, evolutionary trend, and risk grade of an ecosystem in a certain region and period, providing scientific bases for ecological protection, territorial spatial governance, and sustainable development decision-making.

5.2. Weight assignment evaluation methods

1. Entropy Weight Method: This is an objective weighting method based on the principle of information entropy. The smaller the information entropy of an indicator, the greater the amount of information it provides, and the higher its corresponding weight. It effectively avoids deviations caused by subjective weighting and is currently the most commonly used weighting method in land ecological security evaluation [3]. Larger variation in an indicator's values denotes stronger discriminatory power, richer available information and a higher corresponding weight; conversely, the weight becomes lower. It relies entirely on data distribution, features no subjective bias, and

possesses strong objectivity, focusing on indicator variance without considering conflicts between indicators.

2. Delphi Method: This is a subjective weighting approach that consolidates expert experience to calculate indicator weights via several rounds of anonymous expert Delphi consultation. It can balance expert experience with regional reality, making it highly suitable for localized evaluations with strong regional characteristics [7]. This method fits real-world conditions and mirrors expert professional insights; its anonymous feedback curtails authority-based interference, yet it inherently carries subjective bias and is susceptible to fluctuations in the selected experts' professional proficiency.

3. CRITIC-Entropy Weight Combination Weighting: After combination, the derived weights become more robust, the contained information is more comprehensive, and the inherent drawbacks of using a single weighting approach can be circumvented. By balancing the objectivity and correlation of indicators, it effectively improves the accuracy of weights [11]. This method merges weights yielded by the CRITIC and entropy weight methods following predefined rules (e.g., linear weighting or multiplicative normalization) to generate combined weights and thus falls into the category of objective combined weighting. It integrates the advantages of both objective methods—the entropy weight method focuses on the discrete differences of indicators, while the CRITIC method accounts for both discreteness and conflicts between indicators. Post-combination, the weights are more robust, the information is more comprehensive, and the defects of a single method are avoided.

5.3. Spatial analysis evaluation methods

1. Hot Spot Analysis (Getis-Ord G_i^*): This is a spatial clustering analysis method. By computing local indicators of spatial association (LISA), it pinpoints hot spots featuring clustered high values and cold spots with concentrated low values, thereby intuitively depicting the spatial agglomeration patterns of land ecological security [7]. It includes two core types of results: high-value clusters showing high-high aggregation where both the unit itself and its surrounding units have significantly high attribute values (such as high ecological security zones), and low-value clusters showing low-low aggregation where both the unit itself and its surrounding units have significantly low attribute values (such as low ecological security zones).

2. Geographically Weighted Regression (GWR): This is a local regression technique that incorporates spatial coordinates into regression coefficients, effectively quantifying spatial heterogeneity in driving factors and capturing regional disparities in the impacts of explanatory variables [7]. By introducing a spatial weight matrix, this method allows regression coefficients to change with geographic location, thereby capturing the spatial heterogeneity (non-stationarity) of variable relationships. It is mainly used to analyze spatial differences in the influencing factors of ecological security, land degradation, etc. (e.g., how a certain factor promotes in the east but inhibits in the west), revealing the spatial differentiation of driving mechanisms.

3. Spatial Autocorrelation (Moran's I): This approach examines spatial agglomeration features of research variables via the Moran's I statistic, identifies spatial autocorrelation in land ecological security, and lays a foundational premise for subsequent spatial econometric modeling [12]. Its result system includes three types: positive autocorrelation (adjacent units have similar attribute values showing high-high or low-low clustering, such as high ecological security zones being adjacent to high-value zones); negative autocorrelation (adjacent units have dissimilar attribute values showing high-low or low-high alternation, such as the ecological security gradient in urban-

rural fringe areas); and no autocorrelation (the spatial distribution of attribute values is random, with no significant clustering patterns).

4. Spatial Error Model (SEM): This is a type of spatial econometric model. By incorporating a spatially correlated error term, the model characterizes spatial spillover effects among variables and quantifies spatially nonlinear influences of exogenous factors on land ecological security [12]. As a core type of spatial econometric model, the spatial error model assumes that the error terms possess spatial autocorrelation. It is used to handle spatial dependencies caused by omitted variables or measurement errors, thereby correcting the spatial biases of traditional regressions.

6. Classification and analysis methods of influencing factors

6.1. Influencing factors

1. Land Use and Land Cover Change (LUCC) Factors: Land use and land cover change represent the most direct driving factors affecting land ecological security; they act directly on the state of ecological security by altering the structure and processes of ecosystems. Findings from global land-use scenario analyses indicate that forest-to-cropland conversion serves as the dominant factor differentiating divergent land ecological security evolution pathways. In Low Land Ecological Security (Low-LES) scenarios, 67% of cases exhibited a forest loss exceeding 0.5% per decade. Its explanatory capacity outperformed indicators including soil carbon depletion and vegetation productivity decline, rendering it the dominant driver of land degradation [13]. Meanwhile, land structural adjustments such as urban expansion and changes in cropland proportions also significantly affect ecological security. Studies in the Beijing-Tianjin-Hebei region show that the decline in the proportion of cropland is one of the key obstacles restricting the improvement of regional ecological security, while the disorderly expansion of construction land further squeezes ecological space and intensifies ecological pressure [14].

2. Socio-Economic Development Driving Factors: Population and economic development constitute the core macro drivers of land ecological security evolution, which fundamentally reshape land ecological pressure by restructuring the basic pattern of human-land interactions. Research targeting Chinese tourist cities found that population density is the primary factor explaining the spatial differentiation of the coupling coordination between industrial agglomeration and land ecological security [15]. On the one hand, elevated population density promotes industrial agglomeration and development; on the other hand, it improves regional environmental governance capacity and public ecological awareness, thereby exerting a significant positive driving effect. Meanwhile, the level of economic development exhibits a dual impact: economic growth brings land development pressures that directly threaten ecological security, yet the enhancement of economic strength also provides robust funding and support for ecological protection investments [14].

3. Industrial Structure and Agglomeration Factors: Industrial development modes are crucial meso-level factors affecting land ecological security. Different industrial structures and agglomeration states bring about differentiated land-use intensities and ecological pressures. Traditional research has confirmed that an excessively high proportion of secondary industry brings heavy pollution emissions and land occupation pressures, whereas an increase in tertiary industry helps optimize the industrial structure, lowers interference with land ecology, and subsequently elevates the ecological security state.

6.2. Analysis methods

1. **Obstacle Degree Diagnosis Model:** The obstacle degree model represents a mainstream analytical tool for identifying influencing factors in conventional empirical research. Its core lies in quantifying the restriction degree of individual indicators on land ecological security goals, thereby identifying the key bottlenecks constraining regional ecological security improvements. Combining indicator weights with the real attainment level of each index, this approach can precisely quantify the actual constraint effects of diverse factors instead of simply assessing indicator weight significance. In research on the Beijing-Tianjin-Hebei region, the obstacle degrees of 16 evaluation indicators were calculated through this model, identifying 7 core obstacle factors including land economic density, transportation investment, and per capita GDP. It was found that insufficient ecological conversion efficiency of economic development is the primary constraint in the region. This method can visually present the restriction intensity ranking of various factors, providing clear targets for policy formulation [14].

2. **Geographical Detector and Spatial Interaction Analysis:** Aiming at the spatially heterogeneous features of land ecological security, the geographical detector model has become a mainstream approach to explore its spatial driving factors in recent years. This method quantifies the explanatory power of influencing factors on the spatial differentiation of land ecological security through statistics, breaking through the limitations of traditional regression models regarding normal distribution assumptions of data [15]. It is especially suitable for analyzing categorical variables and spatial data. More importantly, this method can identify the interactions between different factors, judging whether two factors working together enhance, weaken, or independently influence the target variable. This method effectively compensates for the shortcomings of traditional spatial analysis methods that only focus on the spatial distribution of ecological security, allowing for a deep analysis of the driving mechanisms behind spatial differentiation.

3. **Machine Learning and Interpretable Driving Identification:** With the emergence of globally sourced high-dimensional land use data, machine learning approaches have gradually evolved into cutting-edge tools for large-sample and multidimensional driver analysis, capable of resolving intricate high-dimensional nonlinear correlations beyond the capacity of conventional statistical approaches. Studies have found that forest-to-cropland conversion, cropland expansion, and nitrogen fertilizer application intensity are core drivers at the global scale. This method provides a new paradigm for analyzing land ecological security driving factors under global-scale, multi-scenario conditions. For instance, when analyzing 1,200 high-quality land use scenario units from the LUH2 database of CMIP6/ScenarioMIP, supervised classification and Variational Autoencoders (VAE) can be used to quantify land use changes. Then, combined with distribution consistency tests and satellite remote sensing images, the correctness of the data trained by the model can be verified. Consequently, after identifying the underlying patterns, large batches of predictive data regarding land use changes and land ecological security can be generated to better support public policy decision-making [13].

7. Implications of land ecological security research for public policy and ESG

Research on land ecological security assessment provides vital references for public policy formulation and environmental governance practices. It can offer a scientific basis for governments to formulate territorial spatial planning and land use policies. By identifying the ecological security levels and spatial differentiation characteristics of different regions, government departments can rationally delineate ecological protection red lines, permanent basic farmland, and urban

development boundaries, achieving coordination and unity between ecological protection and economic development while improving land resource allocation efficiency.

Concurrently, it helps build ecological environment risk early-warning and monitoring systems. With the aid of evaluation frameworks like PSR and DPSIR, alongside GIS, remote sensing, and spatial analysis technologies, management departments can promptly grasp regional ecological security trends, identify ecologically fragile areas and high-risk zones, and implement proactive intervention beforehand to curb hazards including land degradation, ecosystem degradation and environmental contamination.

Furthermore, it provides scientific support for the precise implementation of environmental governance policies. By utilizing obstacle degree models, geographical detectors, and machine learning to identify key driving factors, decision-makers can accurately comprehend the impact mechanisms of land use change, population growth, and industrial structure adjustment on ecological security. This enables the formulation of differentiated, targeted governance measures, maximizing policy implementation effectiveness and resource investment efficiency. Lastly, land ecological security evaluation promotes cross-regional collaborative governance. Cross-scale and transboundary land ecological security assessments facilitate information exchange, benefit coordination and collaborative governance across administrative regions, thereby lifting the overall standard of regional eco-environmental management.

8. Conclusion

This paper systematically reviews domestic and international research outcomes on land ecological security assessment, synthesizing its core connotations, research perspectives, spatial scales, technical approaches and driving mechanisms to construct a holistic research framework. Currently, academia has established an evaluation perspective integrating economic, social, and natural dimensions, generally covering three spatial research scales: watershed landscape, provincial, and municipal levels, which adapt to the research needs of ecological governance in different regions. The evaluation technical system is becoming increasingly mature, forming a mainstream research paradigm centered on the PSR, DPSIR, and DPSIRM models, combined with weighting methods such as the entropy method and GIS spatial analysis technology. Existing studies have identified land use and land cover changes, socio-economic development, and industrial structure concentration as core factors affecting land ecological security. These studies often employ barrier models, geographic detectors, and machine learning methods to conduct driving factor identification and mechanism analysis, providing important theoretical support and practical references for national spatial planning, ecological risk prevention and control, cross-regional collaborative governance, and ESG ecological management.

This study relies solely on existing literature for theoretical review and summarization, without incorporating empirical validation based on measured data, and lacks quantitative analysis of the spatial heterogeneity of driving factors across different regions, thus presenting certain limitations in research depth. Future research could combine remote sensing imagery and panel statistical data, selecting typical study areas for empirical analysis to quantify the spatiotemporal evolution of land ecological security and the interaction mechanisms of its factors, further improving a differentiated and precise research system for land ecological security governance, and addressing the practical shortcomings in current theoretical research.

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