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From 2000 to 2022 evaluate of land ecological security and reveal obstacle factors in Heilongjiang Province

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At present, the global environmental problems are intensifying, and land resources are facing multiple dilemmas such as degradation, pollution and shortage. The rise of the concept of sustainable development, the enhancement of public ecological awareness and the promotion of relevant policies and regulations have jointly promoted the generation and development of land ecological security research. This study evaluated the land ecological security of Heilongjiang Province from 2000 to 2022, found out the main factors affecting the land ecological security, provided the basis for scientific formulation of corresponding measures, provided the guarantee for the sustainable development of regional social economy and agriculture, and maintained the long-term coordinated development of the land natural, social and economic complex. Based on the PSR model, this study constructs an index system for evaluating land ecological security. It employs a comprehensive index model to assess and utilizes the entropy-weighted TOPSIS method to determine the weights of various indicators. It calculated the comprehensive index of Heilongjiang Province from 2000 to 2022. Drawing upon relevant literature, this research establishes the land ecological security level of the region. The obstacle factor diagnosis model is used to analyze the main obstacle factors at each level, and corresponding countermeasures are proposed based on the results. The main results are as follows: (1) From 2000 to 2022, the level of land ecological security in Heilongjiang Province has generally shown a fluctuating upward trend, with the safety level changing from dangerous to relatively safe and moving towards a favorable direction. However, it remained mostly in an unsafe state for the past 20 years; (2) The main threats at the criterion layer have changed significantly, with obstacle degrees rising to 59% for pressure systems and 36% for status systems while decreasing to 5% for response systems. Currently, the main threat comes from pressure systems; (3) The main obstacle factors at the indicator layer have evolved from the proportion of tertiary industry output value and effective irrigation area of arable land to pure amount of chemical fertilizer applied in agriculture and proportion of forest area. In 2022, major factors affecting land ecological security in Heilongjiang Province are pure amount of chemical fertilizer applied in agriculture, proportion of forest area, industrial solid waste generation volume, pesticide use volume, and *per capita* water resources. This study evaluated the land ecological security in

Heilongjiang Province, revealed its influencing factors, and put forward specific suggestions for local construction.

KEYWORDS

land ecological security, Heilongjiang Province, PSR model, obstacle factors, entropy weight method

1 Introduction

In a broad sense, land is a natural complex comprising the earth's specific region surface and the atmosphere, soil and foundational geology, hydrology and vegetation, animals, and the effects of human activities within that area. Narrowly, land is defined as land that has been or can be utilized by humans in the foreseeable future (Feng, 2015), emphasizing its role as a means of production, including its natural and economic aspects. This study focuses on land within the broad and narrow definitions, selecting major land uses such as cultivated land, forest land, urban villages and industrial land, water areas and water conservancy facilities land, and other land types based on the 2022 land status data from the Heilongjiang Provincial Bureau of Statistics. Land ecological security is the core issue of sustainable utilization of land resources, and land ecological security is an important part of national and regional ecological security. At present, the ecological environment problem is a new theme facing the sustainable development of human society in the 21st century. As the material basis for human survival and development, the limited land resources have become one of the key issues in the sustainable development of human beings (Wang, 2023).

Social and economic factors have various influences on land use. Areas with high economic development level will attract more population inflow, while areas with large population and high density have higher demand for residential land and commercial land, which makes the land route change to residential and commercial land use. Different industrial structures have different demands and uses of land. In order to meet production needs, more land is used for industry in developed areas. The developed service areas are more commercial service areas. In areas dominated by agriculture, land is mainly used for agricultural production; The development potential and attractiveness of land in areas with sound infrastructure will be enhanced; The government should formulate the overall urban plan to clarify the land use in different areas and realize the orderly development of the city. In addition, policies also have a direct regulatory effect on land use, such as improving the environment, reducing pollution and protecting cultivated land by adjusting land use.

Ecological security is a new theme for sustainable human development in the 21st century, becoming a frontier topic in sustainable land use research (Li and Cai, 2007). The ecological security of land refers to a state in which the ecological condition of land resources, through scientific management and utilization, can sustainably meet the needs of socio-economic development. In this state, the system's structure and functions are either not threatened or only minimally affected. The value of land ecological security lies in its critical role in maintaining ecosystem service functions, ensuring sustainable development for human society, and promoting the harmonious coexistence of regional economies and the environment (Xiong, 2018). Appropriate measures can ensure the sustainable use of land resources, promote stable agricultural production growth, and provide a strong guarantee for sustainable economic development (Ma and Li, 2023).

Scholars have made remarkable progress in the research of land ecological security, involving many fields and different research methods. The research content is extensive, mainly focusing on ecological risk assessment, ecological security theoretical system construction, evaluation methods and index system development and land quality evaluation. Since Leopold put forward the concept of "land health" in 1941, the problems of ecosystem and environment have gradually become the focus of research. Norman Myers put forward the concept of ecological security in 1993, emphasizing that ecological security is caused by ecological threats, risks and other concepts, and widely publicized this concept. Scholars use a variety of evaluation models and methods to study land ecological security, such as ecological footprint model, entropy weight matter element analysis, BP neural network, principal component analysis and so on. These methods focus on assessing the impact of human production and life on the land ecological environment and its sustainable use (Fu et al., 1997). Since the early 1990s, China has initiated research on ecological security, with scholars like Yu Kongjian and Wang Hanmin laying a solid foundation for ecological security research in China (Yu, 1999; Wang et al., 2001). Scholars Peng Buzhuo and others used dynamic viewpoints for environmental quality evaluation (Peng et al., 1996), Zhao Yuelong and others established quantitative evaluation index systems and methods for vulnerable ecological environments (Zhao and Zhang, 1998), evaluating the ecological environment vulnerability of 26 provinces and regions nationwide. Scholars Ye Yaping and Liu Lujun proposed provincial ecological environment quality evaluation index systems and methods (Ye and Liu, 2000), and Zuo Wei and others constructed a composite model combining hierarchical analysis, variable weight, fuzzy, and grey correlation for regional ecological security comprehensive evaluation (Zuo et al., 2002; Zuo et al., 2005).

Currently, China's research on land ecological security evaluation mainly focuses on defining land ecological security, constructing evaluation index systems, designing and selecting evaluation models, and early warning of land ecological security (Zhang et al., 2009). Although research results are rich, a unified index system and evaluation model have not yet been formed. Existing land ecological security evaluation methods mainly include P-S-R model, GIS grid model, DPSIR model, grey system GM(1,1) model and matter-element model, etc., which are used to evaluate and predict the land ecological security status in different regions (Liang et al., 2023). The research covers a number of regions and fields, such as the Bohai Rim region, the Red River basin, and the Yellow River metropolitan area. It considers the impact of land use change on ecological security, discusses the driving effect of urbanization, industrial emissions, population density and other factors on land ecological security, involves the comprehensive land consolidation and ecological restoration strategies, and focuses on the improvement of legal and policy frameworks. Wu Dafang and others systematically summarized, compared, and analyzed the main research results of cultivated land ecological security evaluation domestically and internationally, focusing on evaluation stages, concepts, characteristics, driving factors, evaluation scales, methods, techniques, index systems, simulation predictions, and protection measures (Wu et al., 2015). Lü Tiangui and others constructed a regional ecological security evaluation index system using the PSR model and explored obstacle factors affecting ecological security within the study area (Lv et al., 2021). Gui Yaling and Li Qiaoyun used the hierarchical analysis method and entropy weight method combined with an optimized PSR model to evaluate the ecological security of the Dongting Lake area, summarizing and analyzing the factors affecting its ecological security (Guo and Li, 2021).

This study constructs the evaluation index system of land ecological security in Heilongjiang Province based on the PSR model, evaluates the land ecological security in Heilongjiang Province from 2000 to 2022, identifies the main factors affecting the land ecological security, provides the basis for scientifically formulating the corresponding measures, guarantees the sustainable development of the regional socio-economics and agriculture, and maintains the coordinated development of the land's natural, social, and economic complexes in the long term.

2 Overview of the study area

Heilongjiang Province is located between latitudes 43°26′–53°33′N and longitudes 121°11′–135°05′E, with vast territory, superior geographical conditions, diverse land forms, and abundant natural resources. The study area for the present study is shown in Figure 1. It is located in the eastern part of the Eurasian continent, the western Pacific coast, and the northeastern part of China. It is higher in the northwest and southeast, and lower in the northeast and southwest, mainly composed of mountains, platforms, plains and water surface. These mountainous landforms make the land use types of Heilongjiang rich and diverse, suitable for the development of forestry, and some intermountain basins and valley plains can be agricultural production.

The climate is a temperate continental monsoon climate, with high summer temperature, concentrated precipitation, rain and heat in the same season, which is conducive to the growth and development of crops and provides good hydrothermal conditions for agricultural production on the land. The winter is long and cold, and the average annual temperature in the province is between 5°C and 4°C. The low temperature in winter makes the land have a longer frozen soil period, which affects the development and utilization of land and the time arrangement of agricultural production to a certain extent.

The soil fertility in Heilongjiang region is generally good, and the black soil widely distributed has high fertility. According to the index of dryness, it is divided into humid region, semi-humid region and semi-arid region from east to west. The vegetation in humid area is flourishing and the land ecosystem is relatively stable. Semi-arid areas may face ecological problems such as land desertification, and corresponding land protection and management measures need to be taken.

In Heilongjiang Province, there are three major water systems: the Wusuli River, the Songhua River and the Heilongjiang River. The Heilongjiang river system is mainly composed of tributaries such as the Songhua River and the Nenjiang River. The north source is from the eastern foot of the Kent Mountain in the territory of the Mongolian People's Republic, and the south source is from the Erguna River on the western slope of the Greater Khingan Mountains in China. The main tributaries of the Songhua River system include Mudan River, Hulan River, Lalin River, Ant River, Tangwang River, Weiken River and other rivers; The upper reaches of the Ussuri River system are formed by the confluence of the Wula River and the Daobi River, flowing northeast to the Bori area and turning southwest to the Heilongjiang River (Niu, 1999).

The total land area of Heilongjiang Province is 473,000 km^2, with a vast area, accounting for 4.9% of China's total land area, ranking sixth in China. With a large *per capita* arable land, it is one of the most important agricultural provinces in China. Heilongjiang Province has Sanjiang Plain in the northeast and Songnen Plain in the west. The plain is flat and open, which provides favorable conditions for large-scale agricultural planting and mechanization. The cultivated land is mainly distributed in Sanjiang Plain and Songnen Plain, the most important agricultural production bases in the province (Li et al., 2014), accounting for 70%–80% of the cultivated land in the province. This forms the basis for Heilongjiang to become an important grain-producing area in China.

Heilongjiang Province has made remarkable progress in ecological stability, and the overall situation is stabilizing. From the perspective of ecosystem services and ecological security pattern, the value of ecosystem services in Heilongjiang Province is on the rise, and it is outstanding in hydrological regulation and forest land services. By building an ecological security pattern, Heilongjiang Province has made remarkable progress in improving the stability and connectivity of ecological networks, especially in the western semi-arid region, by adding potential ecological corridors to enhance the stability of ecological networks. For example, the high intensity of freeze-thaw erosion in the large and small Xingan Mountains poses a serious threat to the natural environment and black soil resources; Problems such as soil erosion, soil degradation and desertification still exist. In terms of vegetation ecological quality, the vegetation growth trend in Heilongjiang Province is generally good, the net primary productivity of vegetation has increased by about 20% in the past two decades, and the biodiversity maintenance function has also been steadily improved. The forest vegetation coverage showed an increasing trend during 2000–2022, and the ecological quality of vegetation in most forest areas was excellent or good.

In general, Heilongjiang Province has a unique geographical location and rich ecological resources. Land ecological security is not only related to the local ecological environment and economic development, but also affects the ecological security and food security of the whole country. Heilongjiang Province is a major agricultural province, crucial for the national granary and agricultural production. Therefore, studying the current situation,

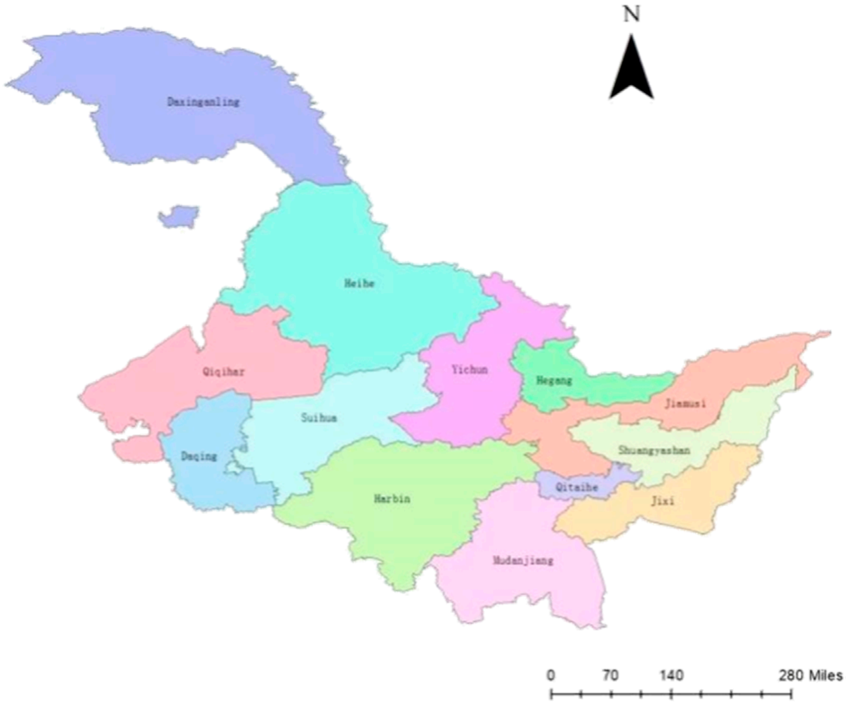

FIGURE 1
Administrative zoning map of Heilongjiang Province.

problems, and solutions related to land ecological security in this region is of significant research importance. It can protect and rationally use land resources more scientifically, promote sustainable development, and build a strong ecological security obstacle in the north of the motherland.

3 Research methods and data sources

3.1 Research methods

The PSR (Pressure-State-Response) model is a commonly used evaluation model in the sub-discipline of ecosystem health evaluation within environmental quality assessment. Initially proposed by Canadian statisticians David J. Rapport and Tony Friend in 1979, it was later developed into a framework system for studying environmental issues by the OECD and UNEP in the 1980s and 1990s (Li and Li, 2014). The core idea of the PSR model is to assess the health and sustainability of ecosystems by analyzing the causal relationship between the Pressure exerted by human activities on the environment, the change in the State of the environment, and the Response taken by society.

The pressure index is used to measure the negative impact of human activities on the environment, such as resource demand, material consumption and emissions in the process of industrial operation, and reflects the load of human activities on natural resources and ecological environment. State indicators describe the state and change of the environment at a specific point in time, including the status of the ecosystem, the natural environment and the quality of life and health of human beings, reflecting the current state of the environmental system under pressure; Response indicators focus on how societies and individuals can act to mitigate, prevent, restore and prevent the negative impact of human activities on the environment, as well as take measures to address ecological changes that are detrimental to human survival and development.

The analytic hierarchy process (AHP) breaks down the elements related to decision into goals, criteria, schemes and other levels, on which qualitative and quantitative analysis decisions are made. The goal level is the highest level of the analytic hierarchy process, which defines the ultimate goal of the research problem or decision. The criterion layer lies between the target layer and the index layer. It is a further refinement and decomposition of the target layer, and is used to reflect all aspects or dimensions of the realization of the goal. The index layer is the lowest layer, the criterion layer is further concretized and refined, and consists of specific, quantifiable or qualitatively described indicators. In this paper, based on the analytic hierarchy process and PSR model, a total of 21 evaluation indicators, including 14 positive indicators and 7 negative indicators, and constructed an evaluation index system of land ecological security in Heilongjiang Province, including 3 levels of target layer, criterion layer and indicator layer and 21 indicators (Table 1). Among them, the greater the positive index, the better the regional land ecological environment; The smaller the negative index, the better the regional land ecological environment[24]. The entropy weight method was used to determine the weight of each index, the land ecological security comprehensive index was calculated to determine the land security level, and the obstacle factor diagnosis model was used to analyze the

TABLE 1 Evaluation index system of land ecological security in Heilongjiang Province.

Target level	Standardized layer	Indicator layer	Nature of the indicator	unit (of measure)	Weight/%
		Population density (X_1) Natural population growth rate (X_2) Cultivated land *per capita* (X_3) Agricultural fertilizer application (X_4) Pesticide use (X_5) Industrial wastewater discharges (X_6) Industrial solid waste production (X_7)	- - + - - - -	Persons/km^2 ‰ hm^2/person million t million t million t million t	5.872 3.189 4.707 5.676 4.429 3.659 3.711
Land Ecological Security Composite Index (Z)	Ecological pressure on land (P) Ecological status of land (S) Land Ecological Response (R)	Level of urbanization (X_8) Forest cover (X_9) Water resources *per capita* (X_{10}) Share of cultivated land area (X_{11}) Share of forested land area (X_{12}) Share of affected area (X_{13}) Greening coverage of built-up areas (X_{14})	+ + + + + - +	% % m^3/person % % % %	5.042 6.825 3.785 5.539 4.805 2.789 2.834
		GDP *per capita* (X_{15}) Consumption level of the population (X_{16}) Grain yields (X_{17}) Gross power of agricultural machinery (X_{18}) Effective irrigated area of arable land (X_{19}) Sewage treatment rate (X_{20}) Share of tertiary output (X_{21})	+ + + + + + +	Yuan/person Yuan kg/km^2 million kW thousand hectares % %	4.183 5.192 4.950 4.870 6.007 5.431 6.505

main obstacle factors at each level, and the regional land ecological security was evaluated.

Obstacle factor diagnosis model is a model used to identify and analyze various obstacle factors that affect the realization of the system goal or the smooth progress of the process. The complex problem is decomposed into multiple levels, including the target layer, the criterion layer, the index layer, etc. First determine the system target to diagnose; Then the criterion layer is constructed to classify the factors that affect the realization of the goal according to different categories. Then the specific index layer factors are subdivided under each criterion. This model is often used in the fields of multi-objective decision making and risk assessment.

3.2 Data sources

The original data required for this study come from the “Heilongjiang Statistical Yearbook” (2000–2022), “China Statistical Yearbook” (2000–2022), and the China Economic and Social Big Data Research Platform.

4 Comprehensive evaluation of land ecological security

4.1 Construction of land ecological security evaluation index system

In the evaluation of land ecological security, the sufficiency of water resources, water quality and water dynamics have important effects on land characteristics and the stability of ecological environment. Sufficient water quantity, good water quality and moderate hydrodynamic power are important factors to ensure the fertility of land and the healthy growth of plants. The shortage of water resources will lead to land degradation, soil salinization, desertification and other phenomena. Improper management of water resources will have a negative impact on land ecological security. For example, overexploitation of groundwater can lead to a drop in the water table, which in turn affects vegetation cover and soil moisture, ultimately leading to landscape degradation. As a driving factor, water plays a crucial role in land ecological security evaluation. Therefore, water resource related indicators are selected as evaluation criteria when conducting land ecological security evaluation. In this study, the consideration of water in driving factors mainly includes two aspects: natural conditions are represented by *per capita* water resources, and social aspects are represented by industrial wastewater discharge, sewage treatment rate and effective irrigated area of cultivated land.

The impact of population as a driving factor on land ecological security involves many aspects, including the impact of population growth or reduction on land use and land cover change, the relationship between population density and land degradation, and the direct and indirect impact of population growth on ecological environment. The increase of population density will aggravate the problem of land degradation. Population change directly affects the change of land use and land cover through the expansion or reduction of construction land and the change of land use. For example, population growth will lead to the reduction of cultivated land area, but with the development of economy, the driving effect of population growth on the reduction of cultivated land area will gradually decrease. Population density and natural population growth rate were selected as the representative indicators in this study.

Industrial pollution is one of the main sources of environmental pollution. The development and utilization of industrial land directly affect the ecological security of land, such as heavy metal pollution and soil degradation. The change of industrial structure has a direct impact on ecological environment, and the optimization of industrial structure helps to improve the quality of ecological environment. Industrial activities consume natural resources and energy, increase the ecological footprint, and put pressure on the ecological environment, and the discharge of industrial wastewater, gas and solid waste will also pose a threat to the ecological security of the land. When evaluating land ecological security, we should consider the impact of industrial activities on ecological environment, the change of industrial structure, and the planning and management of industrial land. This study selected industrial wastewater discharge, industrial solid waste output and other indicators as representatives.

The improvement of the green coverage rate has a positive impact on improving the quality of the ecological environment, increasing biodiversity, improving the stability and resilience of the ecosystem, and alleviating ecological problems such as air pollution and heat island effect in the process of urbanization. The increase of forest coverage rate helps to improve the ecological environment and promote the sustainable development of society and economy. In this study, green coverage rate, forest coverage rate, woodland area proportion and other factors were selected as representatives.

The effects of economic development on land use, the effects of economic policies on land protection, and the direct and indirect effects of economic activities on ecological environment. Economic development is usually accompanied by changes in land use, such as non-agricultural land, urban expansion and so on. Economic activities such as industrial production and transportation construction directly consume natural resources and change land cover, affecting ecological security. In this study, indicators such as *per capita* GDP and residents' consumption level are selected as representatives (Valjarević et al., 2022).

Using the PSR model, this study comprehensively analyzes the influencing factors of ecological security in Heilongjiang Province, constructing a land ecological security evaluation index system that includes 21 indicators across three layers: target layer, criterion layer, and indicator layer. The results are shown in Table1.

In the PSR model, the pressure layer represents the impact of human production and life on land, the state layer represents the state of nature and human life, and the response layer represents the ecosystem's response to environmental changes and human society's related measures. Based on the actual situation in Heilongjiang Province, 21 evaluation indicators are selected, including 14 positive indicators and 7 inverse indicators. Positive indicators mean that the larger the value, the better the land ecological environment, and inverse indicators mean that the smaller the value, the better the land ecological environment (Yu et al., 2023).

4.2 Standardization of evaluation indicators and determination of weights using entropy weight method

4.2.1 Standardization of indicators

Due to differences in dimensions, magnitudes, and positive or inverse orientations of the indicators, data need to be standardized. When the indicator value is larger and more beneficial to land ecological security, a positive indicator calculation formula is used for standardization; when the indicator value is smaller and more beneficial to land ecological security, an inverse indicator calculation formula is used for standardization; the formula is as follows (Equations 1, 2):

$$\text{Positive indicators: } Xij' = \frac{Xij - minXij}{maxXij - minXij} \tag{1}$$

$$\text{Inverse indicators: } Xij' = \frac{maxXij - Xij}{maxXij - minXij} \tag{2}$$

where Xij and Xij ' are the original and normalized values of the *i*th (i = 1, ., m) indicator for the *j*th (j = 1, ., n) year, respectively; maxXij and minXij are the maximum and minimum values of the *i*th indicator, respectively.

4.2.2 Determination of weights using entropy weight method

The entropy weight method is used to determine the weights of the indicators in the land ecological security evaluation index system. The entropy weight method calculates the weight based on the amount of information contained in the data of each indicator. The specific steps are as follows (Equations 3–6):

Characteristic weight of the *i*th evaluation object:

$$P_{ij} = \frac{Xij}{\sum_{i=1}^{n} Xij}, (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \tag{3}$$

Calculate the entropy value of the *j*th indicator:

$$e_j = -k\sum_{i=1}^{n} P_{ij} \ln\left(P_{ij}\right) \tag{4}$$

where, $k > 0$, $k = 1/\ln(n)$, $ej \geq 0$,

Calculate the coefficient of variation for indicator j:

$$g_j = 1 - ej, (j = 1, 2, \ldots, m) \tag{5}$$

Determine the weight coefficient of the *j*th indicator:

$$W_j = \frac{gj}{\sum_{j=1}^{m} gj}, (1 \leq j \leq m) \tag{6}$$

4.3 Calculation of comprehensive land ecological security index

Using the standardized values of the indicators and their weights, the comprehensive land ecological security index is calculated as follows:

$$Z_i = \sum_{j=1}^{m} W_{ij} \times P_{ij}, (i = 1, 2, \ldots, n) \tag{7}$$

Where: Z_i is the land ecological security evaluation index; W_j is the weight of the *j*th indicator; P_{ij} is the standardized value of the *i*th (i = 1,m) indicator in the *j*th (j = 1,.,n) year.

4.4 Analysis of main obstacle factors

Using the obstacle factor diagnosis model, two indicators, indicator deviation (D) and obstacle degree (h, H), the main obstacle factors at various levels are analyzed. The obstacle degree of the (i)-th indicator is calculated as follows (Li and Nan, 2015):

$$\begin{aligned} D_{ij} &= 1 - X_{ij}', \\ h_{ij} &= D_{ij} * W_j / \sum_{j=1}^{n} \left(D_{ij} * W_j \right) \times 100\%, \\ H_{ij} &= \sum h_{ij} \end{aligned} \tag{8}$$

where W_j is the weight of each single index; D_{ij} represents the gap between each individual index and the development goal of land ecological security system, that is, the difference between the standardized value of each individual index and 100%; h_{ij} represents the obstacle degree of the Jth single index in the i sub-system, and H_{ij} represent the obstacle degree of the subsystem.

5 Analysis of results

5.1 Land ecological security level analysis

In the evaluation of land ecological security, in order to be able to better evaluate the regional land ecological security status, the comprehensive index of land ecological security needs to be graded. According to the value of the comprehensive index and the land ecological characteristics of Heilongjiang Province, referring to the relevant literature (Leng and Li, 2022; Zhang et al., 2007; Tang J et al., 2006), the land ecological safety grade of the whole study area is divided into five, respectively, Ihazardous [0.0, 0.4), IIrelatively unsafe [0.4, 0.6), IIIearly warning [0.6, 0.8), IVrelatively safe [0.8, 0.9), Vsafe [0.9, 1.0) (Table 2).

As the value of the composite index increases, the land ecological security situation in the region shows a gradual improvement; on the contrary, when the value decreases, the land ecological security situation in the region deteriorates. From Equation 7, the land ecological security index of Heilongjiang Province from 2000 to 2022 was calculated and the comprehensive index of land ecological security was graded (Table 3; Figure 2).

5.2 Abnormal rate of increase in the composite index

Since 2000, the level of land ecological safety in Heilongjiang Province has shown a fluctuating upward trend on the whole, with the safety level ranging from hazardous (I) to relatively safe (IV), which has improved regional land ecological safety to a large extent, indicating that the region's land ecological safety is developing in a favorable direction. From the chart, the downward trend of the comprehensive index of land safety in the region in the two periods of 2003 and 2007 is mainly attributed to the increasing solid and liquid waste emissions due to the increasing level of urban industrialization under the environment of rapid economic and technological development, and the increasing amount of agricultural fertilizer application and pesticide use, which led to the increasing pressure on the safety of land resources and aggravated the burden on the land. Since 2007, the comprehensive index of land ecological security in Heilongjiang Province has shown a steady increase from 0.2391 to 0.8894, mainly due to the decline in population density and natural growth rate, the level of urbanization, forest coverage, *per capita* water resources, greening coverage of built-up areas, the level of consumption of the population, grain production per unit area, the level of agricultural mechanization, sewage treatment rate, The proportion of output value of tertiary industry and other indicators have all shown an upward trend, which has largely alleviated the pressure on land ecological security in Heilongjiang Province. However, the land in the region was in a hazardous(I) level from 2000 to 2009, in a relatively unsafe (II) level from 2010 to 2014, in a warning (III) level from 2015 to 2019, and in a relatively safe (IV) level from 2020 to 2022, and has been in an unsafe state most of the time in the last 20 years. This means that part of the land ecological environment in the region has been damaged, the land ecological function has been degraded, and the ecological restoration and reconstruction of the land is more difficult. Although the safety level has reached the safe level in 2022, it still needs to be strengthened in all aspects in order to maintain the ecological level of the land in the future.

5.3 Guideline layer index changes

5.3.1 Fluctuations in the ecological stress index decline and then rise significantly

There is a negative correlation between the pressure index and ecological security. The lower the land ecological pressure index is, the less the land is under pressure and the better the land ecological security is.

TABLE 2 The evaluation standards of land ecological security index.

Safety index range	Rank	degree of safety	System characteristics
<0.4	I	Hazardous (nasty)	The ecological environment of the land has been greatly damaged, the structure of the ecosystem is incomplete, the function is low, the degradation changes have occurred, the restoration and reconstruction are difficult, and the ecological disaster is serious
0.4.~0.6	II	Relatively Unsafe (poor)	The land ecological environment has been greatly damaged, the structure has deteriorated greatly, the function is not complete, it is difficult to recover after external interference, the degree of salinization is high, the management is difficult, the ecological problems are larger, and the ecological disasters are more
0.6–0.8	III	Early warning (general)	The land ecological environment is less damaged, the system structure has a deterioration trend, but it can still maintain the basic function, and it is easy to deteriorate after interference, the salinization degree is high, the soil fertility is reduced, and the ecological problems are significant
0.8–0.9	IV	Relatively safe (good)	The land ecological environment is disturbed, the ecosystem structure is still perfect, the function is still good, the soil fertility is high, the agricultural pollution degree is low, the land use degree is high, the soil and water coordination is good, and the ecological problems are not significant
≥0.9	V	Safe (ideal)	The ecological environment of the land is basically not disturbed and damaged, the structure of the land ecosystem is complete, the function is strong, the soil is fertile and there is no agricultural pollution, the vegetation coverage rate is high, there is no desertification and alkalization phenomenon, and the ecological problems are not significant

The research results of this part are shown in Figure 3. Since 2000, the ecological pressure index of land in Heilongjiang Province has fluctuated greatly, showing a fluctuating downward trend until 2012 and a yearly upward trend after 2012. Firstly, the stress index decreased gradually from 0.1869 in 2000 to 0.0699 in 2012, mainly because the population density of the region decreased from 83.85 people/km2 to 82.21 people/km2 in 2000–2012, a decrease of 0.02%, and the natural population growth rate decreased from 3.93% to 1.27%. The *per capita* cultivated land area increased from 2,526.13 hm2 to 4,255.10 hm2, an increase of 0.68%, which alleviated the pressure on land ecology to a certain extent. By 2022, the index will rise from 0.0699 to 0.2747, which is due to the increase in the proportion of the primary industry, the improvement of the level of urban industrialization, the application of pesticides and fertilizers, and the increase in the discharge of industrial wastewater and solid waste, which will intensify the pressure on land ecology. In general, the main reason affecting the land ecological pressure index is the increase in the use of agricultural inputs and pollutant emissions. In 2022, the increase is 0.47% compared with 2000, resulting in the rising land ecological pressure.

5.3.2 Continued small increase in the ecological status index

There is a positive correlation between the state index and ecological security. The higher the land ecological state index is, the better the land ecosystem function is and the better the land ecological security is.

The ecological status index basically showed a fluctuating upward trend. The status index rose from 0.0989 in 2000 to 0.3260, an increase of 2.3%. This is due to the fact that with the progress of science and technology and the continuous improvement of people's awareness of environmental protection, the urbanization level of the region by 2022 increased by 0.27%, the forest coverage increased by 0.02%, the *per capita* water resources increased by 0.82%, the proportion of arable land area increased by 0.72%, and the greening coverage of the built-up area increased by 1.2%. It can be seen that the relevant departments of Heilongjiang Province are highly concerned about ecological environmental protection, continue to strengthen the protection of natural resources and the ecological environment, enhance the forest coverage, effectively enhance the land soil and water conservation and self-recovery capacity, and all indicators have improved.

5.3.3 Ecological response index increases year by year

The relationship between state index and ecological security is complicated. According to the selected indicators in this part, the higher the land ecological response index, the better the land ecological security status.

The ecological response index has demonstrated a consistent upward trend over the years. Specifically, the response index increased from 0.0012 in 2000 to 0.2887, reflecting an overall growth of 2.40%. This positive development can be attributed to the continuous advancement and enhancement of economic, social, and urbanization levels within Heilongjiang Province. In 2022, *per capita* GDP rose by 5.80%, while residents' consumption levels saw an increase of 5.57%. Additionally, grain yield improved by 0.63%, total agricultural machinery power grew by 3.39%, effective irrigated areas of arable land expanded by 2.03%, sewage treatment rates increased by 2.1%, and the proportion of tertiary industry output value rose by 0.63%. These trends indicate that the Heilongjiang Provincial Government places significant emphasis on both ecological protection and management as well as enhancing citizens' livelihoods through timely feedback mechanisms addressing emerging issues; consequently, all relevant indicators have shown improvement.

TABLE 3 Comprehensive land ecology values and grades in Heilongjiang province from 2000 to 2022.

Vintages	Stress index	Condition index	Response index	Composite index	Security level
2000	0.1863	0.0989	0.0012	0.2864	Hazardous (I)
2001	0.1914	0.1263	0.0159	0.3336	Hazardous (I)
2002	0.1880	0.0942	0.0347	0.3169	Hazardous (I)
2003	0.1321	0.0873	0.0085	0.2279	Hazardous (I)
2004	0.1231	0.1195	0.0318	0.2744	Hazardous (I)
2005	0.1217	0.1520	0.0359	0.3096	Hazardous (I)
2006	0.1099	0.1354	0.0487	0.2940	Hazardous (I)
2007	0.0882	0.0968	0.0540	0.2391	Hazardous (I)
2008	0.1067	0.1434	0.0811	0.3312	Hazardous (I)
2009	0.1214	0.1875	0.0899	0.3989	Hazardous (I)
2010	0.1035	0.2334	0.1232	0.4601	Relatively unsafe (II)
2011	0.0933	0.2141	0.1529	0.4603	Relatively unsafe (II)
2012	0.0699	0.2330	0.1756	0.4785	Relatively unsafe (II)
2013	0.0875	0.2665	0.2004	0.5543	Relatively unsafe (II)
2014	0.0939	0.2860	0.2153	0.5951	Relatively unsafe (II)
2015	0.1205	0.2818	0.2255	0.6277	Warning (III)
2016	0.1440	0.2601	0.2355	0.6396	Warning (III)
2017	0.1582	0.2805	0.2462	0.6850	Warning (III)
2018	0.1749	0.2681	0.2485	0.6915	Warning (III)
2019	0.2064	0.3031	0.2587	0.7681	Warning (III)
2020	0.2600	0.3262	0.2610	0.8471	Relatively safe (IV)
2021	0.2621	0.3321	0.2864	0.8807	Relatively safe (IV)
2022	0.2747	0.3260	0.2887	0.8894	Relatively safe (IV)

5.4 Diagnostic analysis of obstacle factors

5.4.1 Guideline layer obstacle factors

Based on the comprehensive evaluation and analysis of land ecological security in Heilongjiang Province, the obstacle degree was measured for three subsystems, namely, pressure layer, state layer and response layer, and the results are shown in Table 4 and Figure 4.

From the above figure, it can be seen that the obstacle degree of the three indicators at the guideline level to the land ecological security of Heilongjiang Province and their change trends are different. Overall, the obstacle degree of pressure system increased from 21.56% to 58.62%, the obstacle degree of state system increased from 30.67% to 36.23%, and the obstacle degree of response system decreased from 47.77% to 5.15%. The pressure layer obstacle degree shows a fluctuating upward trend, mainly due to the accelerating process of urban industrialization, the expanding scope and intensifying intensity of land use, the increasing use of pesticides and fertilizers and the increasing emissions of industrial solid and liquid wastes, which makes the ecological pressure of the site gradually increase; the state layer obstacle degree shows a decreasing and then increasing trend, with little change in the overall situation; and the gradual decrease in the response layer obstacle degree is mainly attributed to the urbanization level. The gradual decrease of the obstacle degree in the response layer is mainly attributed to the increase of urbanization level, which makes the city's state of coping with land problems improved, and the development of regional economy and people's awareness of environmental protection enhanced, which indicates that the protection of

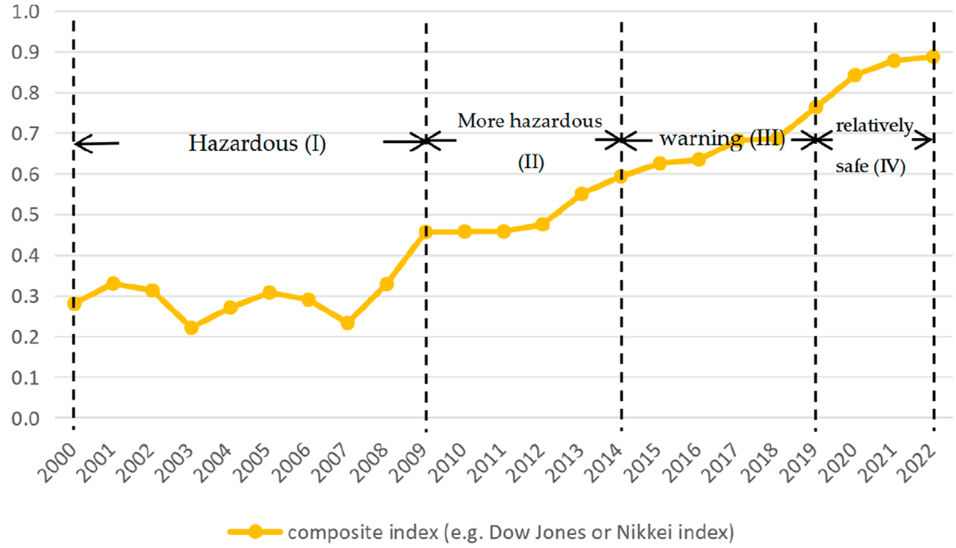

FIGURE 2
Level of ecological security of land in Heilongjiang Province from 2000 to.

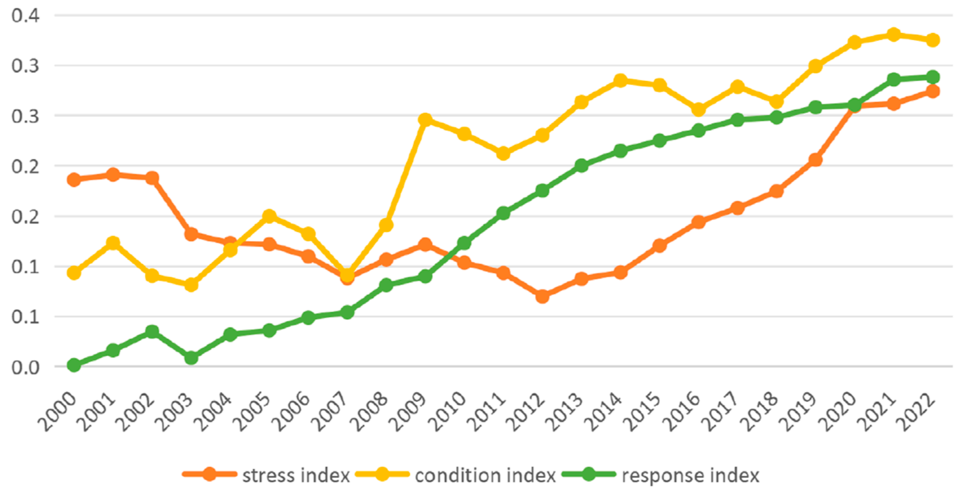

FIGURE 3
Land ecological security index of Heilongjiang Province from 2000 to 2022.

land ecological security in the region should focus on the management of the ecological environment and improve the level of restoration, and pay attention to the economic means, starting from improving the *per capita* income of the people, to promote the wellbeing of people's livelihoods, to increase the financial support, and to build up a sound response mechanism. response mechanism.

Land ecological security is affected by the three factors together, which is a complex interaction relationship. In this study, according to the selection of indicators of each part, the obstacle degree of pressure system is mainly positive correlation, and the increase of its index will increase the pressure on land ecological security. The relationship of state system impairment degree is complicated. After ecological protection and restoration measures are taken, the land ecosystem begins to recover, and the land ecological security situation improves, showing a negative correlation. Due to the new interference or unreasonable use, the state system obstacle degree began to rise again, and the land ecological security level was affected again, and the overall relationship showed fluctuations. The obstacle degree of response system generally shows a negative correlation with land ecological security, and the index decreases, which is conducive to the promotion and application of advanced land restoration technology and ecological protection technology, which means that the government can introduce and effectively implement relevant policies and environmental supervision measures, which is conducive to protecting and improving the land ecological environment and improving the land ecological security level.

TABLE 4 Obstacle degree of land ecological security guideline layer in Heilongjiang province from 2000 to 2022.

Vintages	Pressure system (%)	Rankings	State system (%)	Rankings	Response system (%)	Rankings
2000	21.56	3	30.67	2	47.77	1
2001	22.20	3	29.91	2	47.89	1
2002	22.12	3	33.47	2	44.40	1
2003	21.74	3	33.50	2	44.76	1
2004	23.57	3	31.85	2	44.58	1
2005	24.37	3	29.68	2	45.96	1
2006	25.84	3	30.45	2	43.71	1
2007	27.63	3	32.79	2	39.58	1
2008	28.38	3	31.71	2	39.91	1
2009	33.03	2	22.93	3	44.04	1
2010	36.27	2	24.70	3	39.03	1
2011	37.91	1	27.10	3	34.99	2
2012	42.54	1	25.51	3	31.94	2
2013	46.15	1	24.41	3	29.44	2
2014	50.92	1	21.63	3	27.45	2
2015	53.19	1	24.50	2	22.31	3
2016	53.47	1	29.21	2	17.32	3
2017	56.29	1	28.47	2	15.25	3
2018	55.50	1	31.38	2	13.12	3
2019	57.79	1	30.27	2	11.94	3
2020	52.04	1	33.17	2	14.79	3
2021	60.86	1	35.20	2	3.94	3
2022	58.62	1	36.23	2	5.15	3

5.4.2 Indicator layer obstacle factors

According to the diagnostic method of obstacle factors, the obstacle degree of each indicator was calculated by Formula 8 for the period 2000–2022. Due to the large number of selected indicator factors, this study ranked the obstacle factors of each year according to the size of the obstacle degree (Liu et al., 2023). In this study, the top 5 indicators of each year were selected as the main obstacle factors affecting land ecological security in Heilongjiang Province, and according to the frequency of occurrence of the indicators ranked by the obstacle degree of each year, 8 indicators with a higher frequency were finally filtered, see Table 5.

The obstacle factors that appear more frequently in the top 5 obstacle indicators in each year during 2000–2022 are population density, agricultural fertilizer application, pesticide use, industrial solid waste generation, forest coverage, proportion of forested area, effective irrigated area of arable land, and proportion of tertiary industry output value. In terms of hierarchical distribution, among the above eight major obstacle factors, the pressure layer accounts for four, mainly indicators of population pressure and environmental pressure; the state layer accounts for two, all of which are indicators of ecological environment; and the response layer accounts for two, which are indicators of economic response and social response.

Among them, the obstacle degree values of the four indicators of agricultural fertilizer application discount, pesticide use, industrial solid waste generation and the proportion of forested land area show a fluctuating growth trend, indicating that these four indicators are the main factors restricting the land ecological security of Heilongjiang Province; at the same time, the other indicators show a

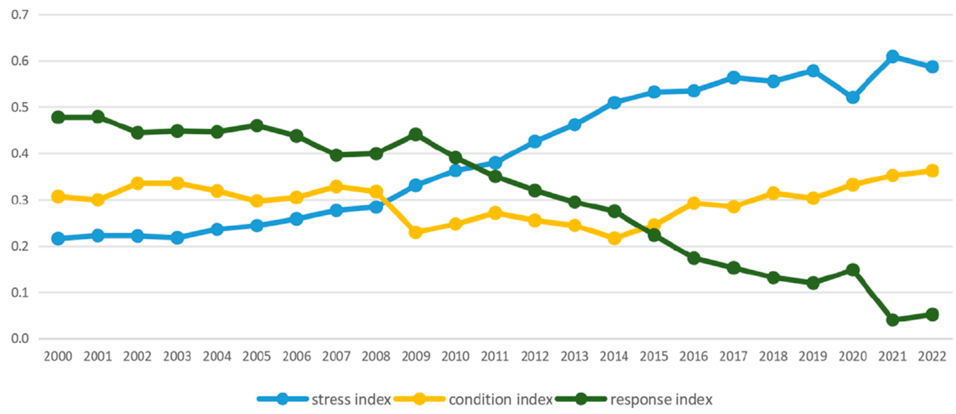

FIGURE 4
Dynamics of land ecological security guideline layer obstacle degree in Heilongjiang Province from 2000 to 2022.

TABLE 5 Main obstacles to land ecological security in Heilongjiang province from 2000 to 2022.

	Pressure system				State system		Response system	
decisive factor	Population density (X_1)	Agricultural fertilizer application (X_4)	Pesticide use (X_5)	Industrial solid waste production (X_7)	Forest cover (X_9)	Share of forested land area (X_{12})	Effective irrigated area of arable land (X_{19})	Share of tertiary output (X_{21})
Frequency (times)	19	13	12	7	7	12	10	15
Frequency (%)	82.6	56.5	52.2	30.4	30.4	52.2	43.5	65.2

fluctuating downward trend, indicating that their hindering effect on land ecology is declining year by year, and they may not necessarily be the key limiting factors for the enhancement of land ecological security in the future. key constraints in the future, but it is still necessary to continue to promote the work related to the above factors. For example, the indicator with the highest frequency, population density (X_1), has shown a stable year-on-year decreasing trend after 2014, which is due to the fact that due to the increased awareness of having fewer children, the cost of raising children, and the serious loss of young people in the region, the natural population growth rate has been reduced from 3.93% to −5.75%, and the contradiction between people and land has eased, so that the population density and the natural growth rate have been lowered, and thus the impeding effect on the ecological security of land has been decreasing year by year.

6 Conclusions and recommendations

6.1 Conclusions

The research of land ecological security is of great significance for supporting policy formulation and management decision-making, scientific management of land resources, promoting ecological civilization construction, assisting territorial spatial planning and ecological restoration, improving land use efficiency, ensuring ecological environment security, and realizing sustainable development.

This study adopts the method of PSR model to construct the evaluation index system of land ecological security in Heilongjiang Province from three aspects of land ecosystem pressure, state and response, to comprehensively evaluate the land ecological security of the area from 2000 to 2022, and to analyze the phenomena and problems of land ecological security in the study area according to the degree of obstacles and main obstacle factors. analyzed, and the main conclusions are as follows:

(1) Since 2000, the level of land ecological security in Heilongjiang Province has generally shown a fluctuating upward trend, with the level of security ranging from hazardous to relatively safe, and the region's land ecological security is developing in a favorable direction. However, in the past 20 years, land ecological security has been in an insecure state for most of the time. At present, land ecological security is at a relatively low level and unstable, and the pressure of land ecological security is still great. In order to maintain the land ecological level in the future, it is still necessary to strengthen efforts in all aspects.

(2) From the degree of guideline level obstacles, the main threats to land ecological security in Heilongjiang Province have changed a lot during the past 20 years, and the current threats to land ecological security mainly come from the pressure system. Developing green organic agriculture, controlling industrial

pollution discharge, improving the efficiency of pesticides and fertilizers and optimizing the layout of construction land are the keys to improve the land ecological security in Heilongjiang Province.

(3) From the obstacle degree of indicator factors, the main obstacle factors are different in each year, and the biggest obstacle factors have evolved from the proportion of output value of the tertiary industry, the effective irrigated area of arable land to the pure amount of agricultural fertilizer application and the proportion of forested land. 2022, the main factors affecting the ecological security of the land in Heilongjiang Province are the pure amount of agricultural fertilizer application, the proportion of forested land, the generation of industrial solid waste, the amount of pesticide use, and the amount of water resources *per capita*. and *per capita* water resources.

(4) The research results obtained from the entropy weight method and obstacle factor diagnostic model in this paper are in line with the actual situation in Heilongjiang Province, but the evaluation of land ecological security is a complex and systematic work, and further research is needed to improve the screening of indicators and the construction of evaluation system.

6.2 Recommendations

In response to the influencing factors revealed by the analysis above, this paper strengthens land ecology in the following aspects to improve land ecological security in Heilongjiang Province:

(1) Fully implement the development strategy for the northeast region in the 14th Five-Year Plan, accelerate the development of modern agriculture, increase the protection of ecological resources, and accelerate the construction of ecological obstacles in the northeast forest belt and the northern sand prevention belt (CPC Central Committee and State Council, 2024); establish different types of ecological function protection zones, strengthen the economical and intensive use of land resources, optimize the allocation of land resources, and avoid disorderly expansion and over-exploitation; and strengthen the management of land degradation areas, such as desertification and soil erosion, and improve land productivity and ecological functions through measures such as afforestation and wetland restoration.

(2) Promote the development of industry in a green and low-carbon direction, restrict the development of highly polluting and energy-intensive industries, encourage enterprises to participate in green manufacturing lists, create green factories, green-designed products, green industrial parks and green supply-chain management enterprises, and realize cleaner production and eco-balance; popularize the use of ecologically friendly materials and technologies, enhance the sense of environmental protection responsibility of industrial enterprises, implement stringent emission standards, and increase the penalties for non-compliant emission penalties.

(3) Establish and improve industrial three-waste treatment facilities, improve the three-waste treatment rate, extract the useful components in the waste for utilization, or discharge the waste after harmless disposal, and reduce the emission of hazardous substances; at the same time, promote the resourceful utilization of industrial solid wastes, agricultural wastes and domestic garbage, and improve the utilization rate of energy, such as reusing the residual pressure and heat of the industry and waste gas and waste liquids after treatment, as well as converting wastes into biomass energy source, etc.; use advanced science and technology to improve the land ecological protection infrastructure, scientificize the use of chemical fertilizers and pesticides, and choose high-efficiency, low-residue pesticides and organic fertilizers as much as possible, so as to reduce the residues of chemical fertilizers and pesticides, and to provide favorable conditions for the improvement of the land ecological environment (Li and Yong, 2023).

(4) Further optimizing the industrial structure according to the existing resource conditions, vigorously developing green and low-carbon industries, encouraging green technological innovation and the development of green and environmentally friendly industries, curbing high-energy-consuming, high-emission and low-level projects, and advocating the introduction of resource-saving and environmentally friendly industries (Li, 2023).

(5) The Government should formulate and implement stricter land management regulations and strengthen the supervision of land use; encourage social capital to participate in ecological protection and restoration efforts, and incentivize more land to be used scientifically; and continue to optimize the regional land-use structure by increasing investment in environmental protection, raising the forest coverage rate, and strengthening the management of soil and water erosion (Li, 2022); to protect the healthy development of the ecological environment, maintain the land survival environment in a healthy development trend, and improve the service capacity of the regional ecological environment.

6.3 Discussions

(1) This study conducted an evaluation of land ecological security and diagnosis of its obstacles at the micro level, focusing on the regional level of Heilongjiang Province from 2000 to 2022. This is mainly due to the current weak statistical data foundation and the difficulty in obtaining annual data at a small scale. In the future, with the deepening of ecological civilization construction, it is expected that statistical data indicators will be integrated and unified. Combined with natural data such as soil, precipitation, and vegetation, further exploration of their coordinated relationship at a smaller scale can be carried out at the micro level to meet the needs of refined management.

(2) Based on the actual situation in Heilongjiang Province and the availability of data, this study selected 21 indicators to establish an evaluation index system. The comprehensiveness and scientificity of indicator selection still need further verification. In addition, only data since 2000 was analyzed in terms of time selection (Zhang et al., 2022). If the research duration is extended, it can more scientifically and objectively reflect

and predict the land ecological security status and its evolving trends in Heilongjiang Province.

(3) This study focuses on the issue of land ecological security in Heilongjiang Province, lacking comparative analysis with other regions. The research results have certain limitations for a comprehensive understanding of regional ecological security in coordinated development. In future studies, comparative research will be conducted with the Northeast region, the Yangtze River Delta, and other areas, which is of great theoretical and practical significance for optimizing regional ecological security in coordinated development and promoting sustainable development in the region.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: Data are limited to this study. Requests to access these datasets should be directed to wangyj@mails.jlnu.edu.cn.

Author contributions

YW: Writing–original draft, Conceptualization, Data curation, Methodology. JG: Writing–review and editing, Conceptualization, Project administration. FG: Writing–review and editing, Resources, Supervision. ED: Writing–review and editing, Supervision. JL: Writing–review and editing, Funding acquisition. WZ: Writing–review and editing, Visualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

CPC Central Committee, State Council (2024). *Outline of the fourteenth five-year plan for national economic and social development of the people’s Republic of China and outline of the vision 2035 [EB/OL]*. Available at: https://www.gov.cn/xinwen/2021-03/13/content_5592681.htm (Accessed January 17, 2021).

Feng, G. J. (2015). Discussion on the definition of “land (system)” from the perspective of land science [J]. *China Land Science* 29 (12), 1–10.

Fu, B. J., Chen, L. D., and Ma, C. H. (1997). Indicator system and methodology of land sustainable utilization evaluation. *J. Nat. Resour.* (02), 17–23.

Guo, Y. L., and Li, Q. Y. (2021). Evaluation of ecological security and analysis of main influencing factors in Dongting Lake area based on improved PSR model. *Agric. Mod. Res.* 42 (01), 132–141. doi:10.13872/j.1000-0275.2021.0014

Leng, C. X., and Li, G. Z. (2022). Evaluation of land ecological security in Baishan City based on principal component analysis. *Agric. Technol.* 42 (23), 84–88. doi:10.19754/j.nyyjs.20221215020

Liang, C., Ma, G. H., Du, X., and Wang, S. F. (2023). Evaluation of land ecological security in Xinyang city based on the “pressure-state-response” model. *Mod. Hortic.* 46(18), 172–174+177. doi:10.14051/j.cnki.xdyy.2023.18.057

Li, C. Y., and Nan, L. (2015). Dynamic evaluation of land ecological security and diagnosis of obstacle factors in Shaanxi Province. *China Land Sci.* 29 (04), 72–81. doi:10.13708/j.cnki.cn11-2640.2015.04.010

Li, F., and Li, Y. (2014). Evaluation of land ecological security and analysis of obstacle factors in Taiyuan City based on PSR model. *Land Nat. Resour. Res.* 2023 (01), 51–56. doi:10.16202/j.cnki.tnrs.2023.01.012

Li, L., Hou, S. T., Zhao, Y., and Zheng, X. L. (2014). Evaluation and prediction of land ecological security in Henan Province based on P-S-R model. *Res. Soil Water Conservation* 21 (01), 188–192. doi:10.13869/j.cnki.rswc.2014.01.037

Li, W. H., and Yong, X. Q. (2023). Evaluation and prediction of land ecological security in Xuzhou[J/OL]. *Nat. Resour. Intell.* 1-8.

Li, X. M. (2022). Evaluation of land ecological security in Lanzhou city based on PSR model. *Agric. Technol.* 42 (08), 74–77. doi:10.19754/j.nyyjs.20220430020

Li, Y. P., and Cai, Y. L. (2007). Evaluation of land ecological security in Hebei Province. *J. Peking Univ. Nat. Sci. Ed.* (06), 784–789. doi:10.13209/j.0479-8023.2007.125

Li, Q. Z. (2023). Exploration of land ecological security evaluation and influencing factors in Xi'an. *Henan Sci. Technol.* 42 (09), 107–111. doi:10.19968/j.cnki.hnkj.1003-5168.2023.09.023

Liu, J. K., Zhang, Z., Liu, X. H., and Wei, L. (2023). Evaluation of water resources carrying capacity of Cebu City based on combined assignment TOPSIS model and study of obstacle factors[J/OL]. *People's Pearl River* 1-8. -12-18].

Lv, T. G., Kong, A. N., and Wang, L. (2021). Evaluation of ecological security of ecological civilization demonstration area and its obstacle diagnosis based on PSR model. *Soil Water Conservation Res.* 28 (02), 343–350. doi:10.13869/j.cnki.rswc.2021.02.043

Ma, J. Y., and Li, J. S. (2023). Research on spatial and temporal changes of land ecological security in Lianyungang City based on PSR model. *Res. Land Nat. Resour.* 2023 (03), 47–50. doi:10.16202/j.cnki.tnrs.2023.03.010

Niu, R. C. (1999). *Dictionary of the origin of geographical names in China* (Beijing: Minzu University Press of China), 479.

Peng, B. Z., Dou, Y. J., and Zhang, Y. (1996). Evaluation of integrated environmental quality from a dynamic point of view. *China Environ. Sci.* 16 (1), 16–19.

Tang, J., Zhu, Y. F., Li, Z. Y., Si, A., and Cui, J. (2006). Establishment and comprehensive evaluation of land ecological environment security index system in Northeast agro-pastoral ecotone: a case study of Zhenlai County. *J. Arid Land Resour. Environ.* (01), 119–124.

Valjarević, A., Popovici, C., Štilić, A., and Radojković, M. (2022). Cloudiness and water from cloud seeding in connection with plants distribution in the Republic of Moldova. *Appl. Water Sci.* 12, 262. doi:10.1007/s13201-022-01784-3

Wang, A. Q. (2023). *Research on the evaluation of land ecological security and influencing factors in the Yellow River Basin*. Basin, Xi'an University of Technology. doi:10.27398/d.cnki.gxalu.2023.001023

Wang, H. M., Guo, W., Cheng, S. L., Wang, Q. J., and Xu, D. H. (2001). National ecological security: concept, evaluation and countermeasures. *Manag. World* (2), 149–156. doi:10.19744/j.cnki.11-1235/f.2001.02.019

Wu, D. F., Liu, Y. Y., Liu, Y. H., Yao, Y. Y., and Liang, D. W. (2015). Prospect of ecological safety evaluation research on cropland. *Chin. J. Ecol. Agric.* 23 (03), 257–267. doi:10.13930/j.cnki.cjea.140918

Xiong, J. H. (2018). A review of land ecological safety evaluation: challenges and reflections. *Geogr. Geogr. Inf. Sci.* 34 (06), 71–76.

Ye, Y. P., and Liu, L. J. (2000). Research on evaluation indicator system of ecological environment quality in Chinese provinces research on. *Environ. Sci.* 13 (3), 33–36. doi:10.13198/j.res.2000.03.36.yeyp.011

Yu, K. J. (1999). Landscape ecological security pattern of biological conservation. *J. Ecol.* 19 (l), 8–15.

Yu, R., Yu, L., Hou, R. Q., HuangFu, F. Z., and Wang, Y. H. (2023). Evaluation and prediction of land ecological security based on PSR model. *Shanxi Agric. Econ.* (15), 123–127

Zhang, B., Jin, F. J., and Hu, D. Y. (2007). Ecological security assessment in central Gansu Province. *J. Nat. Disasters* (05), 9–15.

Zhang, N. N., Shi, S. L., and Li, B. (2022). Evaluation and prediction of land ecological security based on the "pressure-state-response" model–A case study of Shenyang city. *Soil Bull.* 53, 154–196. (01):28-35.Author 1, A.; Author 2, B. Title of the chapter. In Book Title, 2nd ed.; Editor 1, A., Editor 2, B., Eds.; Publisher: Publisher Location, Country, 2007; Volume 3, pp. doi:10.19336/j.cnki.trtb.2021031702

Zhang, X. H., Lei, G. P., Yuan, L., Li, H., and Tian, Q. C. (2009). Evaluation of land ecological security in Heilongjiang Province. *China Popul. Resour. Environ.* 19 (01), 88–93.

Zhao, Y. L., and Zhang, L. J. (1998). Research on quantitative evaluation method of fragile ecological environment. *Prog. Geogr. Sci.* 17 (1), 67–72.

Zuo, W., Wang, Q., Wang, W. J., Liu, J. J., and Yang, Y. P. (2002). Research on indicators and criteria for regional ecological security evaluation. *Geogr. Land Res.* 18 (1), 67–71.

Zuo, W., Wang, Q., Wang, W. J., Wu, X. Q., Yang, Y. P., Yang, L. J., and Zhu, X. H. (2005). Analysis of comprehensive evaluation model for regional ecological security. *Geoscience* 25 (2), 209–214.