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Research on Fuzzy Evaluation of Land Environmental Security in Three Provinces of Northeast China

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Abstract: Among the world's most important three chief black lands, China's northeast region is a vital hub for the commercial extraction of grain, undertaking the task of grain reserves and special transfers. Utilizing the provincial data of the three northeastern provinces from 2010 to 2021, and using existing documents and records as essential elements, we structured a land security appraisal system with five criterion layers and 21 indicator layers of pressure, state, impact, response, and management. The three provinces in the northeast were evaluated for the security of their land resources using the entropy-dependent weight-TOPSIS pattern. The study findings indicate that: (1) In general, land resource security of the three northeastern provinces shows a pattern of decline followed by a gradual increase from 2012 to 2021, and there is a steady improvement in the level of land's ecological stability; (2) There are differences in the ecological stability of the soil across cities and provinces, with Heilongjiang Province having the best land security status and Liaoning Province having the worst; (3) The amount of soil erosion in tiny watersheds is the indicator that has the biggest influence on land ecological stability in the three provinces in the northeast; (4) The response layer is the criterion layer that has the strongest correlation with land ecological safety.

Keywords: land resource security; northeastern provinces; PSIRM modeling framework; fuzzy evaluation

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1. Introduction

As a vital natural resource, land is necessary for people to exist and grow and is a precondition for the long-term growth of the local economy and society [1,2]. Building an ecological civilization and ensuring national and regional ecological security depend heavily on land and its resources' ecological security [2]. Building a civilization that is ecological is strategically vital and holds a prominent position in the push for Chinese-style socialism in the new era, and ecological civilization construction is being promoted as never before [1,2]. Since to the country's rapid urbanization, the rate of socio-economic development has been exceptionally rapid. China's land use structure has undergone drastic changes, and the conflict between the enormous demand for ground brought forth by urban growth and land for ecological security has gained more and more attention [3]. Nowadays, human beings are facing more and more land ecological security problems, such as insufficient land carrying capacity, soil erosion, ecological environment deterioration, and unsustainable utilization of land quantity and quality [4]. One important and crucial element of the sustainable utilization of land resources is the ecological safety of the landscape. In terms of ecology, it preserves the perpetuated equilibrium of intricate business and social ecosystems [4]. To ensure that ecological land is used sustainably, there is a need to balance the need to meet human needs with the expected ecosystem response. The idea of ecological security acts as a bridge between the increasing diversity of land utilization patterns and their ecological consequences and the satisfaction of the ever-expanding range of people's land use needs. The idea of biological safeguards for land fills the gap between the ever-changing ways in which land is used to satisfy human needs and the ways in which such uses have an impact on the environment. An in-depth knowledge of the environmental protection of terrestrial assets, taking into account the health of earth's ecosystems and their ability to meet human requirements, contributes to the realization of optimal trade-offs in land use [5].

Although there is still a lack of a specific definition of what constitutes ecological safety of land assets, the notion of all of land's environmental safety was put forward by Lester R Brown in 1977. In his book, *Building a Sustainable Society*, he made the point that in order to achieve harmony between human beings and the environment, ensuring the security of ecosystems and emphasizing the development of sustainable development concepts are essential [5]. How to protect the ecological integrity of the land while promoting economic growth, social stability, and ecological health in a sustainable state is an issue on which contemporary scholars have also reached a consensus [6]. They contend that the trade-off between ecological environmental protection and socioeconomic development should receive greater focus. Reasonable protection and utilization of the land's ecological environment can encourage socioeconomic growth. Reasonable utilization of land can change surface coverage, and different ways of utilization will cause different ways of interference and damage to land resources. [7] Changes in land utilization have a great impact on regional population size, soil and water conservation, cultivation levels, climatic conditions, and the local natural environment. Realizing the appropriate and efficient use of land is the goal of rational use of land resources. [8] Optimal land use and spatial combination can be realized not only through land use planning and land use technology. In addition, it can stabilize the ecological advantages of land in the long term, achieve maximum economic, social, and ecological benefits, and prevent harm to land resources [8,9].

The research of related scholars on the evaluation of ecological security of land primarily focuses on PSR and construction of former DPSIR and EES models. The evaluation methods mainly include principal component analysis, comprehensive analysis, and hierarchical analysis. At present, many scholars are highly concerned about ecological security problems such as extreme global climate anomalies, biodiversity reduction, the fragile ecological chain, land desertification, soil salinization, etc., and ecological security assessment has become an important research direction of ecological research [10]. From the research direction, one kind of research on ecological security focuses on the protection of biological and ecological health status. Another kind of research approaches land ecological security problems from different angles and using different methods. From the point of view of research territory, it includes county, city, province, key watersheds, and special ecologically sensitive areas. China's land environmental security studies mostly focuses on industrial cities that are industrialized and economically developed, while less research has been conducted on economically underdeveloped agricultural cities, especially in the regions of the three eastern provinces, which have high-quality black soil resources [11]. Agriculture is the economic core of the three northeastern provinces and is also an important commercial grain base in the country. Thus, it is essential to preserve the surrounding land's sustainability. The region's struggle with land and population has steadily emerged as a result of the growing urbanization trend, resulting in notable modifications to land usage. Furthermore, the rising rate of food demand has exceeded the rate of growth in food production. The irrational development of arable land has resulted in the loss of high-quality land for agriculture, jeopardizing the safety of land assets and nutritional supplies. [12,13]In addition, problems such as deforestation and overgrazing of forests and grasslands have arisen as a result of the irrational pursuit of economic benefits. Drought, land desertification, soil erosion, and other ecological issues are all caused by changes in land usage. This has led to greater challenges to land ecological security. How to rationally plan the land use structure and formulate a set of substantial measures to protect the ecologically sustainable development of land resources are also key issues that must be attended to immediately [9].

Considering the background information given above, the three northeastern provinces of China, which comprise China's primary grain-producing region, are selected as the research object. In the research process, it is found that due to the fuzziness and uncertainty of the land's safety information and the complexity of influencing factors, the traditional TOPSIS method based on the exact number is not suitable for dealing with fuzzy data and information. Therefore, using the theoretical model of "Pressure-State-Impact-Response-Management," with the help of Entropy-TOPSIS and gray correlation analysis, the fuzzy TOPSIS of information entropy power combined with gray correlation analysis can minimize the personal subjective influence during the evaluation of the program, and at the same time, reduce the distortion of the information, so as to make the evaluation results more objective and accurate, which is of guiding significance for decision making on the program of enhancing the security of land resources. The study puts forward a proposed viewpoint for protecting land ecological security in the three northeastern provinces, aiming to characterize the evolutionary trend of land ecological security status in the three northeastern provinces from 2012 to 2021. The study's findings offer a solid scientific foundation for the proactive advancement of ecological land security by utilizing the land's potential and promoting sustainable socioeconomic growth in the three provinces in the northeast. It also provides cases and references for land ecosystem management. The research idea is as follows (Figure 1).

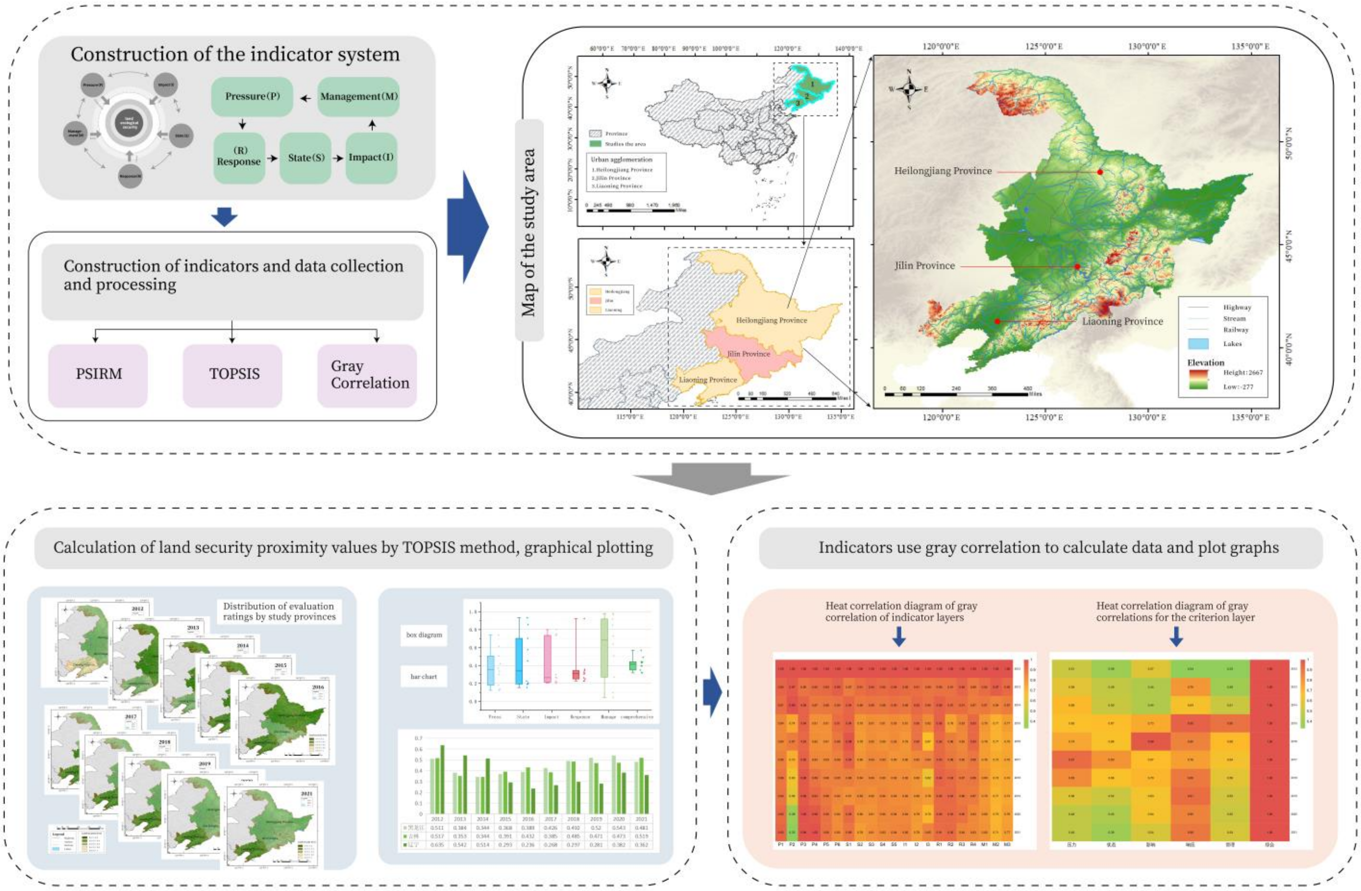

Figure 1. Flowchart of the article framework.

2. Overview of the Study Region

The three northeastern provinces were selected for the study (Figure 2). The three northeastern provinces of the People's Republic of China are Liaoning, Jilin, and Heilongjiang. This region is on the edge of the subtropical rainy meteorological region, located in China's high latitudes. It is geographically situated at latitudes 48°–55° N and longitudes 118°–135° E. The area, which stretches from south to north between the warm temperate zone and the cold mesothermal zone, has a humid and semihumid continental monsoon climate [14]. The three northeastern provinces are located in the northeastern part of the People's Republic of China. The total cultivated area of the three northeastern provinces is about 18.2 million hm^2, with the center plains at a height of roughly 200 m, the Changbai Mountains in the east, and the Daxingan Mountains in the west. The annual precipitation is 500 to 1000 tons, and the annual rainfall is 500 to 1000 tons. Of the 500 mm to 1000 mm of precipitation per year, about 70 percent falls in the summer. The local rice and corn planting areas account for about 15% and 30% of the nation's total acreage dedicated to individual crops, respectively, and the per capita arable land area is the greatest in the country, which is a significant hub for China's commercial grain production [14]. The Northeast Plain is one of the three main black-earth belts in the planet and China's most fertile arable land, ensuring China's access to high-quality agricultural goods and food security. The Northeast's economy is centered on heavy industry, which also contributes significantly to soil contamination [15,16]. In the meantime, inadequate protection of soil resources and scientific management pose a severe danger to the sustainable use of land resources in Northeast China. There is an urgent need for corresponding initiatives to protect land resources.

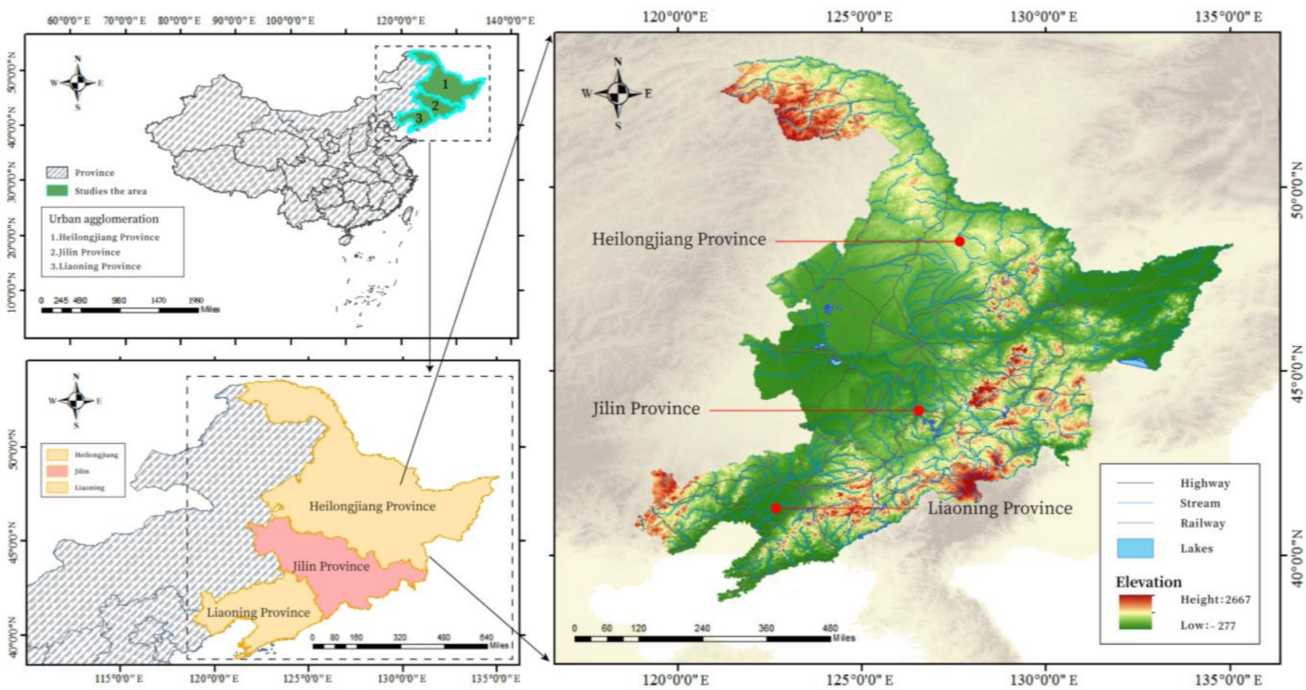

Figure 2. Topographic map of the study area in the eastern province region.

Because of their disparate natural environments, the three provinces in the northeast are diverse from one another. Liaoning Province has a high topography, situated in the hilly western region and the mountainous eastern region, with average altitudes of 800, 500, and 200 m above sea level, making up, respectively, 38%, 26%, and 36% of the province's entire surface area. The average annual precipitation in the region is 600 to 1100 mm, and it belongs to the continental monsoon zone [17] with rain and heat in the same season, long hours of sunshine, high cumulative temperatures, long winters, hot summers, short springs and autumns, and four distinct seasons [18]. Jilin province has uneven precipitation, featuring a dry climate in the western part of the country and a humid one in the southeast. The climate of Heilongjiang is marked by high summer temperatures and abundant rainfall, low spring temperatures and drought, frequent flooding in autumn, early frosts, long, cold winters, short frost-free periods, and marked climatic differences between regions. The three provinces in the northeast are quite sparsely inhabited, highly industrialized, and dominated by arid farming. The varieties of vegetation are varied and intricate, including deciduous coniferous forests, woods with temperate conifers, mixed deciduous forests, temperate forest-steppe, grasslands, and steppes. The three northeastern provinces are distinguished by their distinct vegetation distribution and are one of the hot spots of global climate change research.

3. Indicator Creation and Data Sources

3.1. PSIRM (Pressure; State; Impact; Response; Management)

The ecological security of land resources can be evaluated using a variety of techniques, such as hierarchical analysis, fuzzy synthesis, gray correlation, principal component projection, etc. In this article, we adopt the PSIRM model, an improved model according to the PSR model. In this work, we adopt the PSIRM model, an improved model based on the PSR model, which includes more comprehensive factor elements, a broader scope and richer evaluation criteria. The PSIRM model includes more complete factorial elements, a broader scope of application and richer evaluation criteria [17]. (P) Pressure refers to indicators that show the environmental stresses brought on by both natural and human-caused sources. (S) State refers to the natural state of natural resources, environmental quality, and ecosystems as reflected in the natural state. (I) Impact refers to positive or negative impacts on land resources caused by human activities and the natural environment. (R) Response refers to the economic, administrative, and legal means adopted by humans following feedback from the natural world. (M) Management subsystems represent human impacts caused by human activities. And (D) Management systems represent human impacts on natural resources brought about by human activity and the natural environment. The management subsystem (M) represents the cost of proactive human responses and inputs due to changes in the state of the environment [18,19]. The PSIRM model starts from the interaction and influence of human society and effectively links natural resources and the socio-economy, which is more systematic, comprehensive, and distinctive in terms of causality, as well as simple and practical in terms of operation. Based on the above analysis, the PSIRM framework is established (Figure 3). The example can assist in analyzing the factors influencing land resources and can show how each aspect is interrelated.

The selection of assessment of land ecological security index system should not only consider the condition of natural ecology, but also human factors that have a potential influence on the ecological security of the land. Combining the operationality, accessibility, and scientificity of index data, taking into full consideration the mutual influence between each evaluation, and considering the three northeastern provinces' actual circumstances, 21 evaluation index systems were selected from social, economic, resource, and environmental aspects (Table 1). In this paper, in order to evaluate the natural resource security of the three northeastern provinces, a set of indicators was created, the weights of the assessment indicators were calculated using the TOPSIS method of probability value, and the land's ecological stability score was computed overall.

The PSIMR framework describes the ongoing system of feedback between humans and land ecosystems in five dimensions. The dimension of pressure quantifies the pressure on land ecosystems caused by human activities that create the environment. The stressed terrestrial ecosystem's current condition is reflected in the status dimension. Impacts originate from changes in natural elements and human activities that have a major impact on the security of terrestrial ecosystems. The response dimension is concerned with how people respond in a timely manner to stop or lessen negative effects on land ecosystems. Management is the manifestation of human beings being more proactive in implementing positive interventions and reestablishing the natural hierarchy of land resources. The framework provides systematic recommendations for choosing indicators for various aspects, and it can be used in the development of an extensive ecological land security assessment indicator framework.

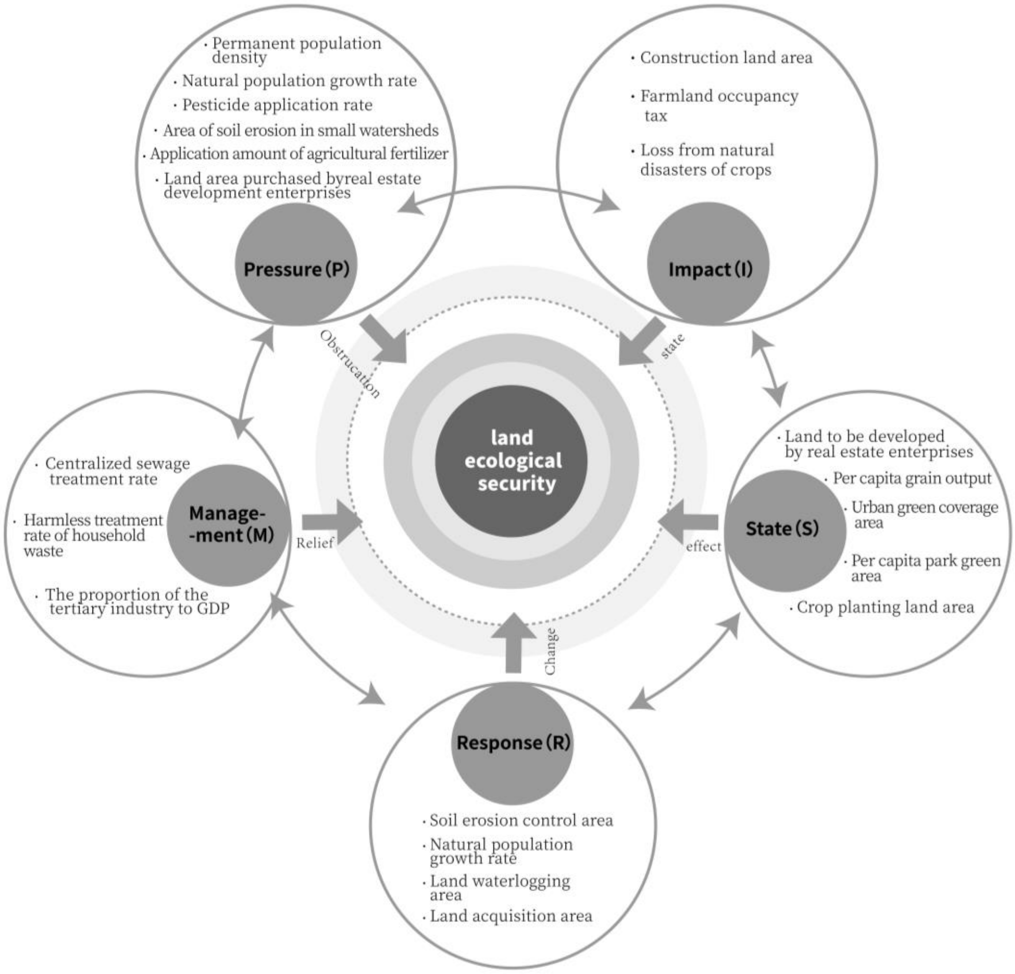

Figure 3. PSIMR framework.

Under the PSIMR framework, 21 evaluation indicators are constructed. Permanent population, natural pace of population expansion to account for the strain on the terrestrial ecosystem, a large population increases the need for ecosystem items like food, water, fiber, etc. and, as a result, increases pressure. The area of soil erosion in small watersheds can negatively affect the land's resource sustainability. The numbers of residents and the rate of natural population expansion indicate the strain on terrestrial ecosystems and, as a result of overcrowding, there is more pressure to produce ecosystem goods like food, water, and fibers. The indicator of the area of soil erosion in sub-watersheds is an indicator of the negative impact of catastrophes that impact the environment's stability of land assets. The use of agricultural fertilizers often leads to soil acidification, water fertilization, and a reduction in biodiversity, resulting in a decrease in soil nutrient cycling capacity. Therefore, we chose the amount of pesticide application, the application of pesticides (selective pure), and fertilizer application to measure the pressure caused by industrial products on agricultural production. The size of the property that real estate developers purchased was selected to represent the extent of building land development. There is more pressure on land when more value is added. The land's current condition and its resilience to pressure changes are reflected in the state dimension. The land appropriateness theory—which gauges how well a piece of land's natural features match the demands of a specific land use type—is mentioned. Thus, crop sowing area and per capita food production were chosen to represent the stability of land resources as of right now. The area covered by urban green space and the per capita area of park green space reflect the rationality of urban land use and the current status of urban development. The land that real estate companies want to develop is a reflection of how efficiently urban land is used, and it also has an impact on how intensively urban construction land is used.

The impact dimension is derived from human activities and natural factors as significant factors of change. The built-up land indicator serves as a gauge of the level of development of established land. The indicator of natural disaster loss of crops reflects the impact of natural disasters on land resources. A special tax, known as the "cultivated land occupation tax," is levied in order to safeguard farmed land and encourage the wise use of available land. It can prevent indiscriminate and abusive use of land and can increase the strength of agricultural development. Therefore, it is also an effective indicator of land ecological security. The response dimension reflects the extent to which people prevent, mitigate, or alleviate pressure through their own actions. We chose the area of soil erosion control and the area of land de-flooding indicators to reflect the cost of land resource management invested in the growth of the local economy. The total forest restoration area indicator shows how much of the region's land area is made up of artificially planted forests on forested barren mountains and fallow land, which can measure the strength of artificial afforestation and the status of green development. The indicator of expropriated land area was chosen to reflect the degree of local control over land management. The management dimension is a manifestation of human beings being more proactive in implementing positive interventions and restoring the ecological order of land resources. The rates of centralized treatment of sewage and innocuous domestic waste treatment are related to different waste treatment facilities that are kept up to date in compliance with regulations. An adequate treatment rate is an important foundation for strengthening land construction and safeguarding land quality. GDP is a useful tool for gauging economic progress and has become an influential dimension for measuring land security. Therefore, to gauge the ecological impact on land, we selected the growing tertiary sector as a percentage of GDP as an indicator.

Table 1. Indicator system of ecological safeguards for the three eastern provinces' land resources.

Category	Normative Layer	Indicator Layer	Unit	Convergence	Weighting
The Three Eastern Provinces' Region's Environmental Security of the Land Indicator System	P: Pressures	P1 Density of resident population	(persons/km^2)	−	0.0374
		P2 Natural population growth rate	(%)	−	0.0267
		P3 Soil erosion area of sub-watersheds	(thousand hectares)	−	0.0406
		P4 Amount of pesticide application	(tons)	−	0.0335
		P5 Fertilizer application for agricultural use (pure)	(million tons)	−	0.0496
		P6 Area of land acquired by real estate development enterprises	(million square meters)	−	0.1053
	S: Stresses	S1 Land to be developed by real estate enterprises	(million square meters)	−	0.0325
		S2 Food production per capita	(Kg/person)	+	0.0374
		S3 Urban green coverage	(hectares)	+	0.0762
		S4 Green park area per capita	(m^2)	+	0.0354
		S5 Crop sown land area	(million hectares)	+	0.0746
	I: Impact	I1 Construction land area	(square kilometers)	−	0.0312

	I2 Cultivated land occupation tax	(billions)	+	0.1107
	I3 Natural disaster losses of crops	(thousand hectares)	−	0.0266
R: Response	R1 Soil erosion control area	(thousand hectares)	+	0.0475
	R2 Total afforestation area	(hectares)	+	0.0223
	R3 Land de-flooding area	(thousand hectares)	+	0.0162
	R4 Land expropriation area	(square kilometers)	−	0.0886
M: Management	M1 Centralized sewage treatment rate	(%)	+	0.0338
	M2 Harmless treatment rate of domestic garbage	(%)	+	0.0339
	M3 Tertiary industries' share of GDP	(%)	+	0.0400

3.2. Data Sources

The required data on population and regional socio-economic development were obtained from the China Statistical Yearbook (2012–2021), Heilongjiang Statistical Yearbook (2012–2021), Jilin Statistical Yearbook (2012–2021), Liaoning Statistical Yearbook (2012–2021), the China County Statistical Yearbook (2012–2021), and the basic data of the CEIC Statistical Database, as well as the official published data of Heilongjiang, Jilin, and Liaoning Provinces and the statistical bulletin of national economic and social development. The Geospatial Data Cloud data platform was used to extract the study area boundary information for the three northeastern provinces. The land's resource information was obtained from the China Environmental Statistics Yearbook (2012–2021), Soil and Water Conservation Bulletin (2012–2021), the bulletin of the ecological environment status of each region, etc. Considering the feasibility of data acquisition and the focus of the study, this paper used the 10 years from 2012 to 2021 as the evaluation period.

4. Data Calculation Process

4.1. The Weight of Indicators Is Determined Using the Entropy-Weighted Approach

The entropy-weighted TOPSIS model is a commonly used global assessment method that effectively avoids the interference of subjective factors in the traditional TOPSIS method, makes full use of original data samples, and objectively and realistically reflects the evolution and changes among influencing factors. In the domains of water environment carrying capacity, land use performance, and economic quality development level, the entropy-weighted TOPSIS model is extensively employed.

As a first step, a standardized assessment matrix was developed for the terrestrial ecosystem sample data from the three northeastern provinces, as follows. Assuming that the "j" evaluation indicator of the evaluation object "i" of land resource ecology, "x" is the overall amount of items used for evaluation, and "y" is the entire set of indicators used for assessment.

$$V = \begin{bmatrix} V_{11} & V_{12} & \cdots & V_{1y} \\ V_{21} & V_{22} & \cdots & V_{2y} \\ \vdots & \vdots & \vdots & \vdots \\ V_{x1} & V_{x2} & \cdots & V_{xy} \end{bmatrix} \quad (1)$$

where V_{ij} (i = 1, 2, 3, ..., x; j = 1, 2, 3, ..., y).

Since the sample unit scale of the raw data was not uniform, the data were standardized using extreme value variance standardization to form the indicator data matrix $W = (V_{ij})_{y \times xo}$. For positive indicators, the normalization of "W_{ij}" is given by the formula:

$$W_{ij} = \frac{V_{ij} - \min\,(V_{1j}, V_{2j}, \ldots, V_{ni})}{\max\,(V_{1j}, V_{2j}, \ldots, V_{ni}) - \min\,(V_{1j}, V_{2j}, \ldots, V_{nj})} \quad (2)$$

For the reverse indicator, "M_{ij}" is normalized by the formula:

$$W_{ij} = \frac{\max(V_{1j}, V_{2j}, \dots, V_{ni}) - V_{ij}}{\max\,(V_{1j}, V_{2j}, \dots, V_{ni}) - \min\,(V_{1j}, V_{2j}, \dots, V_{nj})} \quad (3)$$

where "W_{imax}" and "W_{imin}" are the indicators' highest and lowest values. "W_{ij}" is the standardized index of the " i" evaluation object and "j" evaluation indicator.

In the second step, each indicator was determined to construct a standardized evaluation matrix of land ecology sample data in the three northeastern provinces. The entire amount of the evaluation objective and evaluation indicators is supposed to be the initial evaluation measurement of the land's ecological inspection objective. entropy weights "E_j" and "ω_j" weight values of the first "j" indicator. If the quantity of detail volatility was lower, then a greater amount of data was transmitted and the significance coefficient was larger. The indicator's weight value additionally demonstrated how much data it was carrying. The formula is as follows:

$$E_j = -K \sum_{i=1}^{m} G_{xy} \ln G_{xy} \quad (4)$$

where "G_{xy}" is the share of indicator "x" in year "y", $G_{xy} = \frac{W_{ij}}{\sum_{i=1}^{x} W_{ij}}, K = \frac{1}{\ln m}$.

$$\omega_j = \frac{(1 - E_j)}{\sum_{j=1}^{n}(1 - E_j)} \quad (5)$$

In the third step, the normalization criteria matrix was constructed. Based on the entropy weights constructed in the second step, the normalized data in the first step were weighted, and the following weighted normalization matrix was constructed. The specific formula is as follows:

$$R = \begin{bmatrix} r_{11}\omega_1 & r_{12}\omega_2 & \cdots & r_{1y}\omega_y \\ r_{21}\omega_1 & r_{22}\omega_2 & \cdots & r_{2y}\omega_y \\ \vdots & \vdots & \vdots & \vdots \\ r_{x1}\omega_1 & r_{x2}\omega_2 & \cdots & r_{xy}\omega_y \end{bmatrix} \quad (6)$$

The fourth step was to determine the positive and negative ideal solutions. The positive ideal solution is an envisioned optimal program, and the positive ideal solution in each index value can reach the best value in each alternative; the negative ideal solution is an envisioned worst program, and the negative ideal solution in each index value can reach the worst value in each alternative. Based on the weighted normalization matrix constructed in the third step, the following positive and negative ideal solutions were defined. The positive and negative ideal solution formulas are as follows:

$$r_j^+ = [max r_{xy} | x = 1,2, \dots, m] = [r_1^+, r_2^+ \dots, r_m^+] \quad (7)$$

$$r_j^- = [min r_{xy} | x = 1,2, \dots, m] = [r_1^-, r_2^- \dots, r_m^-] \quad (8)$$

In the fifth step, the Euclidean distance was calculated. Based on the weighted normalization matrix constructed in the third step and the positive ideal solution and negative ideal solution determined in the fourth step, the distance between the evaluation object and the positive ideal solution and the distance between the evaluation object and the negative ideal solution were given to determine the Euclidean distance and the comprehensive score of the evaluation of the land's ecological development of the three eastern provinces region to the positive and negative ideal solution. The specific formula is as follows:

$$D^+ = \sqrt{\sum_{y=1}^{m} (r_{xy} - r_y^+)^2} \; (x = 1,2, \dots, n) \quad (9)$$

$$D^- = \sqrt{\sum_{y=1}^{m} \left(r_{xy} - r_y^-\right)^2} \ (x = 1, 2, \ldots, n) \quad (10)$$

The sixth step was to determine the approximation value of the ideal solution. Setting "C" as the approximation value, this demonstrates how near the ideal option is to the land's supply of assessment object "i" natural carrying capacity. and the worth range is $[0, 1]$. When $C = 1$, it indicates that the land's components have the highest ecological carrying capability; when $C = 0$, it denotes that the land's resources have the lowest sustainable capacity for carrying goods. The precise equation is as listed follows:

$$C = \frac{D^-}{D^+ + D^-} \quad (11)$$

4.2. Evaluation Level Division

Ecological land safety assessment is still in the exploratory stage in China and there is no unified evaluation standard; it must be adjusted to local realities in addition to being complex. With regard to the relevant researchers' related study findings as well as the specific circumstances of the land's environmental safety evaluation in the three provinces in the northeast, the land's environmental security state was classified using the non-equality interval approach of the three northeastern provinces into five assessment categories based on proximity C (Table 2): C ≤ 0.2, uncertain; 0.2 < C ≤ 0.4, relatively uncertain; 0.4 < C ≤ 0.6 extremely safe; 0.6 < C ≤ 0.8, fairly secure; and C ≥ 0.8, safe [16].

Table 2. Standards for evaluating the land resources' ecological safety for the three eastern provinces region.

Closeness	**[0–0.2)**	**[0.2–0.4)**	**[0.4–0.6)**	**[0.6–0.8)**	**[0.8–1)**
Ecological security of land resources	unsafe	less secure	critical safety	relatively safe	secure

5. Data Analysis

5.1. An Assessment of Soil Ecologically Security's Temporal Dimension in the Three Provinces in the Northeast

Using the PSR evaluation model and the entropy-weighted TOPSIS evaluation method, from 2012 to 2021, we computed an environmental land stability ranking for each of the three provinces in the northeast (Table 3). From 2012 to 2021 (Figure 4), there was a trend toward a moderate increase in environmental land stability, and the overall level of environmental land safety was also rising. The degree of proximity demonstrated a decline from 0.569 to 0.322 from 2012 to 2015, but a steady ascent from 0.317 to 0.439 between 2016 and 2021. The land's ecological safety status shifted from safe to uncertain, then subsequently from uncertain to safe. After 2016, the three provinces in the northeast saw an improvement in the overall ecological safety state of their land, which eventually reached a comparatively safe level. Since 2016, the three northeastern provinces' environmental security situation has improved, gradually moving to a relatively safe level. This indicates that, after a period of irrational land use in the three eastern provinces, the importance of ecological protection has been increasingly recognized since 2016, and the protection of land ecological resources has received special attention. However, regional ecological security in the three eastern provinces was still low and there were still gaps in relation to security status.

(1) The period 2012–2015 indicated an upward trajectory. An indicator is the overall area of soil erosion in sub-watersheds. P3 was larger in 2012 and decreased in 2013, but increased from 3202.1 thousand hectares to 3624.1 thousand hectares between 2013 and 2015. Pesticide application (P4) increased from 190,803 tons to 205,109.12 tons.

Pesticide and fertilizer application (P5) increased from 5,939,100 tons to 6,386,400 tons. Residential land area (I1) increased from 5218.8 square kilometers to 5524.5 square kilometers. Crop damage due to natural disasters (I3) increased from 3414.7 thousand hectares to 3504.3 thousand hectares. The area devoted to soil erosion control (R1) decreased from 15,349.2 thousand hectares to 10,485.5 thousand hectares. Overall, negative indicators had a greater impact than positive ones, resulting in a downward trend in the indicators. First, insufficient attention has been paid to environmental management, while the usage of both pesticides and fertilizers with chemicals keeps rising. The ecological environment is the main disincentive at this stage due to incomplete diffusion of the new concept of green agriculture. [20] Second, the three eastern provinces region are large agricultural provinces with economies that are heavily dependent on agriculture and thus face problems of overexploitation and heavy cultivation of arable land. As the size of marshes, meadows, and woods have shrunk, the area of soil erosion has increased over the years, land reserves have decreased, and ecosystem functions have weakened.

(2) The 2015–2018 period saw a slight increase. In terms of negative indicators, the population density of local residents (P1) and there was an annual drop in the rate of population growth (P2) due to natural factors. In terms of positive indicators, the area covered by urban green spaces (S3) increased from 338,355.51 ha to 354,674.46 ha. The area of green space per capita (S4) rose from 12.01 square meters to 12.63 square meters. The area of sown land (S5) rose from 221.93 million hectares to 249,613 million hectares. The area devoted to combating soil erosion (R1) rose from 10,485.5 thousand hectares to 12,675.7 thousand hectares. Domestic garbage (M2) was treated at a rate of 91.23%, up from 86.03%. Positive factors slightly offset negative ones, resulting in a slight increase in the index. The reasons for this are as follows. Firstly, the influence of politics, increased awareness of the need to have fewer children, the rising cost of educating children, and declining population density and natural growth rate have reduced the barriers to pressure. Secondly, economic development of the northeastern region has raised awareness of environmental protection, and the government has made great efforts to manage land, increase the area of flooded land, and improve the rate of soil erosion control. Thirdly, the area has started to prioritize land-use efficiency and utilize scarce building space extensively. In the northeast, the utilization of urban building land has become more intensive, efficient, and comprehensive due to the strengthening of city planning intensity and productivity.

(3) It is basically flat in 2018–2021. In terms of positive contributing factors, per capita food production (S2) rose from 1276.0133 kg/capita to 1596.6467 kg/capita. Positive factors such as urban green space coverage area (S3), per capita park green space area (S4), and soil erosion control area (R1) promoted an increase in the land's ecology index. In terms of negative factors, in small watersheds, the area affected by soil erosion (P3) increased from 3879.8 billion acres to 3953.6 thousand hectares. The domain of land purchased by real estate development enterprises (P6) and (S1) the area of land to be developed by real estate increased from 2020 to 2021. Both favorable and unfavorable influencing elements balanced one another. The reasons for their formation are as follows. First, the level of ecological health within land resources has increased, and the ecological safety index has risen. Second, the influence of the natural world and human activity on land ecology has diminished, while the degree of biological management and repair has increased.

Table 3. Land environmental safety in the three eastern provinces in relation to one another, 2012-2021.

Annum	D+	D−	Value of Total Relative Closeness	Ordering
2012	0.146	0.192	0.569	1
2013	0.159	0.154	0.491	2
2014	0.163	0.129	0.442	3
2015	0.191	0.091	0.322	9
2016	0.197	0.091	0.317	10
2017	0.199	0.106	0.349	8
2018	0.181	0.118	0.393	7
2019	0.186	0.123	0.398	6
2020	0.188	0.141	0.428	5
2021	0.188	0.147	0.439	4

Figure 4. The three eastern provinces' land sustainability on a radar map, 2012–2021.

5.2. Assessment of the Ecological Stability of Land Assets in Terms of PSIMR

The state and management dimensions of the three northeastern provinces region are gradually rising, the pressure and impact dimensions are gradually rising, and the response dimension is beginning to gradually rise after a period of decline. The pressure dimension as a whole shows a decreasing fold-change trend, with slight up and down fluctuations in the middle (Figure 5) (Table 4). The main reasons for this are as follows. First, in the past decade, the three eastern provinces have experienced extraordinarily fast growth in both society and the economy, and the education level of the people has been rising. As a result of the policy of fewer marriages and childbearing, the density of the local resident population and the natural population growth rate have been decreasing in recent years, which reduces the ecological pressure on the land. Secondly, as the government has paid more attention to natural disasters and disasters caused by human activities in recent years, excessive application of pesticides and chemical fertilizers, soil erosion control, and treatment of pollutants have been given more and more attention. The amount of money spent on safeguarding and managing the environment has been rising, while the overall volume of pollutants released has been successfully reduced, resulting in the land's ecological security condition being greatly improved. Thirdly, there has been discussion about how cheap land is used, intensifying the use of construction land, and distributing land resources within the city in a more reasonable manner. The social standing dimension has a rising, flat, and then rising tendency. In 2012–2013, the state index rises from 0.154 to 0.227, varying between 0.2, has no discernible trend between 2013 and 2016, and it rises from 2016 to 2021, from 0.191 to 0.933. The importance that localities have attached to building urban infrastructure and improving land use space can be inferred from the steady improvement of positive factors like per capita food production, greenery in cities coverage, per capita park green space, and land area sown with crops [21,22]. The social advantages of land usage are increased when city property is used wisely, which supports the healthy growth of cities and increases their capacity to spend in infrastructure and other areas.

Overall, the impact dimension exhibits a general tendency to plateau, drop, and then stay mostly steady. This is primarily due to the notable decrease in the arable land occupancy tax [23]. A unique levy, known as the arable land employment fee, was put in place to safeguard agricultural land as well as promote the wise use of land resources. Reducing the arable occupancy tax could encourage irrational land-related growth and use, which would weaken the environment's safety net of these natural assets [24,25]. The overall response dimension shows an initial downward trend, followed by stagnation. Fluctuations in the two indicators of soil erosion control area and total afforestation area led to a significant drop in the response indicator in 2012–2014. However, in subsequent years (2014–2021), with focus on terrestrial ecological resources, government investment in terrestrial resource management has been strengthened and the terrestrial ecological security system is gradually recovering. The management dimension shows a general upward trend. This is mostly because the three northeastern provinces, which have experienced significant growth in both society and the economy, as well as an upgrade and transformation of the industrial structure, have expanded their investments in environmental control and protection. Annual increases have been observed in the rates of harmless domestic waste treatment and centralized wastewater treatment. Additionally, in 2021, the share of tertiary businesses in the GDP increased from 36.33% in 2012 to 51.29%. Investment in solving terrestrial ecological problems in the three eastern provinces has increased, and the local ecosystem safety index has been improved accordingly.

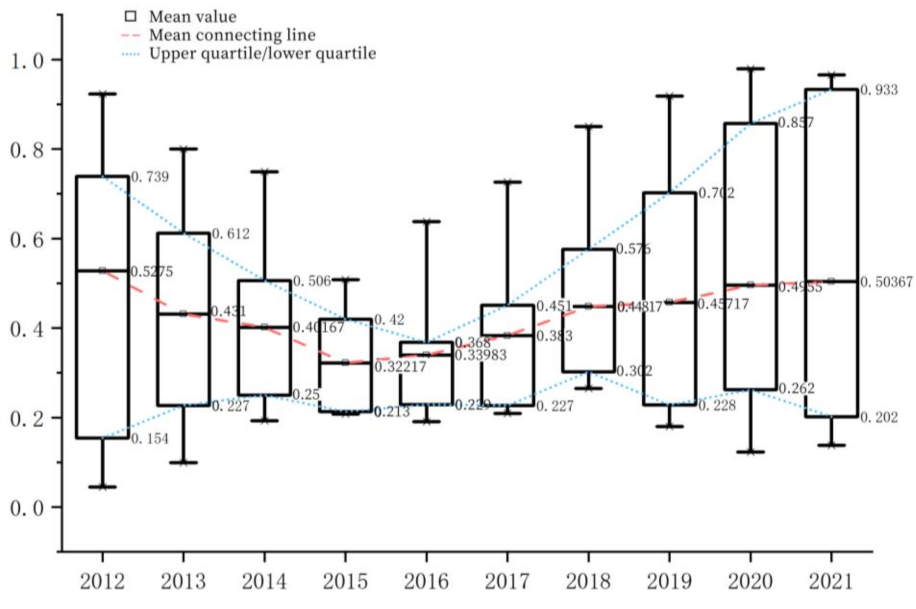

Figure 5. Box plot of land ecological security closeness in the three eastern provinces, 2012–2021.

Table 4. In the three eastern provinces, the land environmental sensitivity index changed, 2012–2021.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Pressure	0.739	0.612	0.506	0.42	0.368	0.336	0.302	0.18	0.123	0.138
Stress	0.154	0.227	0.193	0.208	0.191	0.451	0.576	0.702	0.857	0.933
Impact	0.735	0.8	0.749	0.213	0.296	0.209	0.265	0.228	0.262	0.202
Response	0.923	0.357	0.25	0.262	0.229	0.227	0.303	0.317	0.324	0.344
Management	0.045	0.099	0.27	0.508	0.638	0.726	0.85	0.918	0.979	0.966
Comprehensive	0.569	0.491	0.442	0.322	0.317	0.349	0.393	0.398	0.428	0.439

5.3. Evaluation of Spatial Dimensions of Land Ecology in Each Province of the Three Northeastern Provinces Region

A graphic representation of the location of ecological land security levels in the three northeastern states from 2012 to 2022 was created by digital vectorization using ArcGIS 10.8 software (Figures 6 and 7). The three provinces located in the northeast are included in the map, which shows the study region. The ecological land security level is shown by the color shade. The figure shows that the ecological land security level of Heilongjiang and Jilin Provinces is higher than that of Liaoning, which has the lowest relative ecological land security level. The legend defines the criteria for dividing the relative proximity value of ecological land security in each province and divides the quality of ecological land security in each province into five levels. From 2012 to 2021, in the three provinces, there was a decline in the standard of natural resource security, which then gradually rose and improved.

Heilongjiang's natural land security regional index indicated a generally declining trend, and there was a sporadic rising tendency (Figure 6). Between 2012 and 2014, the ecological land safety index decreased from 0.511 to 0.344. From 2014 to 2020, the index increased from 0.344 to 0.543. It gradually increased and retreated to 0.481 in 2021. The quality of ecological security is gradually improving but remains relatively unstable. Heilongjiang's economy is increasingly dependent on agriculture, putting increasing pressure on land. Economic development destroys arable land and damages forests, grasslands, and other resources to varying degrees, impacting land resource sustainability in the area. In the meantime, excessive cultivation and irrational land use will cause serious soil erosion problems and soil desertification will become increasingly severe, endangering the sustainability safety of the land's assets found in the area.

Overall, Jilin Province's ecological land insecurity score indicated first a declining trend, which subsequently varied and rose; the biological land safety index dropped from 0.517 to 0.344 between 2012 and 2014, and from 2014 to 2021, the index fluctuated from 0.344 to 0.519. The overall level of land resource security has shown a gradual upward trend, but has not yet reached the level of security. In Jilin Province, industrial inputs and outputs occupy a large place, and there is an imbalance in the total amount of land used for urban construction, resulting in an increasingly serious waste of land resources and irrational development and use. In some areas, emissions of major pollutants far exceed environmental tolerances and cleanup capacities, soil quality is poor, and soil erosion is severe. The amount of land used for construction remains high and land quality needs to be improved [26]. Due to the irrational distribution of the agro-industrial structure and the serious phenomenon of land occupation for urban construction, the disparity between appetite and the availability of land is becoming more and more clear.

The general trend of the index of the regional ecological land quality system in Liaoning Province was first downward and then upward; it decreased from 0.635 to 0.236 between 2012 and 2016 and increased from 0.236 to 0.362 between 2016 and 2021. Liaoning's land use problems are manifested in poor land quality and land degradation. Liaoning Province has a large area of sloped cultivated land, which is prone to soil erosion and other disasters during the rainy season, and it has the land degradation problem of declining soil quality. Furthermore, there is the issue of uneven distribution of agricultural land and illogical utilization of land.

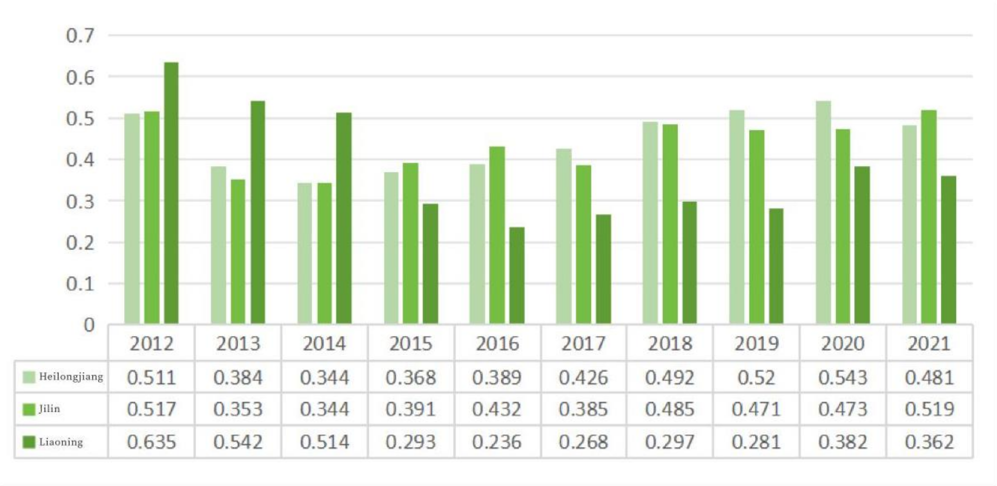

Figure 6. Changes in the index of land ecological security proximity by province, 2012–2021.

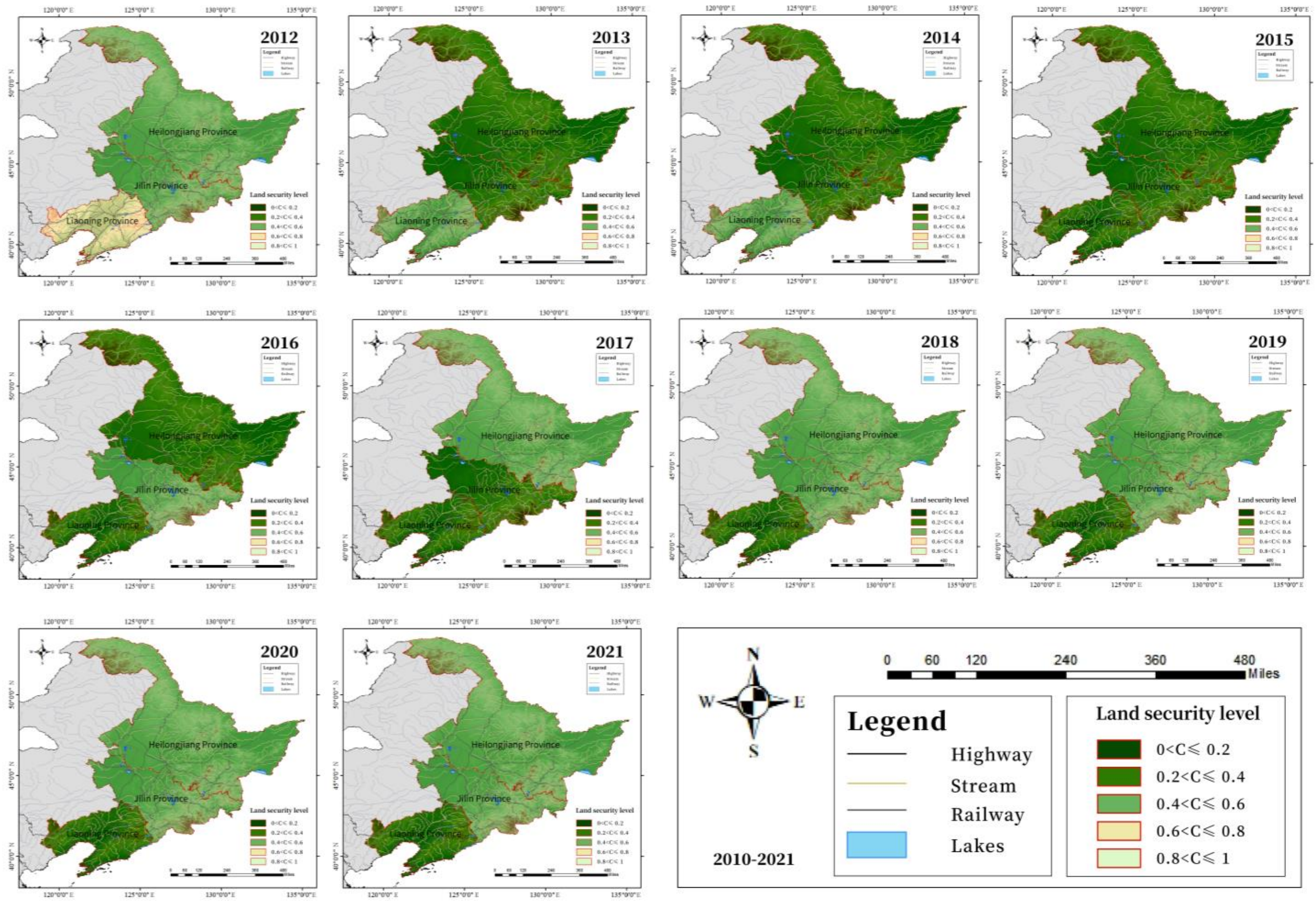

Figure 7. Distribution of evaluation ratings by province, 2012–2021.

6. Indicator Correlation Analysis

Ranking of Factors Affecting Land Ecological Security

When indicator layers were constructed (Table 5), the gray correlations among the 21 indicators ranged from 0.723 to 0.96, with small correlation gaps among the indicators. The highest gray correlation was found in the erosion zone of the P3 sub-catchment, while the lowest was found in the natural population growth rate (P2). This indicated that natural factors were more closely related to land resources in 2012–2021. The small differences between the individual extreme values indicated that there was some degree of correlation among the indicators affecting the three northeast provinces and that the choice of indicators was reasonable.

Table 5. Determinants related to ecological stability in all three northeastern provinces: gray correlations.

Criteria Level	Relevance	Ranking	Indicator Level	Relevance	Ranking
P: Pressures	0.646	2	P1	0.904	5
			P2	0.723	21
			P3	0.96	1
			P4	0.906	4
			P5	0.88	10
			P6	0.884	9
S: Stresses	0.55	5	S1	0.915	3
			S2	0.84	16
			S3	0.857	14
			S4	0.859	13
			S5	0.862	12
I: Impact	0.634	3	I1	0.854	15
			I2	0.864	11
			I3	0.808	19
R: Response	0.786	1	R1	0.935	2
			R2	0.901	6
			R3	0.886	8
			R4	0.891	7
M: Management	0.563	4	M1	0.833	17
			M2	0.78	20
			M3	0.808	18

Each indicator's five most significant gray correlations were P3 (0.96) > R1 (0.935) > S1 (0.915) > P4 (0.906) > P1 (0.904). For every indicator, the top five gray relationship amounts were, in descending order, P2 (0.723) < M2 (0.78) < I3 (0.808) < M2 (0.808) < P2 (0.833). For every single indicator, the top five gray correlation values, listed in order of decreasing magnitude, were P3 (0.96) > R1 (0.935) > S1 (0.915) > P4 (0.906) > P1 (0.904). The top five gray correlation values for each indicator were, arranged in descending order, P2 (0.723) < M2 (0.78) < I3 (0.808) < M2 (0.808) < P2 (0.833) (Figures 8 and 9). It could be concluded that the erosion zone in the small catchment (P3) had the greatest impact on the availability of land resources. This is because soil erosion has many causes. Extreme weather events, human activities, and continued deforestation, unscientific land use, or land management can lead to soil erosion and biodiversity loss. Soil erosion and ecosystem restoration are relatively difficult and require a lot of human and material resources. The pressure on land resources can be alleviated through rational land use and afforestation. The economic benefits generated in the process of urban land use can also be invested in the transformation of production technology to reduce the non-desired output and have a positive effect on the ecological benefits of land. Strengthening investment in land ecological resource management, the improvement of land ecological environment also provides more favorable conditions for urban economic development and sustainable social development. Reasonable utilization and governance can effectively reduce the area of land loss, improve the land security level, and facilitate the recovery of biodiversity [27,28]. The rate of natural population expansion (P2) has the least bearing on the sustainability of land-based ecological resources. In fact, the natural population growth rate in the three northeastern provinces has been declining as socioeconomic development and livelihood pressures increase. The gradual decline in population will reduce the impact on the security of terrestrial ecological resources. The gray correlations between R1, S1, P4, and P1 were 0.904–0.35, indicating a high level. This indicated that the indicators R1 (erosion area), S1 (land to be developed by real estate companies), P4 (pesticide application), and P1 (resident population density) have major effects on the three northeastern provinces' ability to protect their land biological resources. From these aspects, by reducing the amount of urban land to be developed and pesticide application and by taking active measures to combat soil erosion, the land security level of the three northeastern provinces can be effectively upgraded, and the ecological security of land resources can be mitigated.

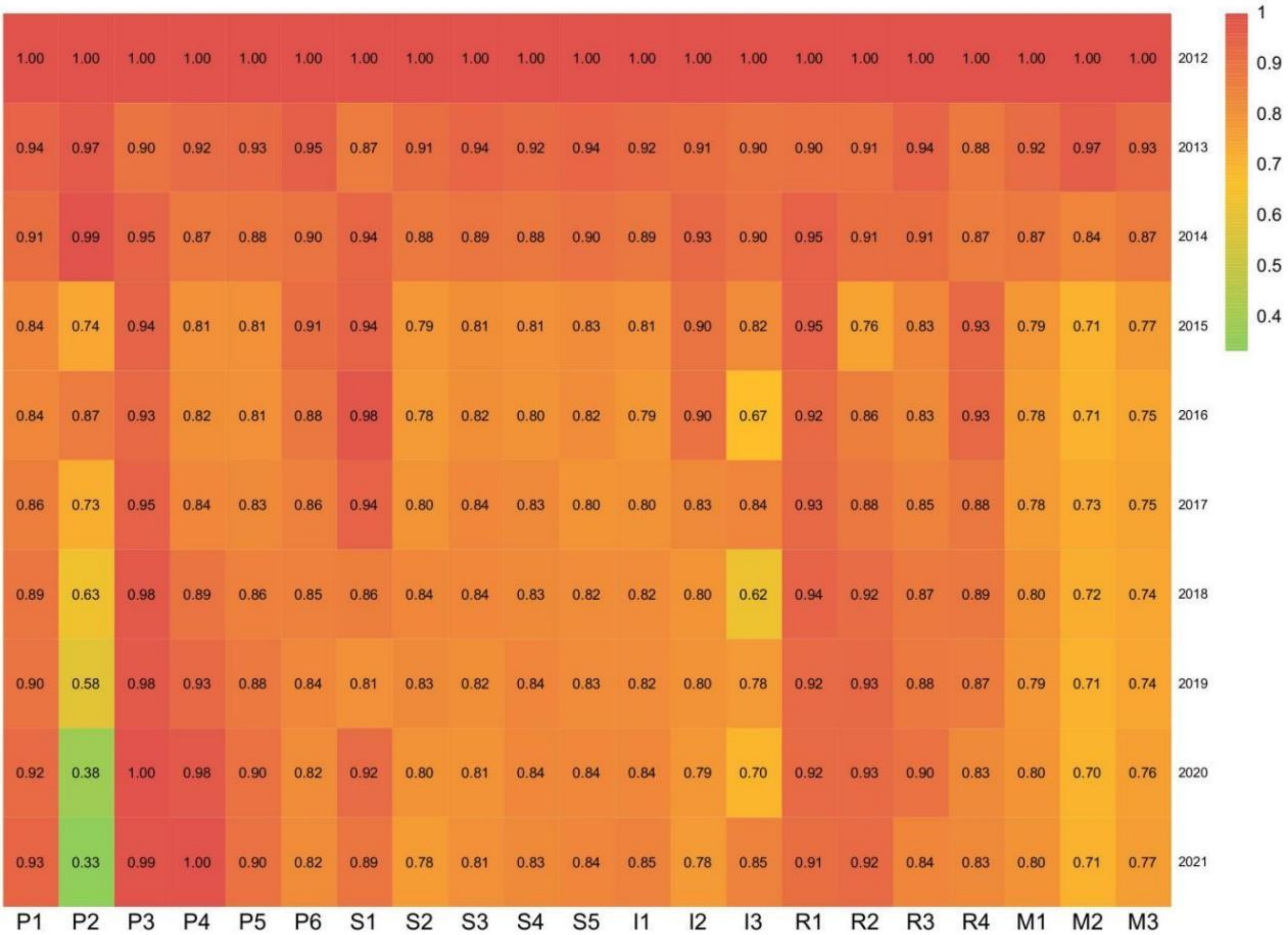

Figure 8. Gray correlation thermal correlation between the three northeastern provinces and the indicators affecting land security (indicator layer).

Figure 9. Thermal correlation of gray correlation between the three northeastern provinces and the indicators affecting land security (guideline layer).

In the reference strata, composite correlated 1.0 with homeland safety, reaction correlated 0.786 with homeland safety, pressure correlated 0.646 with homeland safety, impact correlated 0.634 with homeland safety, management correlated 0.563 with homeland safety, and status correlated 0.55 with homeland safety [28]. In addition to the composite factor, one of the factors with the highest correlations was reaction. The factor with the smallest correlation with homeland safety was status. The correlations for the subsystems were in the order of R > P > I > M > S. The highest gray correlations were for response indicators, ranging from 0.34 to 0.88. This indicated that government implementation programs on land issues have the highest impact on the quality of land resource security. Regions in the three northeastern provinces should formulate relevant land resource protection policies to adjust for the negative socioeconomic and natural environmental pressures on land resources, establish a sustainable land resource environment, formulate land ecology safeguard policies in accordance with the current status of local land ecology, strengthen environmental protection efforts, further optimize the industrial structure while improving economic development and residents' income, enhance energy conservation and emission reduction, reduce pollutant generation and emission, raise awareness of environmental protection, and reduce waste discharge [29,30]. Establish early warning and protection mechanisms against natural disasters, strengthen protection measures against soil erosion and other natural disaster, encourage the continuous and profitable use of land, increase the resilience of land ecosystems to natural calamities, and better achieve improved ecological land security in the three northeastern provinces.

7. Discussion

To ascertain the ecological safety of agricultural land in each of the three provinces in the northeast, the scores of each indicator in this study were determined using the TOPSIS entropy weighting approach. The socioeconomic standing and natural ecological space of the area are immediately impacted by the findings of the environmental safety of land resource evaluation. The degree of land ecology in the three northeastern provinces is improving, but is still at an unsafe level, and land ecological pressures are high. In general, the ecological security system in the three northeastern provinces shows a chronological change of "first decreasing, then increasing." This suggests that the region's land use is not yet rationally adjusted to the social, economic, and environmental surroundings. The percentage of GDP attributable to tertiary industries in the three eastern provinces is one factor influencing the land's environmental assurance system, the area where crops are sown, the quantity of pesticides and chemical fertilizer used, the territory where urban greenery is present, the location of soil erosion, the area of land under yield, and other influencing factors. Therefore, depending on each province's pattern of economic development and the rate at which the natural setting has adjusted, the three northeastern provinces need to adopt appropriate policies and measures in a timely manner and implement macro controls to achieve economic integration and the natural environment's equitable growth [31].

The outcomes of this study provide more reliable information on land resource security in the three northeastern provinces. In the dimension of pressure, land loss and the area of pesticide use in sub-watersheds have the greatest impact. Excessive agricultural activities and excessive use of pesticides and fertilizers lead to diffuse pollution and soil erosion, reducing the level of ecological security in major agricultural production areas. In terms of current conditions and impacts, the greatest impact is on the land area developed and used for real estate and the area of land used for construction. The reason for this is the high urban population density and the large land area occupied by urban construction, which results in a lower level of land security. The corresponding management dimensions have a greater impact on the erosion control area, land flood removal area, and intensive sewage treatment rate. The impacts of the response and management dimensions are mainly socioeconomic and policy factors. Strong government support for infrastructure development and education can help to improve response and management. However, relatively poor economic conditions, weak agricultural infrastructure, and low input rates in science and education in the three northeastern provinces have resulted in low levels of response and management.

The PSIMR theory and entropy-weighted TOPSIS model can reveal the state of the land's security system in a straightforward manner at the macro level, but there will always be some subjectivity. The PSIMR framework for constructing the indicator system also requires reliance on the background and knowledge of experts, which may lead to uncertainty in the model. Some of the key data were difficult to obtain, making it difficult to use them as indicators for evaluation in this paper. The preciseness of the evaluation conclusions is impacted by this. Moving forward, it will be necessary to increase the number of micro-level field surveys and social interviews to obtain more accurate data and to compensate for the lack of subjectivity of indicators in the data sample.

8. Conclusions

Focusing on the PSIMR structure, the TOPSIS entropy weighting approach, and other factors, an ecosystem conservation assessment model was created for the three provinces in the northeast as well as the correlation method. The TOPSIS approach with entropy weighting, centered around the PSIMR framework, can effectively solve the problems of ambiguity and subjectivity of ecosystem conservation evaluation indicators in land decision making. It has the ability to resolve the issue and provide a framework for the application of criteria in the evaluation of ecosystem conservation. The ecological safety of the three northeastern provinces was comprehensively assessed from socioeconomic and environmental perspectives to identify potential barriers that have an effect on the environmental security of the land. This is of great significance in maintaining socioeconomic benefits, improving land ecosystem sustainability, and enhancing environmental safety.

From a chronological standpoint, the relative land sustainability in the three northeastern provinces has been in the range of 0.317–0.569 over the past decade, with an overall upward trend. Regional land ecological security in the three northeastern provinces has been strengthened and improved. The relative ecological safety of the land revealed a decreasing trend from 0.569 to 0.322 from 2012 to 2015 and a gradual increasing trend from 0.317 to 0.439 from 2016 to 2021. This indicates that the three northeastern provinces have increased their investment in land ecological environment management since 2015. Local governments have taken measures to improve infrastructure and increased investment in the cause of improving the land's environment.

From a spatial perspective, the level of security of the land's ecological environment in Heilongjiang and Jilin Provinces is relatively high, whereas there is little sustainability on the land of Liaoning Province. Prominent land ecological problems in the three provinces are mainly land occupation by construction sites, soil erosion, and deterioration of land as a result of excessive use of chemical fertilizers and pesticides.

In terms of the dimensions of the indicator, the highest correlation with land security was response. The indicator with the lowest correlation to land security was status. The correlations resulted in five correspondence indicators, four pressure indicators, and one status indicator in the top ten. The gray correlations of the corresponding indicators ranged from 0.88 to 0.96 or higher, all at high levels. This indicates that the indicators of soil erosion control area, total afforestation area, land flood removal area, planned real estate enterprise development area, pesticide and chemical fertilizer application amounts, and resident population density in the three northeastern provinces have major influences on the safety of natural assets. High pressures can be alleviated through rational control of population and industry or orderly and gradual relocation to neighboring low-pressure areas, and the level of response in neighboring areas can be improved as the economy develops. Land conditions can be improved through measures such as land leveling and rezoning, minimizing the application of chemical pesticides and fertilizers and managing surface contamination from agriculture, increasing investment in land ecosystem management to lessen the area where soil erosion occurs and preserve water and soil, strictly regulating excessive land development, reducing real estate development, and logically distributing the use of resources. The results of this study provide reliable information on the land's resource ecological safety in the three northeastern provinces and give suggestions about the influencing factors affecting land resource ecological stability, which will be essential for efficient organizing and handling of land assets in the future.

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