Study on dynamic change of cultivated land ecological security in main grain-producing areas of Liaoning Province

A case study of Tieling City

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Abstract. In order to correctly evaluate the ecological security of cultivated land in the main grain producing areas of Liaoning Province in recent years, this paper takes Tieling City as an example and uses the PSR evaluation model to dynamically study the ecological security of cultivated land in the whole city. Based on the actual situation, 12 indicator factors were scientifically selected to construct an evaluation indicator system, and the weights of each indicator were determined using the combination weighting method. The weighted TOPSIS model was used to calculate and scientifically analyze the ecological security dynamics of cultivated land in Tieling City from 2014 to 2021. From 2014 to 2021, the ecological security of cultivated land in Tieling City showed significant fluctuations but an overall positive development trend. The dynamic changes in cultivated land ecological security in Tieling City are closely related to the overall economic development of the city. The cultivated land ecological security level of the pressure and response subsystem still needs to be improved.

Keywords: cultivated land; ecological security; PSR model; TOPSIS model; Tieling City.

1 Introduction

Cultivated land resources are the essence of land resources and important resources related to the national economy and the people's livelihood[1]. The ecological security of cultivated land is the cornerstone of maintaining national food security, social stability, and sustainable and coordinated social development[2]. Conducting ecological security assessment on farmland is of great significance for improving farmland production capacity and ensuring food security[3,4].

In the field of ecological security of cultivated land, foreign scholars have conducted research earlier and have rich experience. Rasul et al.[5] established a professional

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evaluation system based on ecological environment and economic conditions, and applied this system to the evaluation of cultivated land in Bangladesh. David L Tulloch et al.[6] selected multiple indicators to evaluate the safety value of land in Hunterton County, New Jersey, and proposed corresponding farmland protection policies. Most of the research in this field in China has focused on defining the connotation of farmland ecological security[7,8], selecting indices and evaluation systems in farmland ecological security evaluation[9,10], and deeply analyzing the influencing factors of farmland ecological security in specific regions[11-13].

Based on the actual situation of the research area and the availability of data, this article selects the farmland data of an important grain producing area - Tieling City as the research object, and evaluates and analyzes the dynamic changes in the ecological security of farmland resources in Tieling City from 2014 to 2021.

2 Study Area and Date

2.1 Introduction to the Study Area

Tieling City is located in the northern part of Liaoning Province, in the central part of the Songliao Plain. The terrain is generally high, medium, and low in the east, high in the north, and low in the south, belonging to a temperate continental monsoon climate. The geographical coordinates of Tieling are 123°27'~125°06' east longitude and 41°59'~43°29' north latitude, with a total area of 12985km2. By the end of 2021, the total registered residence population is 2.827 million. In 2021, the grain sowing area in Tieling City was 489.7 thousand hectares, with the top three crop planting areas being 438.5 thousand hectares for corn, 38.5 thousand hectares for rice, and 6.8 thousand hectares for soybeans. In 2021, the total grain production in Tieling City was 4.16 million tons, including 3.784 million tons of corn, 330000 tons of rice, and 18000 tons of soybeans.

2.2 Data Acquisition

This study used statistical data from the Liaoning Statistical Yearbook from 2015 to 2022 and the Tieling Statistical Yearbook from 2021. The indicators such as population density, per capita arable land area, land productivity, and the proportion of primary industry are calculated based on the statistical data in the yearbook, while other indicators can be directly obtained from the statistical yearbook.

3 Research Method

3.1 PSR Model

Based on the PSR model, this study selected 12 indicators from three aspects: pressure, state, and response to form the farmland ecological security evaluation index system (Table 1). The pressure layer considers the impact of human activities on the ecology of cultivated land, and the main indicators selected include land productivity, per capita cultivated land area, population density, and urbanization rate. The state layer is an important factor affecting the ecological security of cultivated land, and four indicators were selected: grain yield per unit area, grain sowing area, number of electromechanical wells, and fertilizer application amount. The response layer selected four socio-economic indicators that have a significant impact, including total agricultural output value, per capita rural income, proportion of primary industry, and per capita GDP.

3.2 Weight Assignment

Due to the differences in the magnitude of data for various evaluation indicators and the different positive and negative orientations between indicators, the Analytic Hierarchy Process (AHP), which can draw on expert experience, and the Entropy Method (EM), which can be used for quantitative mathematical calculations, are fully utilized to determine the weight values of each indicator. After comprehensive combination weighting, the final weight of the ecological security evaluation indicators for cultivated land is obtained[14] (Table 1).

Table 1. weight assignment of cultivated land ecological security evaluation system based on PSR model

target layer	*criterion layer*	*indicator layer*	*AHP weight*	*EM weight*	*combination weight*
Ecological security of cultivated land in Tieling City	pressure	land productivity	13.49%	8.94%	16.71%
		per capita cultivated land area	7.37%	10.00%	10.21%
		population density	2.36%	8.18%	2.68%
		urbanization rate	1.16%	5.95%	0.95%
	state	grain yield per unit area	38.46%	4.44%	23.63%
		grain sowing area	18.15%	10.73%	26.99%
		number of electromechanical wells	8.40%	5.54%	6.45%
		fertilizer application amount	3.92%	9.39%	5.10%
	response	total agricultural output value	3.45%	6.74%	3.23%
		per capita rural income	2.26%	8.44%	2.64%
		proportion of primary industry	0.66%	9.77%	0.89%
		per capita GDP	0.32%	11.85%	0.53%

3.3 Weighted TOPSIS Evaluation Model

The weighted TOPSIS model can fully consider the relative importance of each indicator by constructing a weighted decision matrix before determining positive and negative ideal values. Calculate the closeness to the ideal solution using the weighted TOPSIS method. The calculation steps of weighted TOPSIS method are as follows[15]:

(1) Index standardization.

Standardization matrix $D=(d_{ij})_{m\times n}$.

(2) Construction of weighted decision criterion matrix.

Combining weight W_i with decision D, the matrix $B=(B_{ij})_{m\times n}$ is obtained. That is, $b_{ij}=w_i\times d_{ij}$, i=1, 2, …, m; j=1, 2, …, n.

(3) Determine positive and negative ideal solutions. Suppose Q^+ is a positive ideal solution and Q^- is a negative ideal solution.

$Q^+=\{\max b_{ij} \mid i=1, 2, \ldots m\}=\{b_1^+, b_2^+, \ldots, b_m^+\}$

$Q^-=\{\max b_{ij} \mid i=1, 2, \ldots m\}=\{b_1^-, b_2^-, \ldots, b_m^-\}$

(4) Distance to positive ideal solution and negative ideal solution D^+, D^-.

$$D^+=\sqrt{\sum_{i=1}^{m}(b_{ij}-b_i^+)^2} \quad (i=1, 2, \ldots, m)$$

$$D^-=\sqrt{\sum_{i=1}^{m}(b_{ij}-b_i^-)^2} \quad (i=1, 2, \ldots, m)$$

(5) The closeness between calculation and ideal solution.

$$C_j=D^-/(D^++D^-) \quad (1\leq j\leq n)$$

Where C_j is the degree of closeness, $C_j\in[0, 1]$. when C_j tends to 0, it means that the lower the level of ecological security of cultivated land, and when it tends to 1, the result is opposite.

At present, there is no unified standard for the classification of ecological security levels. Referring to relevant research and combining with the actual situation of the region, this article divides the ecological security of cultivated land into five levels with a step size of 0.2 based on the evaluation results (Table 2).

Table 2. classification criteria for cultivated land ecological security assessment

safety level	I	II	III	IV	V
security status	safer	safe	borderline safe	less safe	unsafe
safety value	0.8～1.0	0.6～0.8	0.4～0.6	0.2～0.4	0～0.2

4 Results and Analysis

Add the final weight obtained through combination weighting method to the TOPSIS model, calculate the ecological security evaluation results of farmland in Tieling City from 2014 to 2021, and divide the corresponding ecological security levels according to the evaluation criteria in Table 2 (Table 3).

Table 3. Evaluation results of cultivated land ecological security in Tieling City from 2014 to 2021

year	*pressure*	*state*	*response*	*comprehensive*	*safety level*
2014	0.47607149	0.32984329	0.40091454	0.38834063	IV
2015	0.71103897	0.62499996	0.57963808	0.64616924	II
2016	0.47238258	0.63328418	0.38028054	0.56636172	III
2017	0.18291735	0.49274496	0.17549559	0.39968303	IV
2018	0.23520019	0.41890308	0.24565048	0.36175194	IV
2019	0.55966172	0.3448891	0.50269015	0.42654602	III
2020	0.61238748	0.70935061	0.60812982	0.67316347	II
2021	0.5169805	0.76998354	0.59023319	0.66675425	II

The dynamic change trend chart of cultivated land ecological security in Tieling City from 2014 to 2021 (Figure 1) was made by using the evaluation result data to explore the dynamic change of cultivated land ecological security over time.

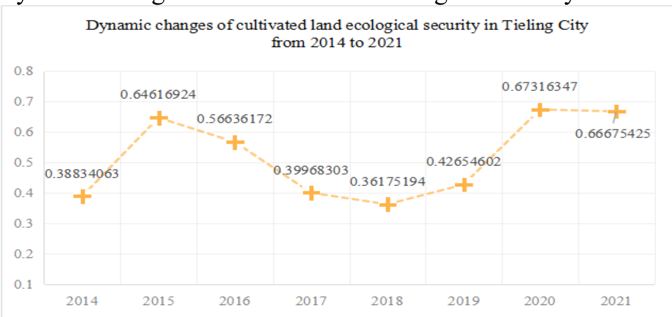

Fig. 1. Dynamic changes of cultivated land ecological security in Tieling City from 2014 to 2021

It can be seen from table 3 and figure 1 that the ecological security of cultivated land in Tieling City from 2014 to 2021 showed obvious fluctuations, but the overall development trend was good. The evaluation score of cultivated land ecological security gradually decreased from 0.646 to 0.362, and then rapidly increased to 0.673. The corresponding ecological security level changes from level II in 2015 to level IV in 2017 and 2018, and then to level II in 2020 and 2021. This means that the overall situation of cultivated land ecological security in Tieling City is optimistic.

Table 4. Total agricultural output value and GDP of Tieling City from 2014 to 2021 (unit: 100 million yuan)

	2014	2015	2016	2017	2018	2019	2020	2021
agricultural output	164.05	180.47	163.89	140.6	144.4	161.8	161.9	154.9
gross output value	867.29	740.9	589.2	594.5	616.6	640	663.1	716

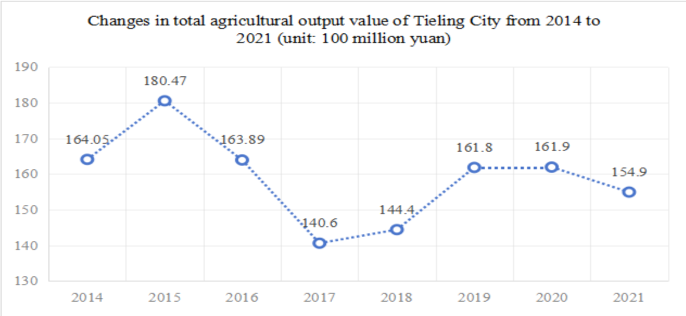

Fig. 2. Changes in total agricultural output value of Tieling City from 2014 to 2021

During the two years of 2017 and 2018, the score of cultivated land ecological security assessment was low, and the level of cultivated land ecological security was reduced to relatively unsafe level IV. It can be seen from table 4 and Figure 2 that this situation is closely related to the economic development of the whole Tieling City. The overall GDP and total agricultural output value of Tieling City in 2017 and 2018 were at the low point in these eight years. The instability of the economic situation has a direct impact on the ecological security of cultivated land. With the improvement of economic situation in Tieling City after 2020, the ecological security level of cultivated land has rapidly returned to a relatively safe state.

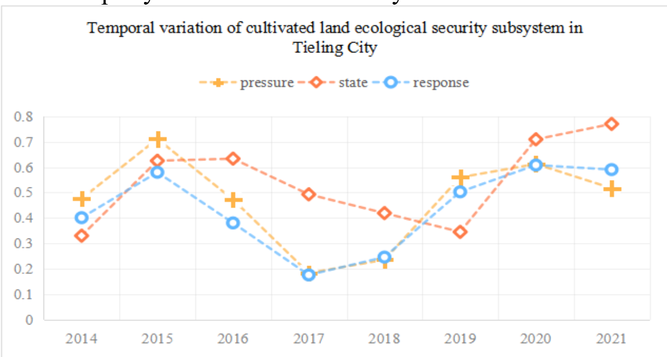

Fig. 3. Temporal variation of cultivated land ecological security subsystem in Tieling City

It can be seen from table 4 and the time sequence change diagram of cultivated land ecological security subsystem in Tieling City (Figure 3) that the calculated values of proximity of pressure, state and response subsystems are similar. The average closeness of the state subsystem is 0.54, which is the highest among the three subsystems. However, the ecological security closeness of the pressure and response subsystems has not reached 0.5, which still needs to be improved.

In order to ensure the ecological security of cultivated land and hold the red line of cultivated land, Tieling City has carried out three special clean-up and rectification actions on greenhouse housing problems since 2019 to ensure that agricultural land is used in agriculture and in compliance with laws and regulations. At the same time, the government has carried out the construction of food production functional areas and important agricultural product production protection areas, and completed the task of delimiting "two areas" of 6.726 million mu. Among them, 6.28 million mu of grain production functional area (890000 mu of rice and 5.39 million mu of corn) and 446000 mu of important agricultural product production protection area will be built. These measures effectively ensured the ecological security of cultivated land in Tieling City.

5 Conclusion

Based on the PSR evaluation model, this article comprehensively considers the social and economic situation and agricultural production situation of the research area, and scientifically selects 12 indicator factors to construct the ecological security evaluation index system for farmland in Tieling City. The final weights of each indicator factor were determined through a combination of Analytic Hierarchy Process and Entropy Weight Method. The weighted TOPSIS model was used to accurately calculate and scientifically analyze the dynamic changes in farmland ecological security in Tieling City from 2014 to 2021. The main research conclusions include:

(1) From the perspective of time series change, the cultivated land ecological security in Tieling City showed obvious fluctuations from 2014 to 2021, but the overall development trend was good, and the ecological security level was between grade IV and grade II. The overall situation of cultivated land ecological security in Tieling City is optimistic.

(2) During the two years of 2017 and 2018, Tieling's cultivated land ecological security evaluation score was low, which was closely related to the economic development of the whole city. The instability of economic situation has a direct impact on the ecological security of cultivated land.

(3) Among the three subsystems, the average value of ecological security closeness of the state subsystem is the highest. The average closeness of the pressure and response subsystems has not reached 0.5, which still needs to be improved.

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