A Quantitative Study on Ecological Compensation for Cultivated Land in the Beijing-Tianjin Surrounding Area from the Perspective of Food Security (Postprint)

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Abstract

Based on ecosystem service value and from the perspective of food security, this study establishes a farmland ecological compensation model by calculating grain farmland surplus/deficit, grain farmland overload index, and compensation coefficient, and investigates the issue of farmland ecological compensation in the Beijing-Tianjin-Hebei surrounding area of Hebei Province through quantifying county-level farmland ecological compensation. The research results indicate: 1) A typical "spatial dislocation" phenomenon exists between "ecological supply" and "ecological consumption" of farmland in the Beijing-Tianjin-Hebei surrounding area, wherein farmland "ecological consumption" is mainly concentrated in the southern region, while farmland "ecological supply" is primarily concentrated in the western region. 2) In 2014, the ecosystem service value of farmland in the Beijing-Tianjin-Hebei surrounding area was 4.4805×10^{1} yuan, showing an overall pattern of inability to be self-sufficient, with a total deficit amount of 7.834×10 yuan. 3) In the Beijing-Tianjin-Hebei surrounding area, 17 counties and cities including Zhangbei County, Xinglong County, Yu County, Shangyi County, and Laiyuan County in Hebei Province exhibited surplus, while all other counties and cities showed deficit status. Among them, Luannan County required the highest farmland ecological compensation payment, amounting to 5.173×10 yuan, followed by Yutian County and Dongguang County at 4.864×10 yuan and 4.849×10 yuan respectively. Although Zunhua City, Luanping County, and Quyang County could receive compensation, their farmland ecological conditions merely demonstrated "tight balance", which still requires extensive attention. 4) From the perspective of food security, the counties in the Beijing-Tianjin-Hebei surrounding area that urgently needed to receive farmland ecological compensation in 2014 were Zhangbei County, Yu County, Shangyi County, Yangyuan County, Laiyuan County, and Quyang

County; the counties required to pay farmland ecological compensation were Luannan County, Yutian County, Xian County, Wuqiao County, and Dingzhou City; while Tang County, Laishui County, and Fengning Manchu Autonomous County neither needed to receive nor pay farmland ecological compensation. Compared with previous studies, this research investigates the farmland compensation issue in the Beijing-Tianjin-Hebei surrounding area of Hebei Province from the perspective of ecological compensation. The research findings play an important role in promoting economic development, farmland ecological environment protection, and sustainable and efficient utilization of farmland resources in the Beijing-Tianjin-Hebei surrounding area. Meanwhile, the application of this method can provide references for quantitative research on ecological compensation in similar regions, offer a basis for determining farmland protection indicators based on ecological value in other areas, and hold guiding significance for research on the value mechanism of farmland ecological compensation.

Full Text

Quantitative Study on Cultivated Land Ecological Compensation in the Beijing-Tianjin Environs from the Perspective of Grain Security

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Abstract: Based on ecosystem service value and from the perspective of grain security, this study establishes a cultivated land ecological compensation model by calculating grain-cultivated land budget, overload index, and compensation coefficient. Through quantitative analysis of county-level cultivated land ecological compensation, the research examines compensation issues in the Beijing-Tianjin environs of Hebei Province. The results indicate: (1) A typical "spatial dislocation" phenomenon exists between "ecological supply" and "ecological consumption" of cultivated land in the Beijing-Tianjin environs, with ecological consumption concentrated primarily in the southern region and ecological supply concentrated mainly in the western region. (2) In 2014, the ecosystem service value of cultivated land in the Beijing-Tianjin environs reached 4.4805×10^{1} ¥, showing an overall deficit trend with a total deficit of 7.834×10 ¥. (3) Among the region's counties and cities, 17 including Zhangbei, Xinglong, Yuxian, Shangyi, and Laiyuan showed surpluses, while all others exhibited deficits. Luannan County required the highest ecological compensation payment at 5.173×10 ¥, followed by Yutian County (4.864×10 ¥) and Dongguang County (4.849×10 ¥). Although Zunhua, Luanping, and Quyang counties were eligible for compensation, their cultivated land ecological conditions remained in a "tight balance" requiring continued attention. (4) From the grain security perspective, counties urgently needing cultivated land ecological compensation in 2014 were Zhangbei, Yuxian, Shangyi, Yangyuan, Laiyuan, and Quyang, while counties needing to pay compensation were Luannan, Yutian, Xianxian, Wuqiao, and Dingzhou. Tangxian, Laishui, and Fengning Manchu Autonomous County neither required nor needed to pay compensation. Compared with previous research, this study approaches the cultivated land compensation issue in Hebei’ s Beijing-Tianjin environs through the lens of ecological compensation. The findings play an important role in promoting regional economic development, cultivated land ecological environmental protection, and sustainable, efficient utilization of cultivated land resources. Additionally, this methodology provides a reference for quantitative ecological compensation studies in similar regions, offers a basis for determining cultivated land protection indicators based on ecological value in other areas, and guides research on cultivated land ecological compensation value mechanisms.

Keywords: Cultivated land; Ecosystem services value; Grain security; Ecological supply; Ecological consumption; Ecological compensation; Beijing-Tianjin environs

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Grain security fundamentally concerns people’s living standards, social stability, and national development. In recent years, the Chinese government has made tremendous efforts to achieve grain security through direct grain subsidies and other measures, effectively alleviating grain security concerns. However, this has simultaneously created new economic pressures. Consequently, research addressing grain security has become a focal point in sustainable cultivated land ecosystem studies. As is well-known, major grain-producing regions, tasked with grain production and cultivated land protection, have lost opportunities for equitable development to some extent. Although grain products generate partial revenue, this falls far short of the benefits derived from maintaining ecological environmental quality. To mobilize the initiative and enthusiasm of cultivated land protection stakeholders and resolve the conflict between “food” and “development,” quantitative research on ecological compensation for cultivated land resources is imperative for ultimately achieving comprehensive grain security.

Current research by domestic and international scholars identifies the core of ecological compensation as clarifying its basis, which directly relates to the scientific validity and effectiveness of compensation and represents a key focus and challenge in current ecological compensation work. Presently, some case studies in China have determined compensation basis through ecosystem service value analysis in fields such as forests and water bodies, playing important roles in advancing ecological compensation theory. However, as the conflict between “food” and “development” becomes increasingly prominent, research on cultivated land ecological value compensation is emerging as a new hotspot, though still in the exploratory stage.

The innovation of this study lies in using grain security as the basis for cultivated land ecological compensation. On the foundation of identifying compensation providers and recipients in the Beijing-Tianjin environs, it calculates compensation amounts based on the non-market service value of ecosystems, quantifies the urgency of receiving or paying compensation, and provides a basis for interregional cultivated land ecological economic compensation.

As an important grain supply and ecological security zone for Beijing and Tianjin, Hebei' s Beijing-Tianjin environs has made significant sacrifices in resource exploitation, industrial production, and entertainment culture. Its grain supply-demand balance remains merely in a "tight equilibrium" state. Therefore, selecting this region as the study area is typical, and the research results facilitate comprehensive understanding of grain security issues in the Beijing-Tianjin environs, clarifying economic relationships in cultivated land ecological compensation, and safeguarding regional economic development while achieving dynamic balance in cultivated land quantity and ecological environmental protection.

1.1 Study Area Status

This study selected 72 counties (cities) under the jurisdiction of six prefecture-level cities in Hebei Province that border Beijing and Tianjin—Baoding, Cangzhou, Langfang, Tangshan, Chengde, and Zhangjiakou—as research subjects [Figure 1: see original paper]. The total land area of the study region is 1.33×10 hm^2, with a total population of approximately 3.78×10 people. Annual precipitation ranges from 400–800 mm, and average annual temperature ranges from 0–12°C. The climate type is north temperate continental monsoon climate, characterized by dry and windy springs, hot and humid summers with abundant rainfall, large diurnal temperature variations in autumn, and cold, dry winters with little snowfall. Landform types are relatively complex, primarily including coastal beaches, plains, hills, and plateaus. Among land types in the study area, cultivated land and forest land are the most abundant, accounting for 30.48% and 28.00% of total land area respectively, while water area is the smallest at only 3.67% of total area. With unique location conditions and important geographical position, the Beijing-Tianjin environs serves as a crucial grain supply and ecological buffer zone for ensuring grain and ecological security in Beijing and Tianjin, bearing the heavy responsibilities of grain production, water conservation, sand fixation, and windbreak.

1.2.1 Regional Cultivated Land Ecosystem Service Value Calculation

Drawing upon research progress from scholars such as Costanza et al. and Xie Gaodi, this paper conducts field investigations to calculate the ecosystem service value coefficient per unit area of cultivated land in Hebei' s Beijing-Tianjin environs. In 2014, the economic value of a single ecosystem value equivalent in China was 567.45 ¥ · hm^2. Combined with the average grain yield of 5,536.32 kg · hm^2 in the Beijing-Tianjin environs in 2014, and considering the national average grain yield of 5,861.62 kg · hm^2, the value of a single ecosystem equivalent in the Beijing-Tianjin environs was determined to be 535.96 ¥ · hm^2 after adjusting the national equivalent. The ecosystem service value coefficient per unit area of terrestrial ecosystems (unit equivalent × equivalent) was then calculated, ultimately yielding the ecosystem service value coefficient per unit land area in the Beijing-Tianjin environs (VC, Table 1).

The ecosystem service value calculation formula is:

$$A_e = \sum_{i=1}^{n} A_i \times V_i$$

where A_e represents the ecosystem service value of land use type i in the study area (¥), A_i represents the area of land use type i in the Beijing-Tianjin environs (hm²), and V_i represents the ecosystem service value coefficient per unit area of land use type i in the Beijing-Tianjin environs (¥ · hm ²). This paper studies only cultivated land resources, meaning the land use type is cultivated land.

1.2.2 Ecological Footprint and Ecological Capacity Calculation

1) **Ecological footprint calculation.** Ecological footprint refers to the biologically productive land area required to maintain resource consumption and assimilate waste for a specific population under certain economic scale conditions. The ecological footprint calculation formula is:

$$EF = N \times ef = N \times \sum_{i=1}^{n} \frac{c_i}{p_i} \times r_j$$

where EF is the total ecological footprint, N is population size, ef is per capita ecological footprint, i is the category of consumption goods, p_i is the world average productivity of good i, c_i is per capita consumption of good i, and r_j is the equivalence factor.

2) **Ecological capacity calculation.** Land productivity factor is the ratio of regional average productivity to world average productivity of similar land. The productivity factors for land types adopt the average values used by Wackernagel et al. when calculating China' s ecological footprint, with cultivated land at 1.8, a value widely used in ecological footprint calculations at various regional scales. To maintain coexistence with other species and protect biodiversity, 12% of land should be reserved for biodiversity conservation, which must be deducted in ecological capacity calculations. The ecological capacity calculation formula is:

$$EC = N \times ec = N \times \sum_{j=1}^{n} a_j \times r_j \times y_j \times (1 - 0.12)$$

where EC is regional ecological capacity, N is population size, ec is per capita ecological capacity, and a_j, r_j, and y_j represent per capita biologically productive area, equivalence factor, and yield factor for consumption good type j, respectively.

3) **Ecological overload index calculation.** The ecological overload index is calculated as:

$$EOI = \frac{EF - EC}{EC}$$

If $EOI = 0$, the studied region' s ecological environment is in balance; when $EOI > 0$, larger values indicate more severe ecological overload, and vice versa.

1.2.3 Determination of Regional Compensation Payment/Receipt and Compensation Ratio Calculation

Drawing upon research by Zhou Xiaoping and Cao Ruifen et al., the grain supply-demand balance method is used to determine regional grain-cultivated land budget, as follows:

1) **Regional grain-cultivated land demand calculation.** Based on comprehensive consideration of regional total population, grain yield per unit area (grain output per unit sown area), grain self-sufficiency rate, and per capita grain consumption level, regional grain-cultivated land demand is calculated using formulas (5) and (6):

$$d_1 = \frac{c \times \alpha}{Y/S_1}$$

$$D_1 = d_1 \times N$$

where d_1 represents per capita grain-cultivated land demand in the study area, α represents grain self-sufficiency rate, c represents per capita grain demand in the study region, S_1 represents total cultivated land area, Y represents total grain output, N represents total population, and D_1 represents total regional grain-cultivated land demand.

2) **Regional grain-cultivated land budget** is the difference between regional grain-cultivated land demand (D_1) and supply (S_1), calculated as:

$$L_1 = S_1 - D_1$$

where L_1 represents total grain-cultivated land budget in the region, i.e., the difference between cultivated land stock and total grain-cultivated land demand. $L_1 > 0$ indicates a surplus state of grain-cultivated land, while the opposite indicates a deficit.

3) **Grain security overload index.** To measure the degree of cultivated land ecological utilization, this paper introduces the grain security overload index, referring to the percentage of the difference between cultivated land stock and total grain-cultivated land demand relative to cultivated land stock:

$$DI = \frac{S_1 - D_1}{S_1}$$

where DI represents the regional grain-cultivated land overload index. If $DI = 0$, the region' s grain-cultivated land is in balance, showing "tight grain security" ; when $DI > 0$, larger values indicate greater surplus degree of grain-cultivated land, higher capacity to maintain grain security in the Beijing-Tianjin environs, and higher grain security level; conversely, when $DI < 0$, smaller values indicate more severe grain-cultivated land deficit and higher grain insecurity level.

4) **Compensation coefficient calculation model.** With rapid contemporary socioeconomic development, awareness of ecological environmental protection has gradually attracted attention. In this deepening process, the S-shaped Pearl growth curve can simulate payment capacity behavior, and the Engel coefficient model can measure and quantify socioeconomic level and human living standards in the study area, as shown in formulas (9) and (10):

$$r = \frac{1}{1 + e^{t-5}}$$

$$En = \varphi \times Ea + (1 - \varphi) \times Eb$$

where r represents the social development stage coefficient related to willingness and capacity to pay for cultivated land ecological protection, i.e., the compensation coefficient, with $r \in (0, 1)$; the numerator 1 represents the maximum value indicating maximum cultivated land ecological payment capacity; En is the comprehensive Engel coefficient; Ea is the urban Engel coefficient; Eb is the rural Engel coefficient; and φ is the urbanization level.

5) **Comprehensive calculation model.** To comprehensively and accurately understand and calculate cultivated land grain security compensation amounts, it is necessary not only to clarify value compensation standards but also to consider resource utilization and actual compensation capacity in compensation regions, establishing a relationship function between cultivated land ecosystem service value and ecological value compensation. This paper combines cultivated land ecosystem service value, grain security, and economic development level to calculate cultivated land grain security compensation amounts, as shown in formula (11):

$$A_{ec} = A_e \times \frac{S_1 - D_1}{S_1} \times r$$

where A_{ec} represents the cultivated land grain security compensation amount to be paid (or received) by the study area (¥ · year^{1}); A_e represents the cultivated land ecosystem service value of the study area (¥ · year^{1}); S_1 is total cultivated land area (hm^2); D_1 represents total regional grain-cultivated land demand (hm^2); and r represents the compensation coefficient. If A_{ec} is positive, the region needs to pay ecological compensation, with larger values indicating greater payment amounts; conversely, if A_{ec} is negative, the region should receive ecological compensation.

1.2.4 Regional Ecological Compensation Priority Calculation

Significant disparities exist in socioeconomic development levels among various regions. Using regional economic development level (GDP) to quantify cultivated land ecological compensation degrees is the most convenient and intuitive method. The urgency of cultivated land ecological compensation for economically developed regions is lower than for less developed regions. Ecosystem service value comprises market value and non-market value components. Since the former has already returned to the region in monetary form through market mechanisms, this portion should be excluded when calculating ecological compensation priority (ECPS), retaining only the non-market value portion. This paper determines a region' s ecological compensation priority using the ratio of per unit area ecosystem service non-market value to per unit area GDP, expressed as:

$$SECP = \frac{VaIN}{GDPN}$$

where $SECP$ represents ecological compensation priority, $GDPN$ is regional GDP per unit area, and $VaIN$ is non-market ecosystem service value per unit area. If a study area has a grain-cultivated land deficit and relatively small ecological compensation priority, it indicates grain insecurity but minimal economic impact after paying ecological compensation, meaning it should prioritize paying cultivated land ecological compensation funds. Conversely, it indicates relatively secure grain supply, and receiving ecological compensation would significantly improve its socioeconomic development level, meaning it should be prioritized for cultivated land ecological compensation.

1.3 Data Sources and Parameter Determination

Through interpretation of 2014 Landsat TM imagery for the Beijing-Tianjin environs, this study obtained research data. Using ENVI4.7 software platform, bands 5, 4, and 3 were combined. After geometric correction and clipping to study area boundaries, ArcGIS10.0 was used with supervised classification combined with visual interpretation to interpret cultivated land in the study area. Referencing the 2014 *Beijing-Tianjin Economic Statistical Yearbook* and Hebei Province land change survey data, interpretation accuracy was verified and adjusted to obtain the cultivated land use database for the study area. Other relevant data were sourced from the 2014 *Beijing-Tianjin Rural Statistical Yearbook*, *Beijing-Tianjin Economic Statistical Yearbook*, and *National Agricultural Product Cost-Benefit Data Compilation*.

Key parameters in this study were determined as follows: For grain supply-demand balance calculations, based on the Food and Agriculture Organization and research by Zhou Xiaoping et al., per capita grain consumption (c) was determined to be 400 kg·person ^{1}. According to the *National Medium and Long-Term Grain Security Plan Outline* formulated in 2008, grain self-sufficiency rate (α) was set at 95%.

2.1 Ecosystem Service Value of Cultivated Land in the Beijing-Tianjin Environs

In 2014, the total ecosystem service value of cultivated land in the Beijing-Tianjin environs exhibited spatial differentiation, gradually decreasing from southeast to northwest. The total ecosystem service value of cultivated land in the Beijing-Tianjin environs was 4.4805×10^{1} ¥, with the highest value in the central region at 1.9384×10^{1} ¥, accounting for 43.26% of the total value; followed by the southern region at 1.4771×10^{1} ¥ (32.97%); and the northern region at 1.0649×10^{1} ¥ (23.77%). Overall, cultivated land ecosystem service value showed an increasing trend from north to south, with values of 2.662×10 ¥, 4.846×10 ¥, and 4.924×10 ¥ for northern, central, and southern regions respectively. This phenomenon directly resulted from the increasing trend of cultivated land quantity from north to south. At the prefecture level, Cangzhou City had the highest value at 5.73×10 ¥, while Chengde and Langfang had the lowest values at 1.933×10 ¥ and 2.425×10 ¥ respectively; other cities ranged from 3.5×10 ¥ to 5.5×10 ¥.

2.2 Ecological Overload Index of Cultivated Land in the Beijing-Tianjin Environs

The ecological overload index of cultivated land in Hebei' s Beijing-Tianjin environs showed an overall deficit trend. Only Tangshan in the eastern region (0.07) and Langfang in the central region (0.05) showed surpluses, while all other counties and cities exhibited deficits. Except for Langfang, all cities in central and southern regions showed deficits because these areas represent more economically developed regions in the Beijing-Tianjin environs, particularly Baoding City, where rapid socioeconomic development has come at the cost of consuming large amounts of high-quality cultivated land resources, with increasing population aggregation making Baoding' s cultivated land ecological capacity insufficient to support its ecological consumption. Cangzhou City in the central region had the largest overload index at -0.57 because, as a coastal city, some of its cultivated land suffers from salinization, resulting in the lowest crop yields among all cities in the province and consequently the largest cultivated land ecological overload index [Figure 2: see original paper].

2.3 Ecological Compensation Priority of Cultivated Land in the Beijing-Tianjin Environs

A typical "spatial dislocation" phenomenon exists between "ecological supply" and "ecological consumption" in the Beijing-Tianjin environs. Cultivated land ecological consumption is concentrated mainly in central and southern regions, while ecological supply is concentrated primarily in northern regions. According to the method for determining whether regions should receive or pay compensation, counties and cities receiving cultivated land ecological compensation in 2014 were concentrated mainly in Zhangjiakou, Tangshan, and Langfang cities, while 17 counties paying compensation including Zhangbei, Xinglong, Yuxian, Shangyi, and Laiyuan were concentrated mainly in Baoding, Cangzhou, and Chengde regions [Figure 3a: see original paper].

Ecological compensation priority for cultivated land in the Beijing-Tianjin environs gradually increased from southeast to northwest [Figure 3b: see original paper]. The northwestern region showed higher priority, such as Kangbao, Zhangbei, and Shangyi counties in Zhangjiakou City and Laiyuan County in Baoding City, which had larger cultivated land ecological compensation priorities. Zhangbei County had the highest priority (0.1680), followed by Laiyuan County (0.1487). These regions should prioritize receiving cultivated land ecological compensation because they have higher-quality cultivated land and more secure grain supply, providing strong support for Beijing and Tianjin' s development. Receiving compensation would accelerate their economic growth. In contrast, northeastern and central regions had lower compensation priorities, such as Kuancheng Manchu Autonomous County, Laoting County, Dachang Hui Autonomous County, and Xinglong County, which should prioritize paying ecological compensation to other regions. Kuancheng Manchu Autonomous County had the smallest priority (0.0145), followed by Laoting County (0.0199). These areas have relatively slow development, poor cultivated land quality, small areas, overall grain insecurity, and minimal economic impact from ecological compensation, thus should prioritize paying ecological compensation funds.

2.4 Analysis of Cultivated Land Ecological Compensation Amounts

From the compensation amount perspective, cultivated land ecological compensation in the Beijing-Tianjin environs in 2014 showed an overall deficit trend, with a total deficit of 7.834×10 ¥. The northwestern region had the highest total payment at 4.694×10 ¥, accounting for 59.91% of the study area' s total.

Cangzhou City had the highest payment at 1.811×10 ¥, followed by Baoding City at 1.541×10 ¥, and Chengde City also needed to pay 1.342×10 ¥. The northern region showed overall cultivated land ecological surplus, eligible to receive 6.97×10 ¥ in cultivated land ecological compensation, with Zhangjiakou City eligible for the most at 6.29×10 ¥, followed by Tangshan at 1.75×10 ¥ and Langfang at 6.7×10 ¥. Although these regions showed surplus, their cultivated land ecological conditions remained merely in "tight balance." At the county level, Luannan County had the highest payment at 5.173×10 ¥, followed by Yutian County (4.864×10 ¥) and Dongguang County (4.849×10 ¥). The smallest payment was from Tangxian County at 4.914×10 ¥, with the maximum being 105 times the minimum, indicating a huge disparity. Zhangbei County received the largest compensation amount at 6.540×10 ¥, followed by Xinglong County (5.944×10 ¥) and Yuxian County (8.2×10^3 ¥). Counties with "tight balance" cultivated land ecological conditions were Zunhua, Luanping, and Quyang [Figure 4: see original paper].

2.5 Cultivated Land Ecological Compensation Amounts from the Grain Security Perspective

Based on calculation results, ARCGIS10.0 natural breaks method was used to classify ecological compensation priority into four levels from high to low: 0.1681–0.0750, 0.0749–0.0484, 0.0483–0.0315, and 0.0314–0.0145, with higher values indicating compensation priority. Analysis of cultivated land ecological compensation amounts [Figure 4: see original paper] shows that counties with the largest grain-cultivated land deficits were 19 counties including Luannan, Yutian, Dongguang, and Cangxian, all with compensation amounts above 3.400×10 ¥. Among these, Luannan, Yutian, Xianxian, Wuqiao, and Dingzhou had smaller ecological compensation priorities, showing grain insecurity, less per capita cultivated land resources, and providing ecological services to other regions at the cost of grain and ecological security. These "ecological consumption zones" experience minimal economic impact after paying ecological compensation and should therefore prioritize ecological payments. Counties with grain-cultivated land surpluses were 17 counties including Zhangbei, Xinglong, Yuxian, and Shangyi. Among these, Zhangbei, Yuxian, Shangyi, Yangyuan, Laiyuan, and Quyang had the largest ecological compensation priorities, showing grain security. Rapid advancement of urbanization and industrialization has made these counties "ecological supply zones," and receiving compensation would significantly impact their economic development, so they should be prioritized for compensation. Tangxian, Laishui, and Fengning Manchu Autonomous County had small grain-cultivated land deficits and small ecological compensation priorities but could basically meet their own requirements and did not urgently need compensation.

3 Conclusions and Discussion

This paper introduces a cultivated land ecological compensation quantification model to explore the cultivated land ecological status of 72 counties (cities) in Hebei' s Beijing-Tianjin environs and quantify compensation intensity. The results show: (1) In 2014, the total ecosystem service value of cultivated land in the Beijing-Tianjin environs was 4.4805×10^{1} ¥, with overall distribution characteristics of low values in the north and high values in the central and southern regions, consistent with the increasing trend of cultivated land quantity from north to south. (2) The ecological overload index of cultivated land in the Beijing-Tianjin environs showed an overall deficit trend. Small areas in Zhangjiakou, Tangshan, and Langfang in the northern region showed surpluses, while all other counties (cities) showed deficits. (3) A typical "spatial dislocation" phenomenon exists between "ecological supply" and "ecological consumption" of cultivated land in the Beijing-Tianjin environs, with "ecological consumption" concentrated mainly in central and southern regions and "ecological supply" concentrated primarily in the northern region. Seventeen counties including Zhangbei, Xinglong, Yuxian, Shangyi, and Laiyuan should receive cultivated land ecological compensation, while all other counties and cities should pay compensation. (4) In 2014, the ecosystem service value of cultivated land in the Beijing-Tianjin environs showed an overall deficit trend with a total deficit of 7.834×10 ¥. Luannan County required the highest cultivated land ecological compensation payment, followed by Yutian and Dongguang counties. Zhangbei County received the largest compensation amount. Although Zunhua, Luanping, and Quyang counties could receive compensation, their cultivated land ecological conditions remained merely in "tight balance" and require continued attention. (5) From the grain security perspective, counties urgently needing cultivated land ecological compensation in the Beijing-Tianjin environs were Zhangbei, Yuxian, Shangyi, Yangyuan, Laiyuan, and Quyang, while counties needing to pay compensation were Luannan, Yutian, Xianxian, Wuqiao, and Dingzhou. Tangxian, Laishui, and Fengning Manchu Autonomous County could basically guarantee grain security and achieve self-sufficiency, neither requiring nor needing to pay cultivated land ecological compensation.

Previous research has focused more on compensation priority—i.e., "who compensates whom first" —with less research on ecological compensation quantification. This study explores cultivated land ecological compensation issues in Hebei' s Beijing-Tianjin environs from the grain security perspective combined with ecological compensation priority, quantifying inter-county (city) cultivated land ecological compensation amounts and priorities, and clarifying economic relationships in cultivated land ecological compensation among counties in the Beijing-Tianjin environs. This plays an important role in promoting economic development, cultivated land ecological environmental protection, and sustainable, efficient utilization of cultivated land resources in the Beijing-Tianjin environs. However, this paper only conducts quantitative analysis of the spatial distribution of cultivated land ecological compensation in the Beijing-Tianjin environs for 2014, without in-depth analysis of causes for this spatial distribution pattern or comprehensive spatiotemporal dynamic analysis combined with temporal variation patterns. Future research could explore appropriate methods for analyzing spatiotemporal variation characteristics and driving forces of cultivated land ecological compensation in the Beijing-Tianjin environs, as well as measures and recommendations for improving cultivated land ecological environmental quality.

References

[1] Semwal R L, Nautiyal S, Sen K K, et al. Patterns and ecological implications of agricultural land-use changes: A case study from central Himalaya, India[J]. Agriculture, Ecosystems & Environment, 2004, 102(1): 81-92

[2] Lai M, Wu S H, Yin Y H, et al. Accounting for eco-compensation in the three-river headwaters region based on ecosystem service value[J]. Acta Ecologica Sinica, 2015, 35(2): 227-236

[3] Li F, Li W H, Zhen L, et al. Estimating eco-compensation requirements for forest ecosystem conservation—A case study of Hainan Island[J]. Journal of Natural Resources, 2010, 25(5): 735-745

[4] Rees W E. Ecological footprints and appropriated carrying capacity: What urban economics leaves out[J]. Environment and Urbanization, 1992, 4(2): 121-130

[5] Wang N J, Liu J, Wu D Q, et al. Regional eco-compensation based on ecosystem service assessment: A case study of Shandong Province[J]. Acta Ecologica Sinica, 2010, 30(23): 6648-6656

[6] Hebei Province Statistics Bureau. Hebei Province Statistics Yearbook 2014[M]. Beijing: China Statistics Press, 2014

[7] Zhang H W, Fang B, Wei Q Q, et al. Building quantitative model of ecological value compensation for regional arable land: A case study of Jiangsu Province[J]. China Land Science, 2015, 29(1): 63-70

[8] Costanza R, d' Arge R, de Groot R, et al. The value of the world' s ecosystem services and natural capital[J]. Nature, 1997, 387(6630): 253-260

[9] Xie G D, Zhen L, Lu C X, et al. Expert knowledge based valuation method of ecosystem services in China[J]. Journal of Natural Resources, 2008, 23(5): 911-919

[10] Guo N D, Li H Z, Li C, et al. Regional ecological compensation based on ecosystem service value in the area surrounding Beijing and Tianjin[J]. Chinese Journal of Eco-Agriculture, 2015, 23(11): 1473-1480

[11] Xu Z M, Chen D J, Zhang Z Q, et al. Calculation and analysis on ecological footprints of China[J]. Acta Pedologica Sinica, 2002, 39(3): 441-445

[12] Xu Z M, Zhang Z Q, Cheng G D. The calculation and analysis of ecological footprints of Gansu Province[J]. Acta Geographica Sinica, 2000, 55(5): 607-616

[13] Zhang Z Q, Yu A Z, Luo Z Z, et al. Dynamic study on ecological footprint and ecological capacity of Qingyang, Gansu[J]. Acta Prataculturae Sinica, 2010, 19(4): 187-193

[14] Zhou X P, Song L J, Chai D, et al. Empirical research on zoning of externalities compensation for regional cultivated land protection[J]. Economic Geography, 2010, 30(9): 1546-1551

[15] Cao R F, Zhang A L. Zoning of economic compensation for cultivated land protection under framework of main function zones—A case study in Hubei Province[J]. Journal of Huazhong Agricultural University: Social Sciences Edition, 2014, 33(4): 98-104

[16] Ma A H, Cai Y Y, Zhang A L. Practice and the research progress on eco-compensation for cultivated land[J]. Acta Ecologica Sinica, 2011, 31(8): 2321-2330

[17] Wackernagel M, Onisto L, Bello P, et al. National natural capital accounting with the ecological footprint concept[J]. Ecological Economics, 1999, 29(3): 375-390

[18] Jin Y Y, Zhao K, Xiao G C. The economic compensation zoning of the cultivated land protection in Shaanxi Province: From the perspective of food and ecological security[J]. China Land Sciences, 2015, 29(10): 12-19

[19] Cai B C, Wen L Q, Lu G F. Theoretical considerations on the establishment of ecological compensation mechanism[J]. Ecological Economy, 2005, (1): 45-52

[20] Ren P, Wu T, Zhou J M. Study on value loss evaluation model and compensation mechanism of cultivated land conversion[J]. Scientia Agricultura Sinica, 2014, 47(4): 786-795

Note: Figure translations are in progress. See original paper for figures.