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Study on the Spatial Differentiation Characteristics and Driving Factors of Cultivated Land Non-grain from the Perspective of Food Security—A Case Study of Huang-Huai-Hai Region

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Abstract: Investigating the spatial heterogeneity characteristics and driving factors can provide decision-making reference for scientifically managing the non-agricultural use of cropland in the Huang-Huai-Hai region. The article uses a comprehensive evaluation method, OLS model, spatial autocorrelation analysis, and geographically weighted regression model to study the spatial heterogeneity characteristics and driving factors of non-grain cultivation in the Huang-Huai-Hai region. The research results show that from 2008 to 2022, the non-grain cultivation rate in the Huang-Huai-Hai region presented a spatial distribution pattern of "north high south low and east high west low", with significant regional spatial differences, mainly characterized by high-high clustering and low-low clustering. The level of non-grain cultivation is affected by the joint action of agricultural, social, economic, and policy factors. Among them, rural residents' consumption expenditures, agricultural subsidies, urbanization rate have a greater impact on the level of non-grain cultivation in the region, while the difference between urban and rural residents' disposable income, the total power of agricultural machinery per unit of cultivated land, and per capita GDP also have an impact on its spatial heterogeneity characteristics to varying degrees. During the research period, the level of non-grain cultivation in the Huang-Huai-Hai region has an upward trend, and the spatial differences are obvious. In the future, precision management of non-grain cultivation should be implemented by adjusting the preferential policies in a targeted manner, improving the compensation mechanism for grain production, strengthening the construction of soil quality and protection of cultivated land, to ensure China's food security.

1. Introduction

Food security is a solid foundation for national stability and sustainable development, and arable

land is the key to ensuring national food security and people's "rice bowls." Protecting arable land is an important measure to safeguard national food security [1]. According to the data released in the 2023 China Natural Resources Bulletin, China's arable land area has remained above 128 million hectares, but compared with the third national land survey data, it has decreased by about 7.53 million hectares, making the urgency of arable land protection increasingly evident [2,3].

In recent years, the academic community has mainly concentrated on the study of non-agricultural use of cultivated land, focusing on the spatial distribution characteristics, causal analysis, and corresponding management strategies. The Opinion divides non-agricultural use of cultivated land into two categories: one is the structural non-agricultural use, namely, the change of the use of cultivated land from grain crops to non-grain crops; the other is the structural non-agricultural use of agricultural production [4]. From the perspective of academic research, scholars pay more attention to structural non-agricultural use of cultivated land, and the research on non-agricultural use of different crop types is relatively less. In terms of research methods, scholars often use panel regression models [5], geographically weighted regression models [6], spatial econometric models [7], multiple linear regression [8], logistic regression [9], and geographical detectors [10] to explore the phenomenon of non-agricultural use. In the identification of non-agricultural use of cultivated land, scholars mainly determine the nature of the plot through macro-analysis, land survey data, and remote sensing images. In the selection of research areas, they cover different administrative levels from provincial to county level, and also involve grain production and sales balance areas, the North China Plain, the Yellow River Basin, Heilongjiang Province, Inner Mongolia Autonomous Region, Hunan Province, etc. However, relatively less attention has been paid to the study of non-agricultural use of cultivated land in western economically underdeveloped regions, which affects the completeness and systematic nature of the research. In the selection of influencing factors, scholars tend to focus on natural resource conditions or socioeconomic factors, while fewer studies have comprehensively considered all aspects. Currently, most studies focus on the driving factors of non-agricultural use of cultivated land from the perspectives of cultivated land resource conditions [11,12], road and transportation conditions [13,14], land transfer situations [15], and social factors. The study on the guiding role of policy factors (such as agricultural subsidies and grain protection policies) is relatively lacking. Therefore, this study takes the Huang-Huai-Hai region as the research object, and selects relevant factors from the social, economic, agricultural, and policy perspectives to explore the spatial distribution characteristics and driving factors of non-agricultural use of farmland in the Huang-Huai-Hai region from 2008 to 2022. The research findings not only have significant practical value for promoting the coordinated development of economic, social, and ecological progress in the Huang-Huai-Hai region and ensuring national food security, but also have significant theoretical significance and practical guidance for the actual situation.

2. Research Design

2.1 Data Source and Construction of Indicator System

Based on the scientific and rationality of the influencing factors, as well as the availability of data, this study selected 8 indicators from the three aspects of agricultural production factors, social and economic factors, and policy factors. The data were normalized using the standard deviation method. The specific indicator selection criteria are shown in Table 1. The data used in this study for the research area came from the Geospatial Data Cloud Website (www.gscloud.cn) and the China Statistical Yearbook (2008-2022).

Table 1: Constructing the Indicator System of Driving Factors for Non-Agricultural Use of Farmland in the Huang-Huai-Hai Region

destination layer	subsystem	Serial number	index	Index attribute
Indicators of Drivers of Non-Food Use of Cultivated Land	Agricultural Production Indicators	1	Mechanized Power per Unit Cultivated Land	+
		2	Effective irrigated area per unit of cultivated land	-
		3	Number of laborers per unit of cultivated land	+
	Social and economic Indicators	4	The income gap between urban and rural residents	+
		5	Consumption expenditure by rural residents	+
		6	Urbanization rate	+
		7	Per capita regional GDP	+
	Policy System	8	Agricultural subsidies	-

2.2 Research Methods and Data Processing

2.2.1 Measurement of non-grain level

This study defines "non-agricultural use of cultivated land" as the "non-food" of crop structure. In this study, the grain crops in the study area are defined as rice, wheat, and corn, while all other crops are classified as economic crops. The calculation formula is:

$$NG=(S_n^{t_2}/S^{t_2}-S_n^{t_1}/S^{t_1})\times 100\% \quad (1)$$

In equation (1), NG represents the change in the non-cropland rate between years t_1 and t_2; $S_n^{t_1}$ and $S_n^{t_2}$ represent the planting areas of economic crops in years t_1 and t_2, respectively; and S^{t_1} and S^{t_2} represent the total planting areas of crops in years t_1 and t_2, respectively.

2.2.2 Spatial Auto-correlation Model

Spatial autocorrelation models refer to the potential interdependence between observations of various variables within the same distribution area, which can be divided into global spatial autocorrelation and local spatial autocorrelation.

(1) Global spatial autocorrelation can reflect the degree of clustering or dispersion of various influencing factors within a certain spatial area. The formula for the global Moran's I index (Global Moran's I) is:

$$I=\frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad (2)$$

In equation (2): n represents the number of elements, x_i and x_j represent the attribute values of the i-th and j-th elements respectively, x represents the average of the attribute values, and ω_{ij} represents the spatial weight between the i-th and j-th elements.

(2) Local spatial autocorrelation can reflect the spatial heterogeneity of various influencing factors and characterize the spatial distribution and clustering features of non-grain cultivation high

and low values in each prefecture-level city in the Huang-Huai-Hai region. The formula for the local Moran's I indexes is:

$$I_i=\frac{(x_i-x)\sum_{j=1}^{n}\omega_{ij}(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-x)^2} \quad (3)$$

In equation (3), n represents the number of elements, x_i and x_j represent the attribute values of the i-th and j-th elements respectively, $\bar{x}$ represents the average of the attribute values, and ω_{ij} represents the spatial weight between the i-th and j-th elements.

2.2.3 Geographically weighted regression model

Without compromising the accuracy of the results, this study takes into full consideration the local effects of spatial objects and firstly uses the OLS model (least squares method) to conduct a regression screening of the influencing factors of non-grain cultivation of cropland in the Huang-Huai-Hai region, followed by a geographically weighted regression model for further analysis. The formula of the model is:

$$\gamma_i = \beta_0(\mu_i,\nu_i) + \sum_{k=1}^{p}\beta_k(\mu_i,\nu_i)\,x_{ik} + \varepsilon_i \quad i = 1,2,\dots,n \quad (4)$$

In equation (4): (μ_i,ν_i) represents the spatial coordinates of each research area in the Huang-Hai River Basin; $\beta_k(\mu_i,\nu_i)$ is the kth regression parameter at sampling point i, which is a function of geographic location; x_{ik} is the observed value of the kth variable at the I; ε_i is the random error.

3. Empirical analysis

3.1 Analysis of Spatial Heterogeneity of "Non-grain" Space

3.1.1 Analysis of Spatial and Temporal Characteristics of Non-grain

The analysis results show that (Table 2), the global Moran 's I index has always been greater than 0, which has passed the 1% significance level test, and the ' non-grain ' phenomenon of cultivated land in this region has a strong spatial autocorrelation.Based on the actual situation of non-agricultural use of land in the Huang-Huai-Hai region, the natural breakpoint method was used to adjust the classification boundaries and visualize the results. The research results show (Figure 1): The geographic distribution of non-grain in the Huang-Huai-Hai region shows a pattern of "northern areas higher than southern areas, eastern areas higher than western areas. With significant regional differences. In terms of time series, the level of non-grain cultivation in the Huang-Huai-Hai region has developed steadily overall, with a slow increase and decrease in amplitude; the central and northern regions have higher levels. Spatially, the degree of non-grain cultivation in the Huang-Huai-Hai region as a whole shows a distribution pattern of "north high south low, east high west low," with significant spatial differences. The average non-grain cultivation rate in the Huang-Huai-Hai region in 2010, 2013, 2016, 2019, and 2022 was 27.6%, 28.3%, 26.7%, 26.2%, and 27.5%, respectively, all of which were at the moderate level of non-grain cultivation. The non-grain cultivation rate decreased by 0.9% from 2010 to 2016, and increased by 0.8% from 2016 to 2022, with a slight deepening of the non-grain cultivation level.

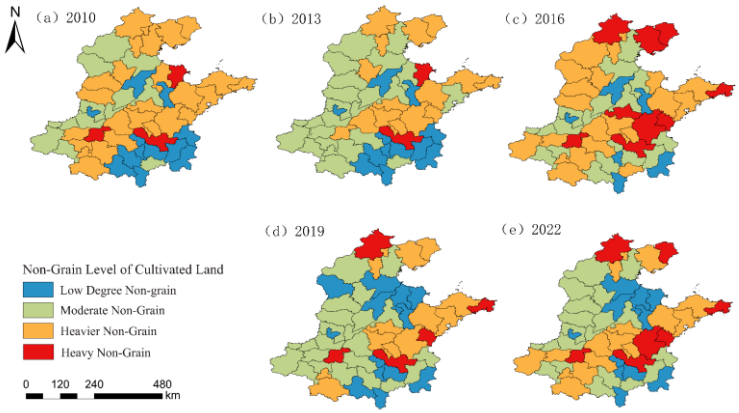

Figure 1: Classification of "non-grain" degree in Huang-Huai-Hai area

3.1.2 "Non-grain" spatial concentration characteristics

Using local spatial autocorrelation analysis, this study explores the degree of correlation and spatial distribution differences among the non-agriculturalization rates of various municipalities in the Huang-Huai-Hai region, and draws the LISA agglomeration map (Figure 2). It can be seen from the figure that the spatial agglomeration of non-agriculturalization in the Huang-Huai-Hai region is significant from 2008 to 2022, mainly manifested as scattered high-high agglomeration and low-low agglomeration, and overall presents a "north low south high" spatial distribution feature. The above research results provide empirical support for the applicability of the GWR model.

Table 2: Spatial correlation test of non-grain conversion rate of cultivated land in Huang-Huai-Hai region from 2008 to 2022

Year	Moran's *I*	Z score	P value
2010	0.344795	6.163386	0.030512
2013	0.412639	6.941083	0.052248
2016	0.463113	7.329674	0.019823
2019	0.496631	8.233035	0.001215
2022	0.575339	9.035372	0.000619

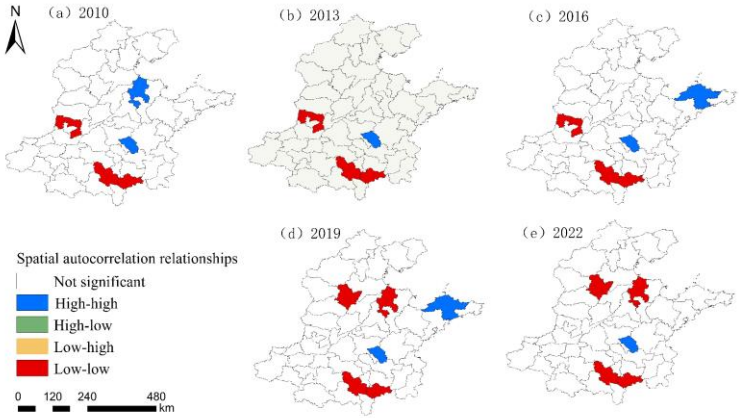

Figure 2: LISA clustering map of cultivated land non-grain conversion rate in Huang-Huai-Hai region from 2008 to 2022

3.2 Analysis of the Driving Factors behind the "Non-Grain"

According to the OLS model regression results (shown in Table 3), the rate of non-agricultural use of cultivated land in the Huang-Huai-Hai region is positively correlated with rural residents' consumption expenditures, the difference in per capita disposable income between urban and rural residents, urbanization rate, per capita regional GDP, and total power of agricultural machinery per unit of cultivated land, and negatively correlated with agricultural subsidies, the number of laborers per unit of cultivated land, and effective irrigated area per unit of cultivated land. The degree of influence of each factor on non-agricultural use of cultivated land is as follows: rural residents' consumption expenditures > agricultural subsidies > urbanization rate > the difference in per capita disposable income between urban and rural residents > total power of agricultural machinery per unit of cultivated land > per capita regional GDP > the number of laborers per unit of cultivated land, and rural residents' consumption expenditures are the main driving factor of non-agricultural use of cultivated land in the Huang-Huai-Hai region.

Table 3: Estimation of OLS model regression results

Model	Standardized coefficient	T value	P value	Collinearity statistics	
				Tolerance	VIF
Constant	0.001	0.012	0.99		
Mechanized Power per Unit Cultivated Land	0.175	2.157	0.031*	0.780	1.281
Number of laborers per unit of cultivated land	-0.173	-3.408	0.001***	0.526	1.900
Effective irrigated area per unit of cultivated land	-0.007	-0.178	0.859	0.765	1.307
Urbanization rate	0.265	3.156	0.002***	0.202	4.950
Per capita regional GDP	0.166	1.536	0.063*	0.377	2.651
Consumption expenditure by rural residents	0.359	2.909	0.004***	0.241	4.147
The income gap between urban and rural residents	0.251	2.629	0.009***	0.347	2.884
Agricultural subsidies	-0.288	1.998	0.046**	0.251	3.981

Note: The distributions of *, * *, and * * * are significant at 10%, 5%, and 1%.

3.3 Spatial Heterogeneity Analysis of Non-Grain Drivers

Using natural breakpoint method, the visualization analysis of the regression coefficients of each factor was conducted to obtain the spatial distribution of the intensity of the impact of each variable on the non-agricultural use of cropland in the Huang-Huai-Hai region (Figure 3). As shown in Figure 3, the rural resident consumption expenditure (Figure 3a) and the difference between urban and rural residents' disposable income (Figure 3d) had a positive impact on the non-agricultural use of cropland in the Huang-Huai-Hai region and showed significant global influence. An increase in rural resident consumption expenditure usually accompanies an improvement in living standards and a shift in consumption structure, which means that farmers may adjust their planting structure and increase the planting of economic crops. The widening of the urban-rural income gap may also lead agricultural workers to choose to work outside or plant labor-saving crops to raise their income levels, thereby aggravating the degree of cropland non-agricultural use. Agricultural subsidies

(Figure 3b) had a negative impact on the non-agricultural use of cropland in the Huang-Huai-Hai region, and the government guided grain production by formulating relevant policies. The increase in agricultural subsidies provided farmers with more economic support. The urbanization rate (Figure 3c) and per capita GDP in each region (Figure 3f) have a positive impact on the non-grain of cropland in the Huang-Hai-Hai region. Economic growth and the improvement of per capita GDP in each region give rise to higher quality and more diverse demands for agricultural and sideline products. Under the influence of supply and demand relations, farmers are more inclined to plant economic crops with higher return rates. The difference in the impact of economic development imbalance between the southern and northern regions on the spatial distribution pattern of cropland non-grain is further exacerbated. In the future, we should adjust our pro-farmer policies according to local conditions, improve the compensation mechanism for grain production, strengthen the construction of soil quality and protection of cultivated land, so as to precisely control the "non-grain" of cultivated land and ensure China's food security.

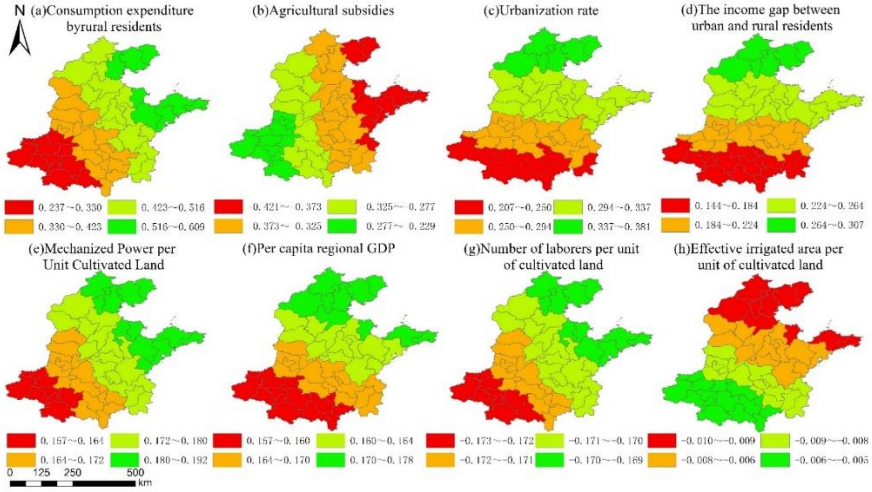

Figure 3: Spatial distribution of regression coefficients of influencing factors of GWR model in Huang-Huai-Hai region

4. Conclusions

This study selected 52 prefecture-level administrative divisions in the Huang-Huai-Hai region as the research area, collected relevant data from 2008 to 2022, revealed the spatial distribution characteristics of non-agricultural use of cultivated land in the region, and conducted a study on the driving factors of non-agricultural use of cultivated land from the perspectives of agricultural production, social economy, and policy, using multiple indicators. The following conclusions were drawn:

(1) Between 2008 and 2022, the "non-agriculturalization" of farmland in the Huang-Huai-Hai region showed a clear spatial concentration difference, with the Moran's global index always remaining positive and showing a sustained upward trend, indicating that the "non-agriculturalization" of farmland in the region has a strong positive spatial correlation. The results of local autocorrelation analysis, on the other hand, showed a scattered distribution pattern characterized by high-high clustering and low-low clustering, indicating that the areas of "non-agriculturalization" are gradually expanding and the clustering effect is increasing, thus forming a "south high north low" spatial distribution pattern.

(2) The phenomenon of non-grain cultivation in the Huang-Huai-Hai region is the result of multiple factors, with four indicators - rural residents' consumption expenditures, agricultural

subsidies, urbanization level, and the gap in disposable income between urban and rural residents - having a particularly positive impact; Meanwhile, the total agricultural machinery power per unit area of cultivated land, regional per capita GDP, and the number of laborers per unit area of cultivated land also have a significant impact on the degree of non-grain cultivation of cropland. The influence of each factor on non-grain cultivation of cropland has regional differences.

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