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Spatio-temporal differences and factors influencing intensive cropland use in the Huang-Huai-Hai Plain

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Abstract: This study developed a comprehensive system to evaluate the intensity of cropland use and evolution of cropland use in the Huang-Huai-Hai Plain. Delphi-entropy methods were adopted to determine the weight of the index, and the GeoDetector model was established to explore the influencing factors. The results are summarized as follows: (1) The intensity of inputs, degree of utilization, and production increased continuously, but the intensity of continuous conditions experienced an overall decline followed by a rebound towards the end of the study period. The number of counties with high and moderately high intensity increased by 56.8% and 14.6%, respectively, from 1996 to 2011. The number of counties with moderately low and low intensity declined by 35.9 % and 11.9 %, respectively. Areas with significant increases in intensity were mainly distributed in northeast Hebei Province, northwest Shandong Province, and north Jiangsu Province. The intensity is high in northern Jiangsu and Anhui; the output effect remained above moderate intensity mainly near Beijing, Tianjin, Tangshan, and counties in the suburbs of Shijiazhuang. (2) Natural disasters, elevation, slope, and road networks were the main factors influencing the intensity of cropland use in this region, with influence values of 0.158, 0.143, 0.129, and 0.054, respectively. Areas with moderately high and high levels of intensity were distributed in low-lying areas. Uneven distribution of precipitation, seasonal drought, and flood disasters can directly affect the stability index of croplands and reduce the intensity of cropland use. Developed road networks are associated with moderately high intensity. Our results suggest recommendations such as promoting agricultural intensification and large-scale management, promoting the construction of road networks, improving early warning systems for drought and flood disasters, and promoting moderate and intensive use of arable land, and focusing on restoration and sustainable use of cropland.

Keywords: intensive cropland use; spatio-temporal difference; influence mechanism; GeoDetector model; Huang-Huai-Hai Plain

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1 Introduction

Croplands are the basic food source for human survival, and its utilization has an important influence on food security, stability of the ecological environment, and social stability (Lü *et al.*, 2015). Intensive use of croplands involves managing agricultural systems to make more productive use of materials and labor and to apply modern technology and management methods to achieve increased production and income on smaller plots of land (Lin and Feng, 2006). However, China's cropland area has declined in recent years mainly as a result of reforestation, construction projects, disaster damage, and agricultural structural adjustment (Zhu *et al.*, 2007). In addition, the excessive input of fertilizers and pesticides, salinization of soil, and other unreasonable uses have reduced the quality of cultivated land to different degrees in different parts of China (Kerr *et al.*, 2004; Herzon *et al.*, 2008; Hof *et al.*, 2011). Therefore, the intensive utilization of existing croplands is essential to achieving sustainable agricultural development and food security. To this end, researching spatio-temporal differences of intensive cropland use and influencing factors restricting intensive utilization are of great theoretical value and practical significance.

Previous studies on the level of the intensive use mainly focused on two approaches: a single index (Yao *et al.*, 2014) and a comprehensive index (Lü *et al.*, 2015; Wang *et al.*, 2015; Xie *et al.*, 2016). The single index is the simplest method for evaluation. However, it is generally insufficient for adequately measuring intensive use; thus, comprehensive index measures are a more common method to evaluate cropland resources. Some scholars directly use the input or output index of cropland to measure the degree of intensive use of cropland (Lambin *et al.*, 2000; Yao *et al.*, 2014; Lü *et al.*, 2015). Others constructed a comprehensive evaluation index system including inputs, utilization, production, and sustainable development for compound measurement (Erb *et al.*, 2013; Liu *et al.*, 2014; Ni *et al.*, 2015).

To date, research on the influence mechanisms underlying land cultivation typically rely on traditional econometric models that focus on factors restricting intensive use, with less emphasis on the spatio-temporal differences, evolutionary principles, and influencing mechanisms (Ning, 2015). Previous studies investigated influencing factors for the intensive use of cropland using correlation analysis (Zhang *et al.*, 2014), typical correlation analysis (Zhao and Yang, 2010; Ke and Ma, 2013), multiple linear regression (Wang *et al.*, 2015), Tobit regression (Chen *et al.*, 2014; Lu *et al.*, 2014), double logarithmic regression (Wu *et al.*, 2012), and co-integration analysis (Wu *et al.*, 2011) from the perspective of farmers. These traditional statistical methods hold many assumptions, such as similarities in variance and normality, and actual research cases rarely meet these assumptions (Ding *et al.*, 2014). Furthermore, most research on the spatio-temporal differences in the overall level of intensity of cropland use mainly employed cluster analysis (Fei *et al.*, 2012), Kernel's density estimation, and the double self-organizing model (Liu *et al.*, 2014).

The GeoDetector model (Wang and Hu, 2012) is based on the theory of spatial differentiation. The model is less constrained by the initial hypothesis (Hu *et al.*, 2011), and it can determine correlations between factor variables and outcome variables, and handle various factors through discrete classification. It uses different processing approaches to analyze and apply domestication of different types of variables at the same spatial scales (Liu and Li, 2017). In recent years, the method has been applied to the studies on social, economic, and environmental issues (Ding *et al.*, 2014; Liu and Yang, 2012).

This study constructed a comprehensive system for evaluating intensive use of croplands based on four aspects: inputs, utilization, production, and sustainable development. Delphi-entropy methods were employed to determine the weight of the index, considering the level of intensity of cropland use and its evolution in the Huang-Huai-Hai Plain from the perspective of the overall level and the four aspects individually. Furthermore, the GeoDetector model was established to explore the influencing mechanisms of intensive use of croplands and then corresponding policy suggestions are made to provide a reliable basis for the sustainable development of cropland in this region.

2 Data and methods

2.1 Study area

The Huang-Huai-Hai Plain (The Huanghe River-Huaihe River-Haihe River Plain, 32°N–40°N and 114°E–121°E) covers an area of 300,000 km^2 and is the second largest plain in China. The plain is located to the west of the Bohai Sea and the Yellow Sea, north of the Dabie Mountains, and west of the Taihang and Qinling mountains. The Huang-Huai-Hai Plain covers seven provinces, including Beijing, Tianjin, Hebei, Shandong, Henan, Anhui, and Jiangsu (Figure 1). The plain is located in a warm-temperate climate zone with an annual average precipitation of about 500–900 mm and annual average temperature of about 8°C–15°C. The active accumulated temperature ≥10°C is about 3800°C–4900°C. There are about 190–220 frost-free days annually. Crops mature three times every two years. There are about 1570 ha of cultivated land and 33,217 ha of construction land in 2010. Forests and grasslands cover 16,238 and 8156 ha, respectively. The Huang-Huai- Hai Plain has a long history of agriculture and a high degree of land utilization and development.

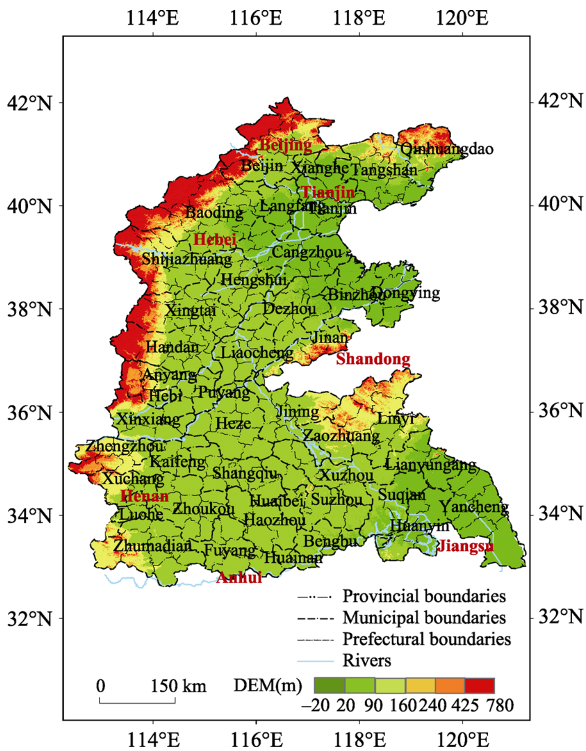


Figure 1 Map of the Huang-Huai-Hai Plain

2.2 Data sources

Land use data were provided by the Resource and Environment Data Center of the Chinese Academy of Sciences. Remote sensing data with a spatial resolution of 1 km for the Huang-Huai-Hai Plain were obtained in 1995, 2000, 2005, and 2010. The study area was divided into farmland, woodland, grassland, water bodies, construction land, and unused land, according to the land use/cover change (LUCC) classification system provided by the data center of the Chinese Academy of Sciences. Slope data for this region was extracted from a 30-m DEM of Shuttle Radar Topography Mission (SRTM). Road data were sourced from the Open Street Map, and meteorological data, mainly average annual precipitation and temperature, were obtained from the Chinese Meteorological Data Sharing Network (http://data.cma.cn).

Evaluation index data related to intensive utilization of croplands were obtained from the Chinese Rural Statistical Yearbook (1997–2012), the Planting Industry Management Department of the Agricultural Ministry of PRC (http://www.zzys.moa.gov.cn), and the Chinese Agricultural Information Network (http://www.agri.cn). There were multiple changes in administrative boundaries during the research, resulting in a change in the total number of counties at different points during the study period. Finally, we organized the dataset to include the area of croplands, fertilizer applications, and agricultural gross production for 344 counties in 1996, 340 counties in 2001, 337 counties in 2006, and 333 counties in 2011.

2.3 Methods

We built an index system and used a subjective and objective combination weighting method to determine the index weight. According to the weighted arithmetic approach used in the multi-factor comprehensive evaluation, the index layer was calculated and then divided into five levels from the highest to the lowest levels using the natural breakpoint method. The GeoDetector model was used to extract dominant factors and quantitatively evaluate the impact of various factors.

(1) Construction of the index system

Based on a review of the literature (Ni *et al*., 2015), the current comprehensive evaluation index system of intensive utilization was mainly considered. In light of the notion of intensive utilization and relevant theory, the preliminary index system was built from the rule layer and index layer. The rule layer comprised the intensity of inputs, degree of utilization, effect of outputs, and continuous state. The intensity of input factors (input of labor, fertilizers, pesticides, and power, etc. per unit area) reflects the input level of labor, chemical fertilizers, pesticides and mechanical power, etc. The degree of utilization factors (cultivation index, multiple crop index, irrigation index, and stable yield index) shows the extent of multiple cropping, irrigation, drainage, stable yield in land use process. The effect of outputs factors (output value per unit land, output value of every farmer, grain yield per unit area, production of foodstuff for every farmer, per capita net income of farmers) is a direct reflection of the economic status of croplands, which can reflect the comprehensive agricultural productivity after the input and utilization. Continuous state (non-agriculture index and per capita net area of cultivated lands) is to maintain long-term productivity and ecological stability of croplands.

On this basis, the average values of four years data for all these factors were calculated at the county level. Then the correlation analysis method was adopted to determine whether some indicators are internally relevant. There showed a significant correlation coefficient (higher than 0.5) between multiple crop index and irrigation index, output value per unit area of land and output value of every farmer, security index of foodstuff and per capita net area of croplands. Combined with the real situation of the Huang-Huai-Hai Plain, the irrigation index, output value of every farmer, and per capita net area of croplands were retained as these factors are important and strongly related to intensification in this area. Finally, we constructed a final evaluation index system for intensive cropland use based on the rule layer (Table 1).

(2) Combination weighting method

In this study, we used the Delphi-entropy method to determine the weight of the evaluation index. The combination weighting method can not only compensate for the subjective limitations of the Delphi method, but also overcome the limitation of the entropy method in only considering the complete mathematical theory and method while ignoring the subjective information of decision makers and the real situation (Shan *et al.*, 2012). We used the weights determined from the entropy method as correction factors to correct the weight produced by the Delphi method (Table 1).

Table 1 Evaluation index system of the intensity of cropland use

Target layer	Criterion layer	Index layer	Metering method	Effect	Weights
Intensive utilization of cultivated lands	Input intensity	Labor input per unit area	Population employed in agriculture per unit area of cropland	+	0.2565
		Fertilizer input per unit area	Application of fertilizers per unit area of cropland	+	0.2148
		Pesticide input per unit area	Application of pesticides per unit area of cropland	+	0.2850
		Power input per unit area	Total power of agricultural machinery per unit area of cropland	+	0.2437
	Utilization degree	Cultivation index	Area of cropland/Total area of all lands	+	0.2252
		Irrigation index	Area of effective irrigation per unit area of cropland	+	0.2235
		Stable yield index	Security areas/Seeded area	+	0.5515
	Output effect	Output value of every farmer	Total output value of agriculture/ Population of agricultural employment	+	0.5646
		The production of foodstuff	Total production of foodstuff/Seeded area	+	0.1613
		The production of foodstuff of every farmer	Total production of foodstuff/Population employed in agriculture	+	0.2740
	Continued situation	Non-agriculture index	Non-agriculture/Total population	–	0.6725
		Per capita net area of croplands	Total area of lands/Total population	+	0.3275

Note: "+" indicates the positive effect, and "–" indicates the negative effect.

(3) Geographical detector

GeoDetector developed by Wang Jinfeng (2010), models the interaction between multiple factors by proposing the "factor force" measurement index, combining spatial analysis technology based on Geographical Information System (GIS) and set theory (Liu and Li, 2017). We conducted an exploratory analysis of the spatial difference of influencing factors and its influence on the intensive use of croplands on the plain. The model is as follows:

$$P_{F,E} = 1 - \frac{\sum_{q=1}^{Q} n_{F,q} \sigma^2 E_{F,q}}{N \sigma^2 E} \tag{1}$$

where $P_{F,E}$ is the influence of F factor on E, which reflects the level of intensive utilization, and it is dimensionless. When the value of $P_{F,E}$ is close to 1, the level of intensive utilization is increasingly influenced by the factor F. Conversely, when the value of $P_{F,E}$ is close to 0, the level is less influenced by the factor F. Q is the number of the secondary regions, signifying that the factor F is the number of natural clustering classification. N is the number of counties; $\sigma^2 E$ is the variance in the degree of intensive utilization in the region; $n_{F,q}$ and $\sigma^2 E_{F,q}$ are the number of secondary zones and corresponding variance in the intensive use of croplands.

(4) Factors influencing the intensive use of croplands

Based on findings from previous studies (Ning, 2015) and consulting expert opinions on cropland use, natural resource conditions, and socio-economic policy, we selected nine factors (Table 2), such as elevation, temperature, Gross Domestic Product (GDP), density of road networks, for inclusion in the GeoDetector model. Factors affecting the level of intensity in the Huang-Huai-Hai Plain could be divided into five layers through natural clustering method of Jenks in GIS software (Figure 6). We generated a spatial distribution pattern of influencing factors, and added the spatial distribution pattern of intensive use of arable land. We then ranked the degree of influence by combining various factors. We quantitatively analyzed the factors influencing the spatio-temporal patterns of the intensive use of croplands to determine the degree of influence of the factors on intensive cropland use at the regional level (Table 2).

Table 2 Selected influencing factors, their influence value and proportion

	Influencing factors	Code	Variables	Unit	Influence value	Proportion (%)
Natural resources conditions	Elevation	X1	Average elevation	m	0.143	23.55
	Slope	X2	Average slope	°	0.129	21.23
	Temperature	X3	Annual average temperature	℃	0.042	6.94
	Precipitation	X4	Annual average precipitation	mm	0.051	8.37
	Natural disasters	X5	Natural hazard rate	%	0.158	25.9
Social, economic, and policy conditions	Economic development state	X6	Gross domestic product	10,000	0.013	2.17
	Supportive policy	X7	Agricultural subsidy	10,000	0.006	1.03
	Urbanization extent	X8	Built-up area	Ha	0.012	2.03
	Transport condition	X9	Density of road network	m/ha	0.054	8.78

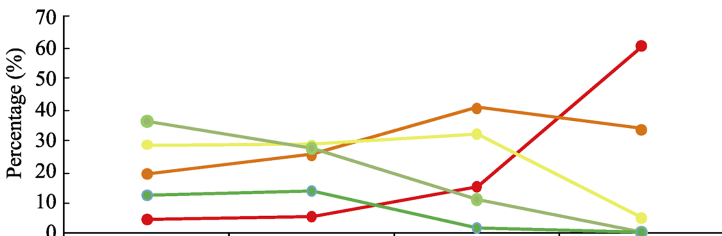
Annotation: The influencing factors in the chart are based on the data of 2011.

The influence of the selected factors was calculated using the GeoDetector model (Table 2). We then selected the top factors, such as the elevation, slope, natural disasters, and road networks, for a deeper analysis.

3 Results and analysis

3.1 Temporal changes in intensive use of croplands

As the northern breadbasket for China, the intensity of cropland use in the Huang-Huai-Hai Plain improved significantly from 1996 to 2011. Although the number of counties with high intensity accounted for a low overall proportion (8%), the overall intensity of cropland use improved rapidly during the study period, especially from 2006 to 2011. From 1996 to 2006, the number of counties with high intensity rose gradually and then demonstrated a rapid increase by 46% after 2006. The number of counties with moderately high intensity and moderate intensity also rose with some fluctuation and accounted for a relatively high proportion of the influencing factors. The number of counties with moderately low and low intensity showed a trend of continuous decline. The number of counties with low intensity declined gradually, especially during the period of 2001 to 2011. However, in the last five years of the study period, the number of counties with high intensity varied, and the intensity of cropland use improved rapidly; the proportion of moderately high intensity and moderate intensity slightly dropped. The number of counties with moderately low intensity and low intensity declined almost linearly, occupying a negligible proportion (0.6%) by the end of the study. From the results above, the utilization level of the vast majority of counties in the Huang-Huai-Hai Plain is high (Figure 2).

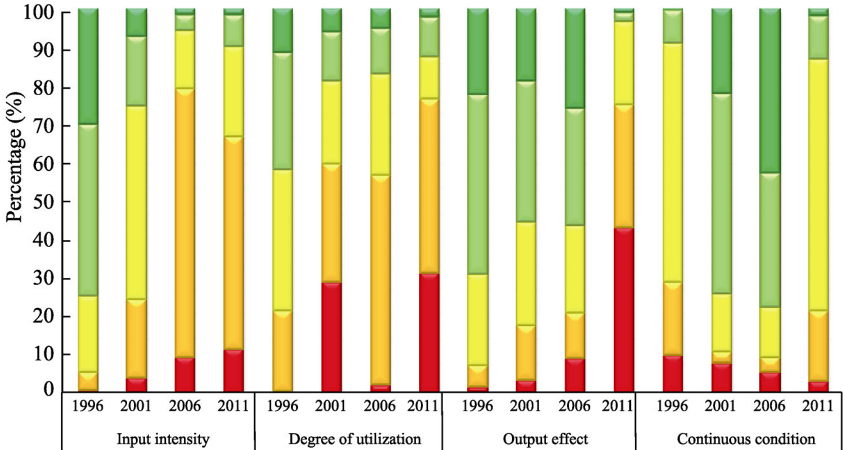


	1996	2001	2006	2011
High intensity	4.15	5.29	14.83	60.96
Moderately high intensity	18.99	25.29	40.70	33.63
Moderate intensity	28.49	28.53	31.98	4.80
Moderately low intensity	36.20	27.35	10.76	0.30
Low intensity	12.17	13.53	1.74	0.30

Figure 2 Number and percentage of counties at each level of intensity in cropland use

The intensity of input increased significantly from 1996 to 2001. The intensity of the continuous situation was at the highest point in 1996. Between 1996 and 2006, the per capita area of croplands declined continuously (as well as measures of sustainable utilization) due to rapid economic development and conversion of agricultural lands in the region. The low level of agricultural management, underdeveloped agricultural mechanization, and inadequate water availability were not favorable for intensive cropland use. After 2006, farmers in the region spared no effort to economically develop croplands, and the intensive use level showed a steady increasing trend from 2006 to 2011. Nearly two thirds of the counties were maintaining a level of intensive use above moderately high intensity from 2001 to 2011. The intensity of degree of utilization was maintained at a higher level, especially in the last ten years. The intensity of utilization above moderate intensity improved in nearly 80% of the counties owing to the constant improvement in cropping systems, irrigation infrastructure, and agricultural production. By 2011, the continuous situation of this area was significantly improved; nearly 85% of the counties had recovered to the moderate level (Figure 3). At the end of the research period, more than 90% of the counties achieved over moderate intensity, indicating a significant improvement.

In short, the degree of intensive utilization in the Huang-Huai-Hai Plain increased during the period of 1996–2011. The intensity of input, degree of utilization, and effect of output showed an increasing trend (with some fluctuation) and the continuous situation showed a trend of overall decline (by 4.9% per year), which then rebounded.



	Input intensity 1996	2001	2006	2011	Degree of utilization 1996	2001	2006	2011	Output effect 1996	2001	2006	2011	Continuous condition 1996	2001	2006	2011
Low intensity	30.29	7.42	1.74	1.80	11.63	6.18	5.34	2.40	22.55	18.82	26.16	1.20	0.58	22.06	43.03	2.10
Moderately low intensity	44.41	18.10	4.07	8.11	30.23	12.65	11.87	10.21	46.59	36.76	30.23	2.40	8.72	52.06	34.72	11.11
Moderate intensity	20.00	50.15	15.12	23.42	36.92	21.76	26.41	11.11	23.74	27.06	22.97	21.62	61.92	15.29	13.06	65.47
Moderately high intensity	4.71	20.47	69.77	55.56	20.93	30.59	54.30	45.35	5.64	14.12	11.63	31.83	18.90	2.94	3.86	18.32
High intensivety	0.59	3.86	9.30	11.11	0.29	28.82	2.08	30.93	1.48	3.24	9.01	42.94	9.88	7.65	5.34	3.00

Figure 3 County number and intensity level of the subsystem

3.2 Spatial differences in intensive use of croplands

3.2.1 Spatial differences in the overall level of intensive cropland use

From 1996 to 2011, the overall level of intensive cropland use in the Huang-Huai-Hai Plain gradually increased, with obvious spatial differences. Generally, the availability of irrigation water was sufficient in river basins of the Huang-Huai-Hai Plain. Therefore, the overall level of intensive use of croplands was moderately high for croplands. The overall level of intensive use of croplands in coastal districts and counties was above the moderate intensity level. Through the 15 years, the coverage of districts and counties with high intensity and moderately high intensity of cropland use increased (Figure 4). Areas that showed significant improvement in the level of cropland intensity were mainly distributed in northeast Hebei, northwest Shandong, and north Jiangsu provinces. Most of these areas shifted from low intensity to moderate intensity or from moderately high to high intensity. Highly intensive regions in the suburban counties (or ring districts and counties) of developed cities gradually expanded to districts farther from downtown areas, transferring improved agriculture technology and management techniques. These grain- and oil-producing areas have a strong economic foundation, backing of industry, and access to agricultural infrastructure, such as money, chemical fertilizers, pesticides, and inputs. Districts and counties located in southeast Henan and north Anhui provinces have a relatively low level of intensive utilization of croplands, with intensity levels decreasing in some cases. These areas lack sufficient irrigation water, their agricultural infrastructure is underdeveloped, and possess a low level of economic development.

3.2.2 Spatial differences in the rule layer of intensive cropland utilization

The results of the spatial analysis of intensive use of croplands for each rule layer showed

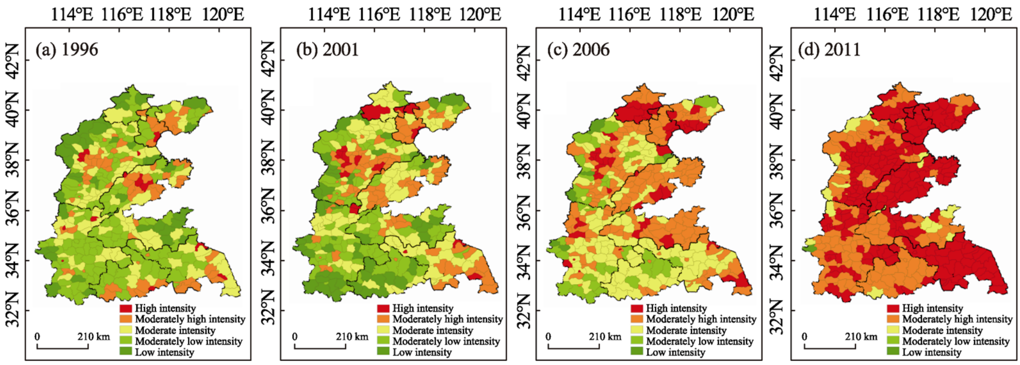


Figure 4 Variations in the overall level of the intensive utilization of croplands from 1996 to 2011

that in several major agricultural provinces, such as Hebei, Shandong, Henan, and Anhui, there were high levels of input intensity and utilization, but the output effect was slightly inferior. However, after 2006, the increase was significant; regions showing increases in intensity were mainly distributed in west Shandong and north Jiangsu provinces, while other areas showed a continuous annual decline (Figure 5).

Regarding input intensity, the levels of agricultural investment in the region constantly improved from 1996 to 2006. Investment levels were moderately high in counties in central Hebei, northeast Henan, and west Shandong compared to other regions in 2006. In addition, the overall investment level was moderately high in the Yellow River Basin. With economic development, many districts and counties do not simply invest more in the intensive use of croplands, but they also pay more attention to intensive utilization to improve efficiencies.

The central and southern regions in the Huang-Huai-Hai Plain have high temperatures and abundant rainfall, allowing for three crop harvests within a 2-year period. In the Yellow River and the Huaihe River basins, irrigation water is adequate so the irrigation index is moderately high. The average elevation in the central Huang-Huai-Hai Plain is low, so it is more suitable for farming; the cultivation index is moderately high with intensive human activities. Thus, favorable climatic conditions and a solid foundation of agricultural infrastructure have led to continued improvement in the level of intensive use of croplands in most areas in the plain from 1996 to 2011, especially from 1996 to 2001 and 2006 to 2011.

The output effect has improved significantly from 2006 to 2011 because of constant investment and increasingly intensive utilization. Districts and counties where the output effect has remained above the level of moderate intensity are mainly located near Beijing, Tianjin, Tangshan, counties in the suburbs of Shijiazhuang city, and north Jiangsu, where the agricultural economy is strong. These areas are close to other areas with a great market demand for agricultural products, so their output effect is significantly higher than other districts. Because of the favorable climate and other basic agricultural conditions, the output effect in central Shandong and north Jiangsu is also relatively high. From 1996 to 2006, the output effect of Henan, Anhui and Hebei improved slowly, but rapid development was achieved in the last five years.

Regarding the continuous conditions, from 1996 to 2006, in addition to north Jiangsu, where conditions are favorable, the level of intensity in the Huang-Huai-Hai Plain is declining with rapid economic development, rapid increases in urbanization, declining per capita arable land, and continuous increases in the non-agriculture index. This is especially true in most counties in Hebei and Henan provinces, in which the continuous situation reached the lowest level in 2006. At the end of the study period, the continuous situation of a majority of counties in the Huang-Huai-Hai Plain then reverted to its original level in 1996.

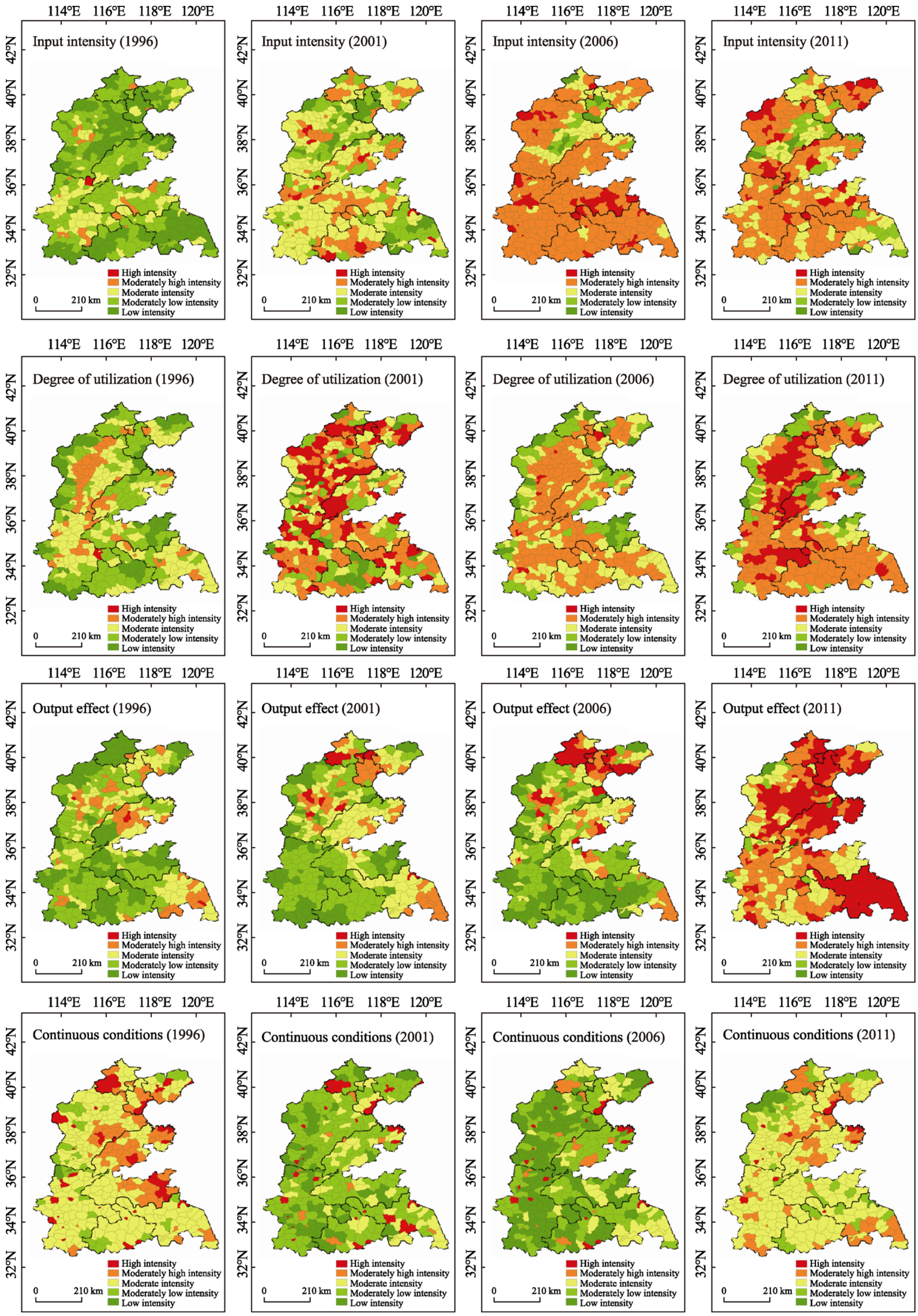


Figure 5 Variation in the intensive level of each subsystem from 1996 to 2011

3.3 Influencing factors of intensive cropland utilization

We generated a spatial distribution pattern of influencing factors, and added the spatial distribution pattern of intensive use of arable land (Figure 6). The analysis revealed the influence of these factors on the intensity of cropland use in the Huang-Huai-Hai Plain. Overall, the results showed that natural disasters were the dominant factor affecting the spatial pattern of intensive utilization of cultivated land, with an influence value of 0.158, accounting for 25.90% of the analyzed influencing factors. Elevation had an influence value of 0.143, accounting for 23.55% of the influencing factors. Slope had an influence value of 0.129, accounting for 21.23% of the influencing factors. Road networks had an influence value of 0.054, accounting for 8.78% of the analyzed influencing factors. The results of this analysis provide a reference point for enhancing the level of intensive use of croplands in the plain, and implementing different agricultural policies.

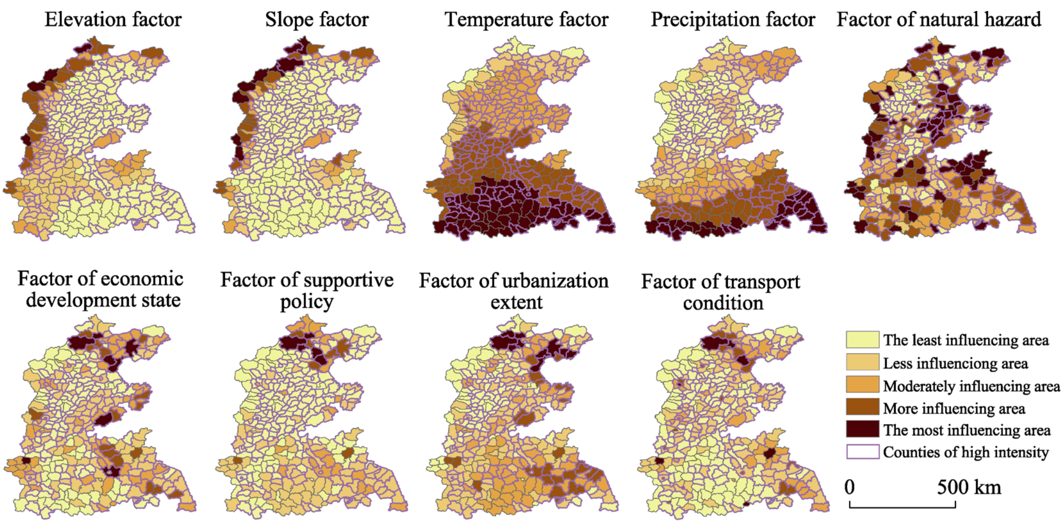


Figure 6 Spatial distribution of influencing factors and the degree of intensive use of croplands
(Annotation: Both influencing factors and districts with high intensity in the chart are based on the data of 2011.)

3.3.1 Influence of elevation and slope on the spatio-temporal patterns of intensive cropland use

Topography is an important factor affecting regional differences in the intensive use of cultivated land, which mainly shows that differences in elevation and slope will cause changes in the spatial patterns of cultivation intensity. We found that areas with moderately high and high levels of intensity in cropland use were distributed in low-lying areas. Areas at high elevations and with steep slopes were found to have very low intensities of cropland use. For example, in areas around Taihang and Yanshan mountains, farms were scattered and there was little arable land. Areas at low elevations with flat terrain have more concentrated croplands and frequent human activities. These locations have favorable conditions for agricultural production, and adequate inputs of labor and material resources per unit area of cultivated land. Road networks are also well developed and conducive to agricultural mechanization. Thus, the intensive use of croplands was relatively high.

3.3.2 Impact of natural disasters on the spatio-temporal patterns of intensive cropland use

The Huang-Huai-Hai Plain is located in the monsoon climate region, which means there are more frequent droughts and floods. Temperature and precipitation in the region show a decreasing trend from south to north, but surprisingly the counties with moderately high and high levels of cropland intensity are mostly distributed in the areas where the average annual temperature is slightly lower and rainfall is moderate. In areas where there is an uneven distribution of precipitation, seasonal drought and flood disasters can directly affect the stability index of croplands and reduce the intensity of cropland use.

3.3.3 Influence of road networks on the spatio-temporal patterns of intensive cropland use

Road networks influence the spatial pattern of cropland use. Under normal circumstances, more developed road networks are associated with moderately high levels of cropland intensity, and sparser road networks are related to moderately low levels of intensity in the use of cultivated land. Areas with high-density transportation networks in and around Beijing, Tianjin, south Shandong, and north Jiangsu have developed economies, high levels of urbanization, and a great demand for agricultural products. These factors drive farmers to actively embrace the development of intensive agriculture. However, in remote areas, sparse road networks increase the cost of agricultural production, resulting in less intensive modes of operation. In these areas, farmers still rely mainly on traditional grain and economic crops, which reduce the intensity of cropland use. With economic development and improvement in road networks, transportation becomes an active factor in the intensity of cropland use and its influence may be positive on the spatial pattern of the cropland intensity.

4 Discussion

From the results, we make the following recommendations: 1) The main grain-producing areas in the Huang-Huai-Hai Plain should actively promote agricultural intensification and large-scale management. Government agricultural agencies should improve the efficiency of agricultural production by developing large-scale management and comprehensive planting and breeding programs. In addition, agricultural officials should promote rural land rights and ownership on the part of local farmers to improve rural land management. Once land rights and contracts are established, agencies should explore the effective implementation of moderate-scale management. 2) The government should also actively develop the economy and promote the construction of road networks. In rural areas with relatively low levels of intensive cropland use, efforts must be made to promote road network construction, with emphasis on field roads, ensuring smooth operation of large-scale agricultural machinery. This will significantly contribute to improving the efficiency of farming and the level of agricultural mechanization. 3) The government should also strengthen prevention and early warning systems for drought and flood disasters, as well as improving response capacity to natural disasters. To this end, the local government should first establish an effective network to monitor potential climate threats by linking meteorological stations, hydrological stations and rainfall monitoring stations located in different regions. Second, water conservancies should be set up to regularly dredge the main rivers (such as the Yellow River, Huaihe River, and Haihe River), renovate and construct new coastal dams, and improve flood storage capacity. 4) The government should promote moderate and intensive use of arable land, focusing on restoration and sustainable use of cultivated land. Further research are required to find a reasonable threshold of land intensity, according to the law of diminishing returns. In agricultural production, the government should determine the most appropriate level of inputs, such as the application of fertilizers, through experimental testing of the effects on soil to maximize the overall benefit of cropland use and achieve sustainable use of cultivated land.

The general trend of change in intensive use of croplands on the Huang-Huai-Hai Plain is in agreement with the conclusions of Cao *et al*. (2009). They demonstrated that constructing an evaluation index system from inputs, outputs, utilization, and sustainable use, as well as introducing the method of emergy value, were feasible in the evaluation of intensive use of croplands. However, the results of the index system, evaluation units, and research methods slightly varied across time and space in comparison to their study results. In addition, our concepts about moderate intensity, proper fallow, and promoting sustainable development were in agreement with Zhao *et al*. (2001), Zhang *et al*. (2014) and Wu *et al*. (2000). The Zhao's and Zhang's study also focused on spatio-temporal differences in the continued status of the subsystem and law of decreases in land remuneration. The Wu's study focused on super high yield characteristics of intensive planting systems, groundwater crises, and the unity of opposites in agricultural intensification and sustainability.

The shortcomings of this study were primarily in the difficulty in obtaining or quantifying ecological indicators, and the impacts of agricultural production on carbon emissions and biodiversity. In addition, it is difficult to accurately measure the sustainability status of arable land, which inevitably reduces the accuracy of evaluation. Because of time limitations, we only considered the influence of environmental, social, and economic factors at a large scale. The influence from towns, villages, farmers, plots and other micro-scale factors should also be considered for a more in-depth analysis.

In the future, we should focus on acquiring and quantifying relevant ecological indicators, and improve the existing index system and scientific methods for evaluation. To enhance the objectivity and rationality of the analysis, various research efforts should be integrated into a driving force analysis that features relevant indicators of intensive use of arable land.

5 Conclusions

We conducted a spatial analysis of different levels of intensive use of croplands and its evolution in the Huang-Huai-Hai Plain. For this purpose, an index system and a comprehensive evaluation model were constructed. The Delphi-entropy method was adopted to determine the weight of the index, and a GeoDetector model was built to explore influencing mechanisms of intensive use of croplands. The following main conclusions can be drawn:

(1) In terms of temporal changes, from 1996 to 2011, the overall intensity of the use of arable land in the Huang-Huai-Hai Plain has increased. The number of counties with high intensity rose gradually and then rapidly increased by 46% after 2006. The number of counties with moderately high intensity and moderate intensity also rose with some fluctuation and accounted for a relatively high proportion (38%) in 2011. The number of counties with moderately low and low intensity declined gradually, especially during the period from 2001 to 2011, occupying a negligible proportion (0.6%) by the end of the study period. Overall, the intensity of input, degree of utilization, and effect of output showed an increasing trend

(with some fluctuation) and the continuous situation showed a trend of overall decline (by 4.9% per year), which then rebounded. On the whole, the utilization level of the vast majority of counties in the Huang-Huai-Hai Plain was high. The results are in agreement with descriptions of the current characteristics of cropland use in the Huang-Huai-Hai region.

(2) In terms of spatial differences, the overall level of intensive cropland use in the Huang-Huai-Hai Plain gradually increased, with obvious differences in different regions. In the Yellow River and Huaihe River basins, water resources are abundant, so the overall level of arable land use intensity is relatively high. There are intense inputs in Shandong, Henan and Anhui, which are the major agricultural provinces. Jiangsu and northern Anhui have favorable natural conditions and high utilization level of arable land. There is an obvious output effect in most areas, especially evident after 2006. From 1996 to 2006, in addition to northern Jiangsu, the level of intensity in the Huang-Huai-Hai Plain declined at the end of the study period; the continuous situation of a majority of counties in the Huang-Huai-Hai Plain then reverted to its original level in 1996.

(3) The most important factors affecting the intensity of cropland use in the Huang-Huai-Hai Plain are natural disasters, elevation, slope, and road networks. Natural disasters are the core factor limiting arable land intensification in this region. However, damage from disasters can be reduced or mitigated through early warning systems and rational use of land. Elevation and slope factors, as stable congenital conditions, will not cause a fundamental change in arable land intensification. However, road networks can significantly influence intensification and are relatively easy to develop.

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