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Spatiotemporal characteristics and driving mechanisms of arable land in the Beijing-Tianjin-Hebei region during 1990-2015

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ABSTRACT

This paper is an analysis of the spatiotemporal evolution characteristics of arable land in the Beijing-Tianjin-Hebei region from 1990 to 2015 and detects the driving factors of arable land change. On the basis of the study, the existing problems of arable land are discussed and some suggestions to promote regional rural development are proposed. The conclusions are as follows: (1) The proportion of arable land gradually decreased from 1990 to 2015 and the proportion of arable land in the south of the Beijing-Tianjin-Hebei region was larger than that in the north of the Beijing-Tianjin-Hebei region: arable land with a proportion of more than 75% lies in the low elevation and slope. The proportion of arable land in Beijing has also decreased faster than in other regions because most arable land was converted primarily into construction land due to urban expansion. (2) The mechanism showed that county economies and populations influenced the change in the quantity of arable land, and the position and natural conditions influenced the pattern changes in arable land. (3) Finally, this paper details some suggestions on the terms of legal institutions, the land consolidation project, and developing modern agriculture and industrial upgrading, which could provide scientific support for rural sustainable development and arable land protection in the Beijing-Tianjin-Hebei region.

1. Introduction

Cultivated land is a basic resource and condition for human survival. With economic development and urbanization, there is an increasing demand for land to be used for construction and, as such, the amount of arable land has decreased since the twentieth century. In addition, waste and pollution have led to a substantial drop in the quality of land. Both of these conditions have contributed to an increasing challenge to food security [1,2,3,27]. Furthermore, the human population continues to increase rapidly and human survival is being seriously threatened. Thus, the incongruity between people and land is one of the most serious problems of the 21st Century.

More and more scholars have begun to pay attention to cultivated land protection and food security using scientific methods and measures [4–7]. In recent years, international researchers have studied cultivated land from aspects of soil quality and nutrients, breeds of crops, planting techniques, and management measures [8,9]. Contrastingly, Chinese scholars have paid more attention to land quantity over land quality because there is less cultivated land in China, in comparison to other countries around the world. Thus, the land comprehensive consolidation project has been one important measure, in recent years, that has seen the implementation of protection policies of 1.8 billion mu cultivated land red line [10,11], such as tideland reclamation, hollowing village renovations [12,13], the development of barren hills, and the control of gullies [14,15]. However, there continue to be problems in the quality of arable land including soil erosion, heavy metal pollution in soil, the salinization of arable land, and soil compaction [16–19].

Thus, diagnosing various problems and detecting their influencing factors are important paths through which to propose scientific measures to improve cultivated land quality and ensure food security [20]. This study made innovative use of the multivariable linear regression, path analysis, and a geographical detector to detect temporal and spatial driving factors, and analyzed the characteristic spatial differences and evolutionary laws of arable land level on the scale of the county in the Beijing-Tianjin-Hebei region from 1990 to 2015. In this article, the level of arable land is the proportion of cultivated land area in each cell (5 km*5 km). Furthermore, the study included a deep analysis of the mechanisms of influencing factors in arable land level, and a summary of existing problems of arable land in the Beijing-

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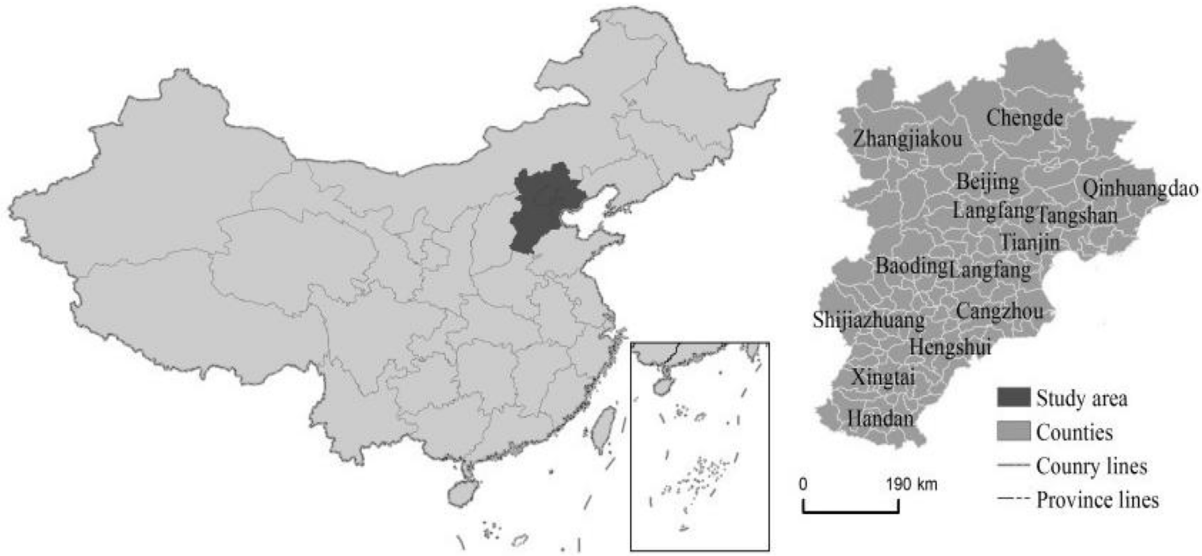

Fig. 1. Study area.

Table 1
The driving factors of arable land.

	Temporal driving factors		Spatial driving factors
Economy	GDP index (x_1)	Regional factors (natural conditions)	Altitude (y_1)
	Fixed assets investment index (x_2)		Slope (y_2)
	Fiscal income index (x_3)	Line factors (Traffic location)	Distance to the main railway (y_3)
Population	Population density index (x_4)		Distance to the main river (y_4)
	Urbanization rate (x_5)		Distance to the main road (y_5)
Industry	Second industry structure index (x_6)	Point factors (Economic Location)	Distance to the city center (y_6)
	Third industry structure index (x_7)		
	Value of industrial output index (x_8)		

Tianjin-Hebei region and, finally, a list of suggestions for arable land protection for the government.

2. Geographic scope and methods

2.1. Study area

The Beijing-Tianjin-Hebei region is the “capital circle” of China and includes 13 cities and 200 counties (Fig.1). It is one of the most developed and prosperous regions and attracts worldwide attention. At the end of 2015, the total population of the Beijing-Tianjin-Hebei region was 111 million and of those, people living in urban areas totaled 69.7 million: its urbanization rate was 62.5%. The gross domestic product (GDP) was about one trillion dollars and the per capita gross domestic product had already exceeded 9000 dollars. Increasing numbers of people living in rural areas have been attracted to work in cities. With subsequent socioeconomic development, urban and industrial extensions have led rural economies surrounding cities to develop rapidly. More farmers have abandoned traditional agriculture and converted to modern methods to promote higher earnings. As a result of these factors, substantial change has taken place in the rural areas of the Beijing-Tianjin-Hebei region over the past 30 years. As such, the region was a typical case area through which to study rural transformation in the last 20 years.

2.2. Data and methods

The raster of land use (in which the resolution ratio is 100 m) is sourced from the China Academy of Sciences Data Center for Resources and Environmental Sciences to analyze the evolution characteristics of arable land in the Beijing Tianjin region from 1985 to 2015. DEM data (in which the resolution ratio is 90 m) is sourced from the National Geographic Information Center. In this study, we converted the raster resolution to 5 km for scale unification and each grid is taken as a sample point. Thus, the level of arable land is calculated based on the proportion of cultivated land in the area of each cell (5 km*5 km). Following this, we obtained altitude (y_1) and slope (y_2) through image correction and slope analysis, and calculated the distance of sample points to line and point factors, including the distance to the main railway (y_3), the distance to the main river (y_4), the distance to the main road (y_5) and the distance to the city center (y_6) using GIS spatial neighborhood analysis. Lastly, we selected the temporal driving factors at the level of the economy, population, and industry according to previous experience. The data comes from the “Chinese Statistical Yearbook”, the “Chinese City Statistical Yearbook” and the “Chinese City Construction Statistics Yearbook” (Table 1).

(1) The multivariable linear regression was used mainly to understand the statistical relationship between independent variables and dependent variables, and the influence of various factors on the rural transformation development in terms of quantity relationship. This method allowed the elimination of the collinearity effects of independent variables and enabled us to obtain the linear model of factors and rural transition development [21,22].

$$y = \sum_{i=1}^{n} \beta_i * z_{ij} \tag{1}$$

(2) The path analysis was a multivariate statistical technique that was proposed in a paper published by number geneticist, Se-wall Wright, in 1921, about the “related”, and studied the direct and indirect importance of dependent variables to independent variables through

the decomposition of the direct correlation between an independent variable and dependent variable, which could provide a reliable basis for statistical decisions [23,24]. The equations were constructed by using the relationship between independent variables (x_m), the dependent variables' path coefficient (P_{my}), and the correlation coefficient (r_{my}):

$$\begin{cases} P_{1y} + r_{12}P_{2y} + \ldots + r_{1m}P_{my} = r_{1y} \\ r_{21}P_{1y} + P_{2y} + \ldots + r_{2m}P_{my} = r_{2y} \\ \vdots \\ r_{m1}P_{1y} + r_{m2}P_{2y} + \ldots + P_{my} = r_{my} \end{cases} \tag{2}$$

The residual path coefficient is $B_{e.y} = \sqrt{1 - (\sum_{k=1}^{m} D_{k.y} + \sum_{k\neq j}^{m} D_{kj.y})}$. A larger value of $B_{e.y}$ reflects that there are other factors influencing the dependent variables. The path coefficient is "$P_{my}=\beta_m \frac{S_{x_m}}{S_y}$" and the coefficient of determination is $D_{my} = P_{my}^2$, which shows the degree to which each variable is related to the dependent variable. S_{x_m} is the standard deviation of x_{mi} and S_y is the standard deviation of y. $D_{k.y}$ and $D_{kj.y}$ reflect the direct or indirect determinant coefficient of the dependent variable. The study determined whether the multiple regression model was reasonable according to the size of residual path coefficient; the model was considered better when the residual path coefficient was less than 0.1, showing that the selected independent variables had a significant influence on the dependent variable. Conversely, the model was worse when the residual path coefficient was larger than 0.2, showing that there were other factors influencing the dependent variable.

(3) The geographical detector is used to obtain the correlation factor variables and outcome variables through the discrete classification of various factors with different processing methods, based on the theory of spatial difference, and an analysis of the influence of different variables in the same spatial scales [25,26]. The factor force (q) is introduced to describe the effect value of variables. In this article, the factor force is used to measure the influence of spatial factors on the distribution of arable land. Firstly, the spatial factors are divided into different types according to their own characteristics. If the level of arable land in each factor type has no difference, it indicates that the factor has a greater effect on the spatial distribution of arable land; otherwise, it has no effect.

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \tag{3}$$

3. Results

3.1. Spatiotemporal evolution characteristics of arable land

There were great differences in arable land in terms of temporal and spatial changes from 1990 to 2015. In this study, we divided the proportion of arable land into four types using the method of quadrate: types include lower-level [0–25%), low-level [25%–50%), middle-level [50%–75%), and high-level [75%–100%). The level of arable land in the southern region of Beijing-Tianjin-Hebei was higher than that of the northern region, and most counties of the southern region belonged to the high-level type (Fig.2). However, the proportion of arable land in the Beijing-Tianjin-Hebei region gradually decreased from 1990 to 2015; ratios in the high-level were 53.09%, 50.62%, 49.38%, and 47.53%, and the ratios in the lower-level were 11.11%, 12.35%, 12.96%, and 12.96%. Thus, the spatiotemporal evolution characteristics of arable land were that it decreased progressively over time and there were obvious differences between the north and south of the Beijing-Tianjin-Hebei region.

To further analyze changes in arable land proportion, we used spatial calculation to acquire Fig. 3. There were both positive and negative changes in arable land proportion. The percentage of positive change was 8.62%, in the southwest of the Beijing-Tianjin-Hebei region, and the arable land proportion change in most counties was negative, at a percentage of 91.38%. The largest region in which the proportion of arable land decreased is located in the vicinity of Beijing and Tianjin, as shown in Fig. 3, and their values were less than −10%. The results show that arable land proportion has decreased in most counties of the Beijing-Tianjin-Hebei region with the socioeconomic development over the period of 1990–2015.

3.2. Detecting factors of arable land change

According to a multivariable linear regression and correlation analysis, the temporal driving factors were identified as the fixed assets investment index (x_2), the fiscal income index (x_3), the population density index (x_4), and the rate of urbanization (x_5). These factors allowed the construction of a regression model by the enter method as shown in Formula (4) and their correlation coefficients are −0.159, −0.299, −0.546, and −0.436, respectively, showing a significant correlation with a change in arable land proportion at the 0.05 confidence level. This study also needed to test the rationality of variables by path analysis, and the result shows that the residual path coefficient is 0.34, which is larger than 0.2, meaning that there are other factors influencing changes in arable land.

$$y = 5.306 + 0.039x_2 - 0.073x_3 - 0.113x_4 - 0.027x_5 \tag{4}$$

The spatial driving factors were primarily detected through the geographical detector. Firstly, we divided the spatial factors into different degrades according to their characteristics: the slope was divided into eight types at intervals of five; the altitude was divided into 23 types with a spacing of 100 m; the distances to main railway, main river, main road, and city center are divided into 16, 16, 18 and 19 types with a spacing of 10 km (Fig. 4). Following this, we loaded all spatial factor types into the geographic detector for results.

The results show that all factor forces are only slightly different from each other and the values of their P are less than 0.01, with the exception of their distance to the main road (Fig.5). In addition, the factor forces of slope and distance to the city center are greater than 0.1, which reflects that slope (y_1) and distance to the city center (y_6) are the spatial driving factors with greater influence on the changes in arable land than other factors; their values are 0.11 and 0.13, respectively. However, the distance to the main road had little influence on changes to the proportion of farmland.

3.3. The driving mechanism of arable land change

In the detection of factors of arable land change, temporal and spatial driving factors include the fixed assets investment index (x_2), the fiscal income index (x_3), the population density index (x_4), the rate of urbanization (x_5), slope (y_1) and the distance to the city center (y_6). These represent the economy, population, natural conditions, and position (Fig. 6). Thus, it is crucial to analyze the mechanism of driving factors in the changes to the arable land proportion in order to realize the sustainable development of arable land in the Beijing-Tianjin-Hebei region. This could provide a reference for the scientific division of grain production functional areas.

(1) Economic factors include the fixed assets investment index and the fiscal income index. These two indexes represent the economic ability of the region, showing a need for more land and capital to support regional development. Cities attract substantial rural labor and this contributes to the development of arable land for industry and to cater to an increased demand for residential properties. Thus, the economic factors are the attracting forces for agriculture and villages. However, economic strength also provides capital support for agricultural development, which could contribute to the development of agricultural facilities and expand the market for agricultural products to counterbalance problems around the occupation of arable land. Counties in Beijing and Tianjin are developed and their arable land has

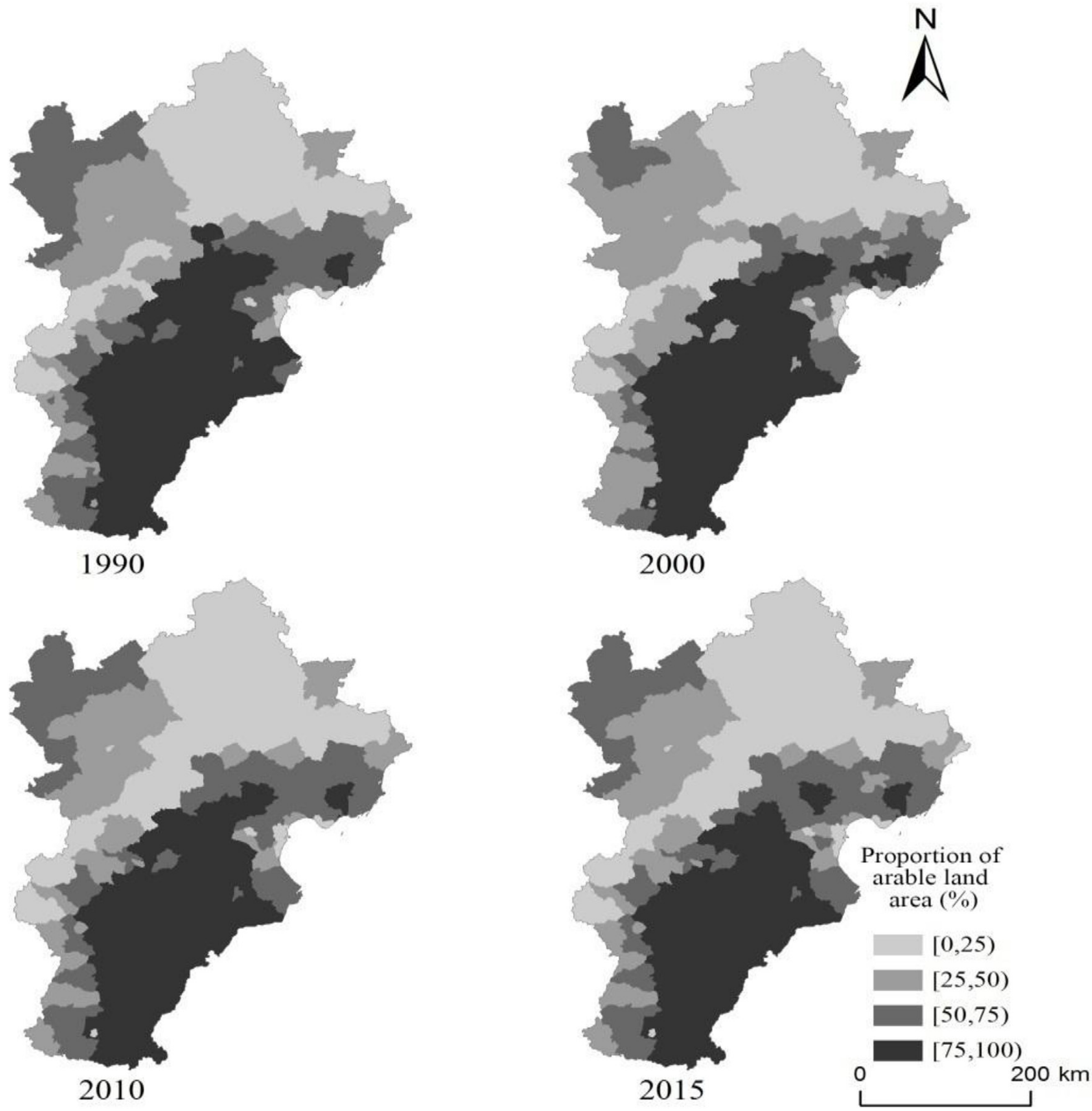

Fig. 2. The spatiotemporal evolution of arable land proportion from 1990 to 2015.

decreased with economic development but their agricultural production continued to have a high output. However, agriculture in counties in Hebei developed poorly in spite of a substantial amount of farmland.

(2) Population factors include the population density index and the rate of urbanization, which mainly refer to the growth of the population and have a heavy bearing pressure on food security. On the one hand, a growing population requires more food and more space in which to reside, and this manifests the incongruity between man and land. On the other hand, while the population is increasing, young rural labor is being depleted as people move out of villages to seek employment in cities. As a result, a substantial amount of arable land is abandoned. Thus, problems in rural areas include both a diminished number of farmers and the accompanying wastage of arable land. For instance, this study shows that counties in Baoding and Xingtai experienced a substantial loss of young labor to Beijing and Tianjin every year, which is why counties around Beijing and Tianjin, such as these, have been poor in rural development and require increased assistance from the government every year.

(3) The factor of position is the distance to the city center and represents the radius of arable land to a city. The influence of cities on arable land mainly manifests in two aspects. Firstly, arable land nearest to cities has been easily occupied and developed into industrial and commercial land as an increased number of farmers relocated to an urban population. Thus, the amount of arable land nearest to cities diminished faster. Secondly, regions nearest to cities could obtain facilities and services like better medical treatment and education, and provide convenient market sale channels for agricultural production. The counties of Langfang and Tangshan near Beijing and Tianjin had better agricultural development than those further from large cities.

(4) The natural condition of land is the basic factor influencing the pattern of farmland. As has been established, the slope of arable land is generally less than 25° and patches of arable land should be level. Urban areas and towns built on the plains have developed faster than other places because they are more convenient for infrastructure such as transport. In the northwest of the Beijing-Tianjin-Hebei region, there is less arable land because of the natural topographic features of the area. However, what arable land that was available in these regions was occupied for the construction of industrial, commercial, and residential land. In addition, these

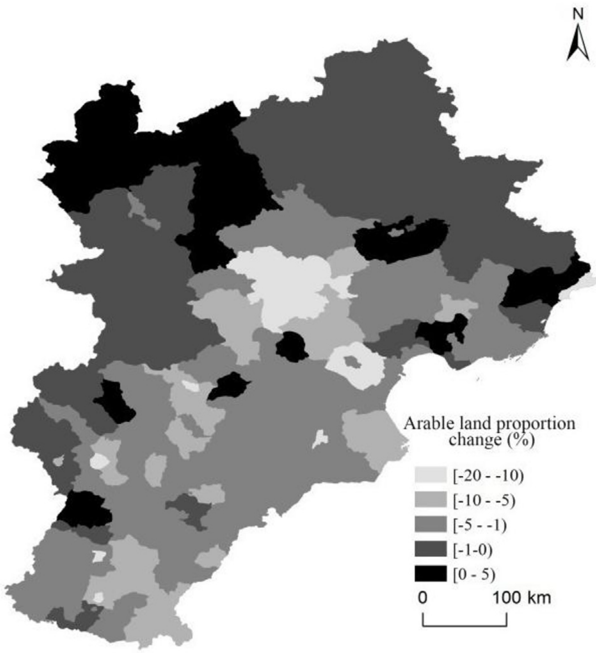

Fig. 3. Changes in the proportion of arable land from 1990 to 2015.

regions have greater ecological and tourism resources with the potential for development and bear the function of ecological conservation.

Thus, the economy, population, position, and natural condition of land are the essential factors influencing changes in arable land with spatial and temporal aspects. These factors combined play an important role in the system of driving mechanisms.

4. Discussion

Arable land is the material basis of agricultural living and the security of the entire nation's livelihood and development. Thus, detecting the driving factors of differences in arable land over space and time could be significant for arable land protection and food security, and will allow us to realize the sustainable development of arable land in the Beijing-Tianjin-Hebei region. Thus, exploring the origin and location of arable land could offer scientific support for rural development planning and arable land protection in the Beijing-Tianjin-Hebei region.

The area of arable land has decreased by 4967.9 km^2 between 1990 and 2015, and the area of arable land that has been converted to other functions is 8507.4 km^2. In addition, the area of other land that has been converted into arable land is 3539.5 km^2. The primary conversion of arable land has taken place around cities and towns in terms of rural residential land, which account for 25.99% and 32.60% of the total area. The main land use types which have been converted into arable land are grassland and rural residential land, which account for 37.92% and 21.55% of the total area, as shown in Fig. 7.

According to the raster calculation from 1990 to 2015, we obtained the spatial pattern of arable land change, as shown in Fig. 8. Arable land around city centers has been converted primarily into construction land, such as Beijing, Tianjin, Tangshan, Shijiazhuang, and Baoding. These are the more developed cities in the Beijing-Tianjin-Hebei region with high GDPs and population density. Higher economic levels tend to offer an increased chance of employment, which has attracted many rural laborers as well as the need for more land in order to meet social and economic demands. Thus, arable land around the cities has been reduced faster than in other places, and most of this land has been repurposed as construction land for the expansion of cities. Areas of

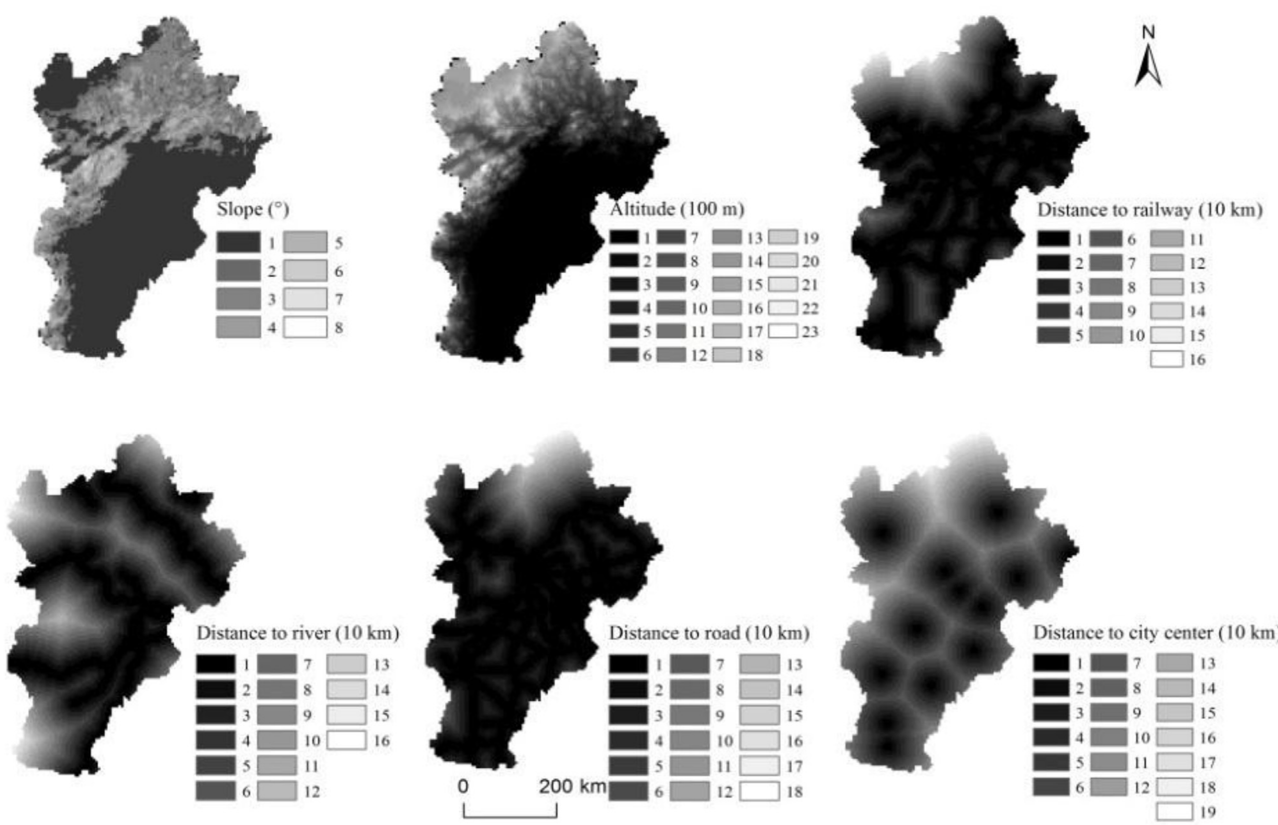

Fig. 4. Spatial factor types.

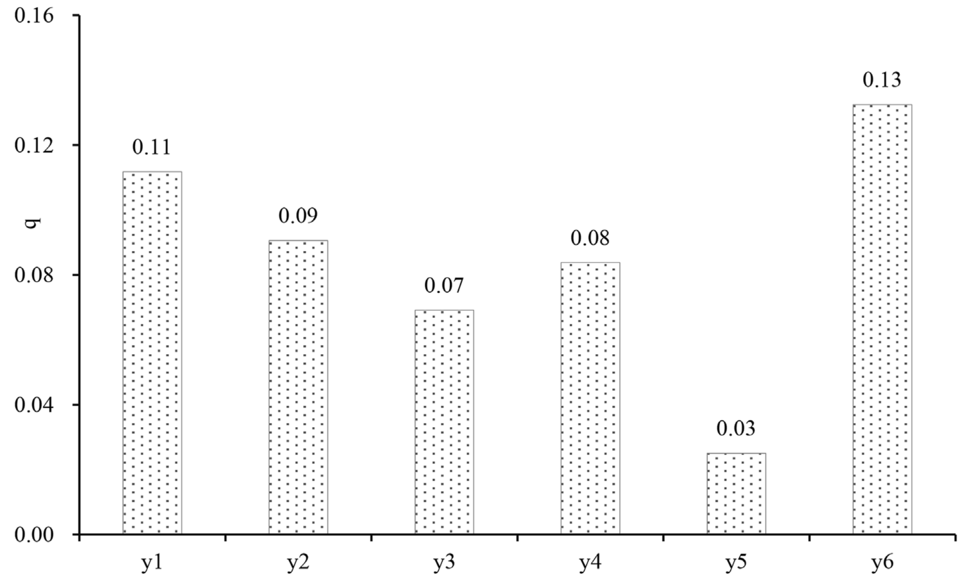

Fig. 5. Forces of spatial factors.

grassland which have been repurposed as arable land are located in the northwest of the Beijing-Tianjin-Hebei region and these regions have lower GDPs than other places in the region. Thus, the development of arable land to meet demand is an important measure. Additionally, the repurposing of rural residential land into arable land tends to have taken place around the coastal area because of new types of urbanization and new rural constructions that have dismantled rural construction land to renovate arable land and improve land use efficiency.

There is still a decrease of 20000 hm^2 of arable land per year and most of this has been repurposed into construction land, accounting for 70.03% of the total area, and which has been used to meet the demand for urban expansion. Especially in the last ten years, the demand for land has gradually increased alongside the development of society and the economy. However, there are also problems with remaining arable land including land pollution, poor quality of arable land, and a shortage of resources in reserve.

In 2017, it was recorded that 11 million 440 thousand acres of arable land have poor environmental geological conditions, including 6 million 100 thousand acres with land subsidence and 5 million 340 thousand acres with salinization and pollution. In addition, there are 650 thousand acres of arable land with heavy metals or serious pollution, accounting for 5.68% of total problematic arable land in the Beijing-Tianjin-Hebei region, which is primarily distributed around old industrial regions and towns and that could not be used as crop growing areas. Problematic arable land should be addressed through control of the planting structure and the reuse of farmland for other purposes according to the report of the Geological Survey Department of Ministry of Land and Resources.

The level grades of arable land in the Yanshan Mountain and Taihang Mountain were lower than that in the central and southern plain of the Beijing-Tianjin-Hebei region. In addition, the arable land of the northern and western mountains has poor natural conditions and weak infrastructure. However, the central and southern region of the Beijing-Tianjin-Hebei region have developed economies and the urban sprawl has grown faster than other regions; the arable land of these regions has been repurposed as urban and rural residential land. Thus, the arable land has gradually decreased to meet the demand of urban expansion. The northwest of the Beijing-Tianjin-Hebei region was used to plant crops in order to meet the demand for food and balance the distribution of land use.

The third problem in the Beijing-Tianjin-Hebei region is insufficient arable land resources. There are less than 1 million acres of arable land

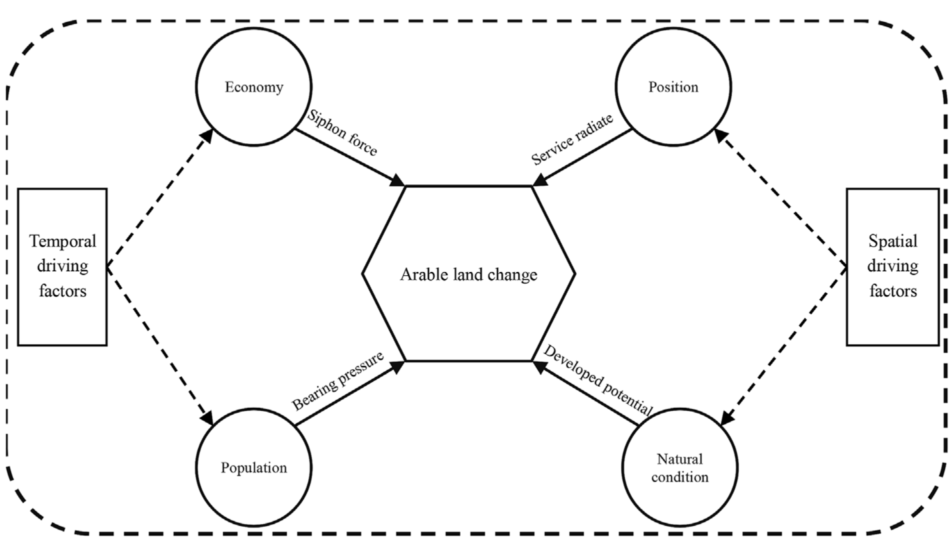

Fig. 6. Driving mechanisms of spatiotemporal factors.

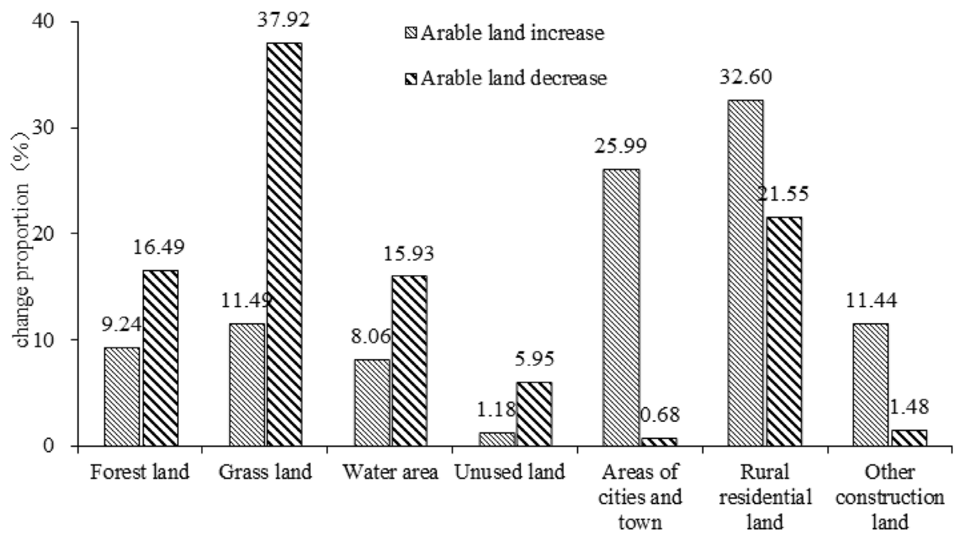

Fig. 7. Arable land conversions from 1990 to 2015.

resources in reserve in the Beijing-Tianjin-Hebei region, according to government statistics released in 2014. More and more supplementary arable land, which was needed to balance the quantity of available arable land, is located in remote mountain areas. This arable land is of low quality. In addition, the development of this land has also destroyed the local ecological environment. Arable land is the basis of human living and fundamental for food security. Thus, the total arable land resources in reserve could support regional socioeconomic development. The government in the Beijing-Tianjin-Hebei region must control the occupation of arable land in the process of urban expansion and improve basic farmland protection. However, there is another rich resource that could enable an increase in arable land through several engineering measures. According to the result of this study, 1.14 million acres of rural residential land was repurposed into arable land from 1990 to 2015. Thus, rural residential land consolidation is an important project to grow the quantity of arable land and support urban

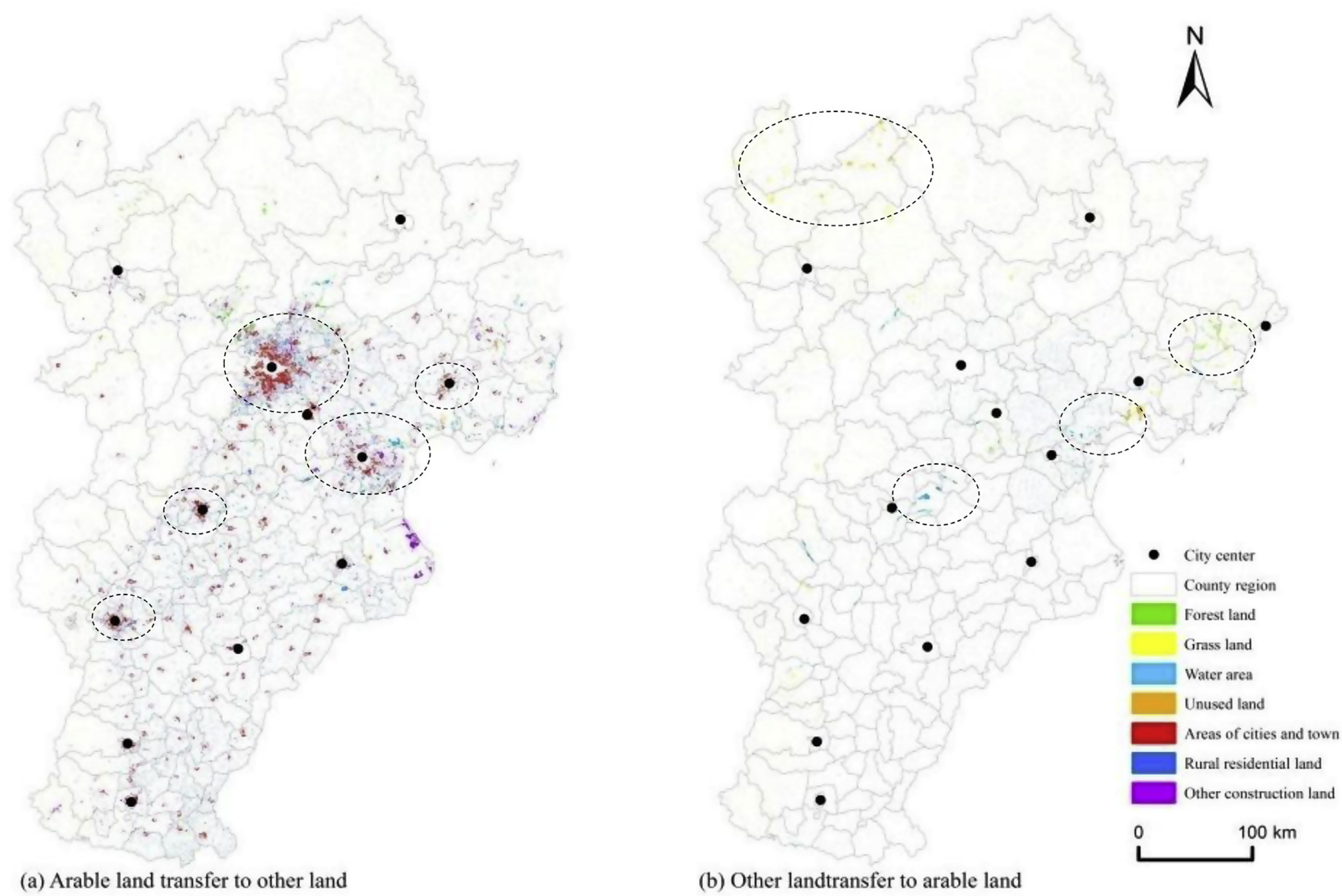

Fig. 8. The spatial patterns of arable land repurposing from 1990 to 2015.

development.

These three problems have seriously influenced the sustainable development of arable land in the Beijing-Tianjin-Hebei region and have restricted regional socioeconomic development and urban expansion, especially Beijing and Tianjin. Thus, it is necessary to propose scientific and effective suggestions for realizing regional sustainable development.

(1) A key measure is the formulation of a scientific development strategy plan given the limited arable land in the Beijing-Tianjin-Hebei region. This plan will guide development and provide technical references for scientifically backed, sustainable development. On the one hand, arable land protection laws must be formulated to make the destruction of basic farmland illegal, enabling the punishment of illegal behavior of occupying arable land. On the other hand, a scientifically backed and sustainable plan should be developed for each different region, according to their conditions, to better resolve developmental problems in the context of integration in the Beijing-Tianjin-Hebei region. Thus, the overarching strategy should strictly control urban boundary expansions to protect basic arable land from being repurposed and bear the responsibility of regional services. Strategies in the southern and eastern areas of the region need to identify key economic cities and major gain production cities with rich arable land, which bear the responsibility of regional food security and economic development. Strategies in the northern and western areas of the region must forbid the repurposing of arable land and protect the ecological environment due to poor natural conditions.
(2) The land consolidation project is an important measure to maintain the dynamic balance of arable land in the Beijing-Tianjin-Hebei region and is a key method to coordinate urban-rural development. Firstly, hollowing village renovation is the process of demolition and removal, soil construction, land reclamation, environmental construction, and community reconstruction in areas of vacant, abandoned, and unused land using engineering and biological measures by means of participation of farmers and the general public, which also takes into account the demand of arable land protection, new rural construction, and balancing rural and urban development. In Hebei Province, there are 7500 hollow villages and causing 40,000 ha of land waste. If these hollow villages are renovated, a large amount of arable land can be added. Secondly, land improvement is an essential measure through which to improve arable land quality and protect food security and includes arable land quality improvement, land reclamation, and land renovation such as channel regulation, desert governance, and barren hills reclamation, which could convert mountain and desert areas into high-quality arable land. There is a substantial amount of mountainous land in the northwest of the Beijing-Tianjin-Hebei region, which has been repurposed in recent years. Since 2015, Fuping County in Hebei Province has increased 1200 ha of arable land by barren hills reclamation and improved the income of more than 7400 farmers in 23 villages. However, construction quality must be guaranteed to protect the ecological environment from destruction.
(3) Modern agriculture has been the only way to realize agricultural sustainable development under the macro background of rapid urbanization in the Beijing-Tianjin-Hebei region, which is conducive to the improvement of agricultural production capacity and efficiency, including green agriculture, leisure agriculture, tourist agriculture, characteristic agriculture, and factory farming. Beijing-Tianjin-Hebei is a region which lacks arable land but still bears the burden of grain production. Thus, science and technology must be used to maintain food security under the condition of limited arable land in the region. In addition, the development of modern agriculture could increase farmers' income and promote their enthusiasm for production.
(4) Industrial upgrading should increase the value of agricultural products through the improvement of production factors, changing production structures, increasing production efficiency and product quality, and upgrading the industrial chain, which could alleviate the incongruity between man and land and improve the employment rate of rural laborers. Since the agricultural product is singular and primary, the price of products is low, and farmers have had to expand the scale of agricultural production to meet increasing material needs, especially in poverty-stricken areas of the Beijing-Tianjin-Hebei region. Industrial upgrading could improve the quality of agricultural products and market competitiveness, which could attract more rural laborers to work in villages and improve the living standard of rural residents. In addition, industrial development should promote the farming of one product in each village and thus developing a trademark and forming an industrial chain of production, processing, and marketing.

5. Conclusions

In this study, we analyzed the spatiotemporal evolution characteristics of arable land in the Beijing-Tianjin-Hebei region from 1990 to 2015 and identified the driving factors behind arable land change using a multivariable linear regression and a geographical detector. On this basis, this paper is a presentation of the existing problems of arable land and the proposal of a series of suggestions to promote regional rural development through an analysis of the driving mechanisms behind arable land change. Conclusions are as follows:

(1) The proportion of arable land has decreased gradually over the period of 1990–2015 and the proportion of arable land in the south of the Beijing-Tianjin-Hebei region was greater than that in the north of the Beijing-Tianjin-Hebei region. Arable land with the proportion of more than 75% lies in the low elevation and low slope regions. The proportion of arable land in Beijing has also decreased faster than in other parts of the region and most of this land has been repurposed into construction land due to urban expansion.
(2) Temporal driving factors behind the repurposing of arable land include the fixed assets investment index (x_2), the fiscal income index (x_3), the population density index (x_4), and the rate of urbanization (x_5). Spatial driving factors include slope (y_1) and distance to the city center (y_6). These factors represent the economy, population, position, and natural conditions of the land, which play an important combined role in the system of driving mechanisms. These mechanisms show that county economies and populations influenced changes in the quantity of arable land and that position and natural conditions influenced changes in the pattern of arable land.
(3) According to spatiotemporal evolution characteristics and the driving mechanisms of arable land change in the Beijing-Tianjin-Hebei region, we analyzed problems around arable land, including land pollution, poor quality arable land, and a shortage of resources in reserve and proposed some suggestions in terms of legal institutions, land consolidation projects, the development of modern agriculture and industrial upgrading, which could provide scientific support for rural sustainable development and arable land protection in the Beijing-Tianjin-Hebei region.

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Appendix A. Supplementary data

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