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Spatial–Temporal Evolution Characteristics and Driving Factors of Rural Development in Northeast China

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Abstract: An assessment of rural development and its driving factors can effectively reflect the characteristics and transformation of rural areas and provide important information for the formulation and implementation of rural development strategies. Taking Northeast China as study area, a rural development index framework was constructed from three dimensions, i.e., basic rural conditions, the state of agricultural development, and farmers' living standards, based on which the rural development level of each city in Northeast China for the years 2000, 2005, 2010, 2015 and 2020 was assessed. Then, an exploratory spatial data analysis was used to explore the spatial and temporal variations in the rural development level in Northeast China during the period 2000–2020. The driving factors were also analyzed using a geographically and temporally weighted regression model. The results showed that the rural development level showed an increasing trend overall, with a spatial pattern of "high in the central, low in the east and west" in most periods. The degree of spatial agglomeration of the rural development level also showed a strengthening trend overall. The hots spots of rural development were mainly distributed in the Southern and Northern regions, while the cold spots were mostly concentrated in the central, eastern and western regions. Urbanization processes, elevation, annual precipitation and other natural factors have weakened the level of rural development to a certain extent, while agricultural production upgrading, an increase in the general public budget expenditure per capita and the sound financial situation of the government can promote rural development in Northeast China. The effects of the natural environment and local economic conditions on rural development were different in different regions. To improve rural development in the future, we should scientifically grasp the basic conditions, such as rural resource endowment, location conditions, agricultural technology, policies, investment and other external conditions, and formulate regional rural development strategies according to local conditions and in light of local rural characteristics.

Keywords: rural development; spatial–temporal divergence; driving factors; Northeast China

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1. Introduction

Sustainable development is a common goal of all countries in society [1,2]. However, most studies currently focus on the sustainable development of countries as a whole or on urban areas as the main areas of socio-economic activity [3]. As an important part of the country, especially in developing countries, the sustainable development of rural areas is often neglected [4,5]. Rural decline, rural population reduction and outflow, land loss, rural ecological environment pollution, backwards infrastructure and other problems are becoming increasingly serious and significantly hinder the sustainable development of rural areas [6]. As a typical developing and agricultural country, China's three rural issues (agriculture, rural areas and farmers) have been some of the major social issues

concerning the government and all sectors of society [7]. These issues constitute the major contradictions in China's economic and social development. In recent years, China's rapid economic development has led to a rapid urbanization process [8]. However, this has also led to an imbalance in the development of rural and urban areas [9,10]. The sustainable development of rural areas is further constrained by the shift of arable land to other types of land [11,12], the loss of rural labor [13,14], the increasing aging of the rural population [15,16] and the loss of rural culture [17]. The imbalance between urban and rural areas must be addressed urgently, and rural revitalization is an important part of future socio-economic development [18].

A quantitative evaluation of rural development is a prerequisite for recognizing the current state of rural development and for gaining insight into the weaknesses of rural development [19]. Research on rural areas mainly focuses on rurality evaluation [20], the spatial differentiation of rural settlements [21], rural reconstruction and rural multifunctions [22,23]. In addition, the evaluation of rural development should not be limited to a single aspect but should be based on the actual situation and a reasonable choice of evaluation angles [24]. Rural revitalization covers several areas, including ecological viability [25,26], industrial development [27], harmonious human governance [28,29] and cultural prosperity [30]. Therefore, scholars generally adopt the construction of rural indicators, field surveys and grouping to evaluate the level and characteristics of rural development [31]. The evaluation system changes with different research areas and data dimensions [32]. The evaluation indicators mainly include employment structure, traffic patterns, population density and structure, resident satisfaction, distance from the city center and other socio-economic and geospatial patterns and subjective survey indicators [33]. Conventional indicators can be applied in most research areas, but the selection of micro-indicators and more detailed and targeted indicators can be adapted to local conditions to carry out unique analyses of the actual situations in rural areas [34,35]. For example, rural areas endowed with tourism resources need to incorporate more tourism-related factors such as the number of hostel beds, the number of tourists and the number of scenic spots into the evaluation system [36]. In rural areas dominated by the planting industry, more consideration should be given to industry-related indicators such as the yield of agricultural products and input of agricultural capital [37].

After the quantitative evaluation of rural development, the factors influencing rural development must be identified [38]. Based on this identification, the weaknesses in rural development analyzed in the quantitative evaluation are targeted for improvement and management. Rural development can be driven by both external factors and internal factors [39]. A variety of models and methods are applied to identify and analyze the driving factors of rural development [40–42]. Ma et al. quantitatively analyzed the urban–rural transition in Gansu Province by constructing a comprehensive evaluation index system for county population and land industrial systems and a quantitative model of the degree of urban–rural transition and explored its spatiotemporal changes and driving forces through the use of hotspot identification and a geographic detector model [43]. Yang et al. used the entropy weight-TOPSIS method to measure the rural resilience level in 31 regions in China and analyzed the configuration of influencing factors using a fuzzy-set qualitative comparative analysis (fsQCA) [44]. Yuan et al. used a spatial regression model to determine the core influencing factors and main driving mechanisms extracted at different stages [45]. Nie et al. used an intensity index of rural spatial reconstruction and the contribution rate of rural spatial reconstruction to quantitatively evaluate the spatial development levels of tourist villages on a microscale, investigating the stage characteristics of their spatial reconstructions [39]. Clarifying the relationship between the influencing factors and sustainable rural development and exploring the specific mechanisms of influencing factors can provide theoretical guidance and policy suggestions for the implementation of a rural revitalization strategy and provide a reference for rural development research [46].

In view of the above research background and deficiencies, this paper aims to carry out a comprehensive and quantitative empirical study on the spatiotemporal patterns and driving mechanisms of rural development in Northeast China. The contribution of this study is mainly reflected in the following three aspects. Firstly, from the perspective of a rural revitalization strategy, the study is set in Northeast China, an important grain base in China. Moreover, there is a great difference between urban and rural development in Northeast China. The study spans a long period of time, from 2000 to 2020, with time intervals of five years. This makes the research results more representative. Secondly, representative indicators are selected from the perspectives of the state of agricultural development ("agriculture"), basic rural conditions ("rural areas") and farmers' living standards ("farmer") to explore the development of rural areas in Northeast China and to derive the characteristics of the spatial and temporal differences in sustainable rural development in different dimensions so as to provide a reference for the realization of sustainable rural development models. Third, for the analysis of the driving factors, the results of ordinary least squares regression (OLS), geographically weighted regression (GWR) and geographically and temporally weighted regression (GTWR) models are compared, and the GTWR model with the best fit is chosen to make the results more convincing.

2. Materials and Methods

2.1. Study Area

Northeast China covers 36 prefectures in three provinces, i.e., Liaoning, Jilin and Heilongjiang (Figure 1). Straddling the mid-temperate and cold temperate zones from south to north, it has a temperate monsoon climate with four distinct seasons, warm–rainy summers and cold–dry winters. Northeast China is rich in water resources and diverse in topography. It is surrounded by the Yellow and Bohai Seas to the south, the Yalu River, Tumen River, Ussuri River and Heilongjiang River to the east and north, and the land boundary to the west. The inner part of Northeast China contains the high mountains, middle mountains, low mountains and hills of the Greater Khingan Mountains, Lesser Khingan Mountains and Changbai Mountains, and the central part contains the vast Songliao great plain and Bohai sunken area. The complex and diverse geographical environment provides abundant agricultural resources such as arable land, natural vegetation and fresh water, constituting the foundation of regional rural development. Northeast China vigorously developed a heavy industry for the economic construction of China during the early period of its founding. Since China's reform and opening up, due to environmental pollution, as well as the old industrial bases in Northeast China and other problems, the development of urban and rural areas in Northeast China is unbalanced, relatively slow, and some remote areas even remain backwards, with a lack of living facilities, poor traffic conditions and other problems. In this paper, 36 prefecture-level cities in Northeast China were taken as the research object to evaluate spatial–temporal evolution characteristics and the driving factors of rural development in Northeast China during the period 2000–2020.

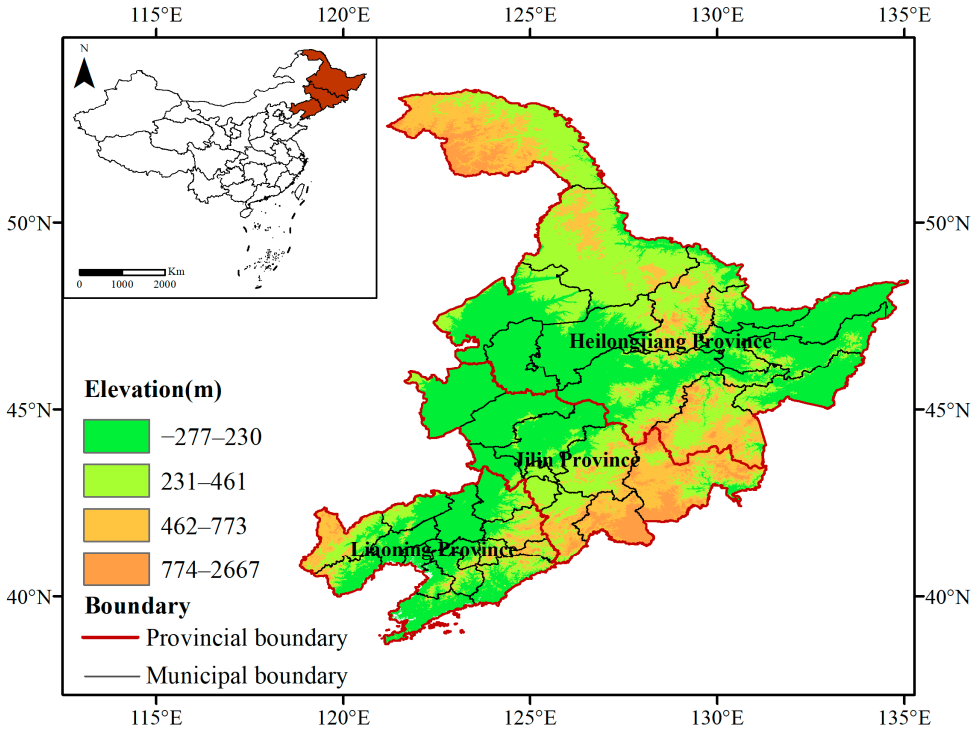

Figure 1. Geographical location of Northeast China.

2.2. Data Sources

In order to explore the level of rural development and driving factors in Northeast China in the context of rural revitalization and urban–rural integration, considering the time of rural development and the desirability of the research data, five time nodes of 2000, 2005, 2010, 2015 and 2020 were selected for analysis. The data sources for this paper were divided into two categories. One category comprises attribute data, which mainly reflect the socio-economic indicators of rural development and its influencing factors in Northeast China and were obtained directly from the *China County Statistical Yearbook*, *China Rural Statistical Yearbook*, *China Regional Economic Statistical Yearbook* and the statistical yearbooks of the provinces and cities in Northeast China for the period 2000–2020. The other category comprises basic geographic information data, which mainly reflect the ecological indicators, topographic factors, vegetation coverage and location variables of rural development in Northeast China. The relevant data were derived from remote sensing image interpretation, digital elevation model data (DEM) and map vector data, respectively, and were processed and extracted using ArcGIS.

2.3. Methods

2.3.1. Index System Construction

Based on the relevant literature and combined with the regional development situation in Northeast China and the availability of data at the prefecture city-level, this paper concludes that the rural development level can be characterized via three dimensions, i.e., "rural areas", "agriculture" and "farmer", and establishes an index system, as shown in Table 1. The ratio of population in the current year to the population in 2000, the per capita electricity consumption of the rural population, the number of beds in welfare homes, the number of hospital beds per capita and the amount of fertilizer applied per hectare of crop area sown were selected to represent the basic rural conditions. In addition to the amount of fertilizer applied per hectare of crop area sown, the higher the values of other indicators, the better the rural development situation. Agricultural development is represented by the production of grain per hectare of grain sown area, agricultural machinery power per hectare of grain sown area, meat production per capita, rural grain production per capita,

agricultural output value per hectare of grain sown area and the added value of the primary industry. The greater the values of these indicators, the better the agricultural development situation. The per capita disposable income of rural households, the per capita savings balance of urban and rural residents, the Engel coefficient of farmers and the per capita housing area in rural areas were selected to represent the living standards of farmers. In addition to the Engel coefficient of farmers, the larger the index value, the better the living standards of farmers, and the smaller the Engel coefficient of farmers, the higher the living standards of farmers. Apart from the Gini coefficient, the higher the other indicators, the better the farmers' living standards. The weights of the indicators were determined using the principal component analysis method.

Table 1. Evaluation index system for the rural development at city level in Northeast China.

Dimension	Indicator	Weight	Calculation Method	Property
Rural basic conditions	Attractiveness	0.05	Rural population of current year/rural population in 2000	+
	Rural vitality	0.02	Rural electricity consumption/rural population	+
	Level of social welfare	0.07	Number of beds in welfare homes/total population of regional household registration	+
	Medical and health conditions	0.05	Number of hospital beds/total population of regional household registration	+
Agricultural development state	Agricultural environmental pressure	0.08	Fertilizer application/crop sown area	−
	Production efficiency	0.01	Total grain production/grain sown area	+
	Mechanization level	0.02	Total agricultural machinery power/grain sown area	+
	Meat production per capita	0.1	Total meat production/total population of regional household registration	+
	Grain production per farmer	0.07	Total grain production/rural population	+
	Production benefits	0.01	Total agricultural output value/grain sown area	+
	Agricultural scale	0.1	Primary sector value added	+
Farmers' living standards	Income level	0.12	Disposable income per rural household	+
	Savings deposits per capita	0.09	Urban and rural savings deposit balance/total population of regional household registration	+
	Living standards	0.1	Rural Engel coefficient	−
	Housing	0.09	Housing area per capita in rural areas	−

In order to eliminate the influence of the difference in the scale of the indicators, the indicators were standardized using the polar difference method. Based on the standardized values and indicator weights obtained, the rural development index was calculated for each year. The standardized formula is as follows.

$$X'_{m,ij} = \frac{X_{m,ij} - X_{m,jmin}}{X_{m,jmax} - X_{m,jmin}} (positive\ indicator) \quad (1)$$

$$X'_{m,ij} = \frac{X_{m,jmax} - X_{m,ij}}{X_{m,jmax} - X_{m,jmin}} (negative\ indicator) \quad (2)$$

$$RI_{m,i} = \sum_{j=1}^{n} W_j X'_{m,ij} \quad (3)$$

where $X_{m,ij}$ is the value of the indicator j for a municipality i in the year m; $X'_{m,ij}$ is the standardized value of the indicator j for a municipality i in the year m; and $X_{m,jmax}$ and $X_{m,jmin}$ are the maximum and minimum values of the indicator j in the year m, respectively.

$RI_{m,i}$ is the rural development index for a municipality i in the year m. W_j is the weight of the jth indicator; and n is the number of indicators.

2.3.2. Exploratory Spatial Data Analysis

An exploratory spatial data analysis (ESDA) revealed similar agglomeration and differentiation characteristics via an exploration of intrinsic spatial correlations, which can be divided into global autocorrelation and local autocorrelation. Global autocorrelation generally explores the degree of aggregation or differentiation of the global space, and the research methods include Moran's I, global G statistic, etc. The global Moran's I is as follows:

$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{4}$$

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})}{n} \tag{5}$$

Local autocorrelation mainly reveals the characteristics of high and low concentrations in local areas, that is, the formation of "hot spots" and "cold spots". The local Moran's index can be utilized to further measure the degree of spatial association between region and the surrounding regions. The local Moran's I is calculated as follows:

$$I_i = \left[\frac{x_i - \overline{x}}{s^2}\right] \times \left[\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})\right] \tag{6}$$

2.3.3. Analysis of Driving Factors

(1) Selection of driving factors

Scholars generally believe that natural factors and economic factors will have an impact on rural development. By referring to the relevant research results, based on the research purpose and considering the availability of the data and other practical situations, 11 explanatory variables were selected to comprehensively reflect the driving factors of rural development. The natural factors include elevation, slope, precipitation, temperature and NDVI, and the socioeconomic factors include the proportion of primary industry added value to the GDP, the urbanization level, population density, general public budget expenditure per capita, public financial revenue and social fixed asset investment. The raw data were normalized to eliminate multicollinearity between variables.

(2) Geographically weighted regression

Ordinary least squares regression (OLS), as a full domain regression model, generally explores the linear influence relationships between multiple independent variables and the dependent variable. However, this method only reflects spatially consistent patterns of influence and has difficulty revealing differences in the influence of factors over space. An OLS model estimates the value of the dependent variable in each urban unit using the full range of independent variables, and the model equation is

$$Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j X_{ij} + \varepsilon_i \tag{7}$$

where Y_i is the rural development index for a city i. X_{ij} is the value of the jth driving factor. ε_i is the random error term of the independent distribution of the model. β_j is the regression coefficient, which is assumed to be a deterministic constant.

Compared to OLS, geographically weighted regression (GWR) is an extension of the OLS model that captures spatial trends in the regression coefficients of variables as they move with geographical location. The GWR model is expressed as follows:

$$Y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{K} \beta_k(u_i, v_i) X_{ik} + \varepsilon_i,\ i = 1, 2, 3\cdots,\ n \tag{8}$$

where Y_i is the dependent variable, X_{ik} is the kth independent variable, $\beta_k(u_i, v_i)$ is the kth coefficient at location (u_i, v_i) and ε_i is the random error term. Unlike OLS, the parameters are allowed to vary by location (u_i, v_i).

Traditional GWR models have shortcomings in their specific uses due to the limited sample size of cross-sectional data, such as the fact that the stability of interpretation is limited by the sample size and thus cannot estimate the model parameters. Geographically and temporally weighted regression (GTWR), on the other hand, effectively breaks through this limitation by introducing the time dimension into the GWR model to solve the problem of spatial and temporal non-smoothness, making the estimation more effective [47,48]. Its general form is as follows:

$$Y_i = \beta_0(u_i, v_i, t_i) + \sum_{k=1}^{K} \beta_k(u_i, v_i, t_i) X_{ik} + \varepsilon_i,\ i = 1, 2, 3\cdots,\ n \tag{9}$$

where t_i represents the observation time point. The problem here is to provide estimates of $\beta_k(u_i, v_i, t_i)$ for each variable k and each space–time location i. The estimation of $\beta_k(u_i, v_i, t_i)$ can be expressed as follows:

$$\hat{\beta}(u_i, v_i, t_i) = [X^T W(u_i, v_i, t_i) X]^{-1} X^T W(u_i, v_i, t_i) Y \tag{10}$$

where $W(u_i, v_i, t_i)$ is the spatial–temporal weight matrix, $W(u_i, v_i, t_i) = \mathrm{diag}(w_{i1}, w_{i2}, \cdots, w_{ij})$ and the element on the diagonal of Equation w_{ij} is the spatial–temporal distance decay function. In this paper, a Gaussian function was used to define the weight matrix, and the specific formula is as follows,

$$w_{ij} = \exp\left(-\left(\frac{d_{ij}}{h}\right)^2\right) \tag{11}$$

where d_{ij} is the spatial distance between the regions i and j; h denotes bandwidth and refers to the non-negative decay parameter of the functional relationship between weights and distance.

3. Results

3.1. Spatial–Temporal Analysis of Rural Development at the City Level in Northeast China

3.1.1. Spatial–Temporal Pattern of Rural Development in Northeast China

The rural development indices of 36 prefecture-level cities in Northeast China in 2000, 2005, 2010, 2015 and 2020 are visually presented in Figure 2. They were classified into five grades, including weak (RI $\leq$ 0.2), relatively weak (0.2 < RI $\leq$ 0.35), moderate (0.35 < RI $\leq$ 0.45), relatively strong (0.45 < RI $\leq$ 0.50) and strong (RI > 0.50), according to the Jenks natural breaks method.

From the perspective of different periods, the rural development level in Northeast China has been enhanced overall, but its spatial distribution in different stages is different. In 2000, the rural development level of Northeast China mainly consisted of weak-type areas and relatively weak-type areas. The relatively weaker type areas were mainly distributed in the north and south, such as in Dalian and Qiqihar. This is closely related to the rapid development of the level of mechanization since Dalian began to produce electric locomotives in 2000, which further promoted and developed the mechanization levels of

local rural areas. In 2005, the scope of weak and relatively weak rural development level areas gradually expanded further, and this change was mainly concentrated in the central part of Northeast China. By 2010, the trend had intensified. During this period, there was no weak rural development level area in Northeast China, and most areas were relatively weak rural development level areas. Meanwhile, there were medium rural development level areas, mainly in Harbin, Dalian and Qiqihar. This may be related to the significant increase in agricultural and rural input, the improvement of the agricultural subsidy system, the increase in the minimum grain purchase price and the improvement of rural financial services around 2010. The local government's earnest implementation of national policies promoted the rapid development of the rural development level in Northeast China. In 2015, areas of medium-level rural development were further expanded. By 2020, due to the gap between urban and rural development, the development of Northeast China, as a traditional old industrial base, is slow. The "Rural revitalization Policy" and "Revitalization Policy of Northeast China" were put forward successively. The government attaches importance to and invests in the development of Northeast China, promotes the development of rural infrastructure construction and the improvement of agricultural technology in Northeast China, and the national subsidies for Northeast China improve the income and quality of life of farmers and promote rural development.

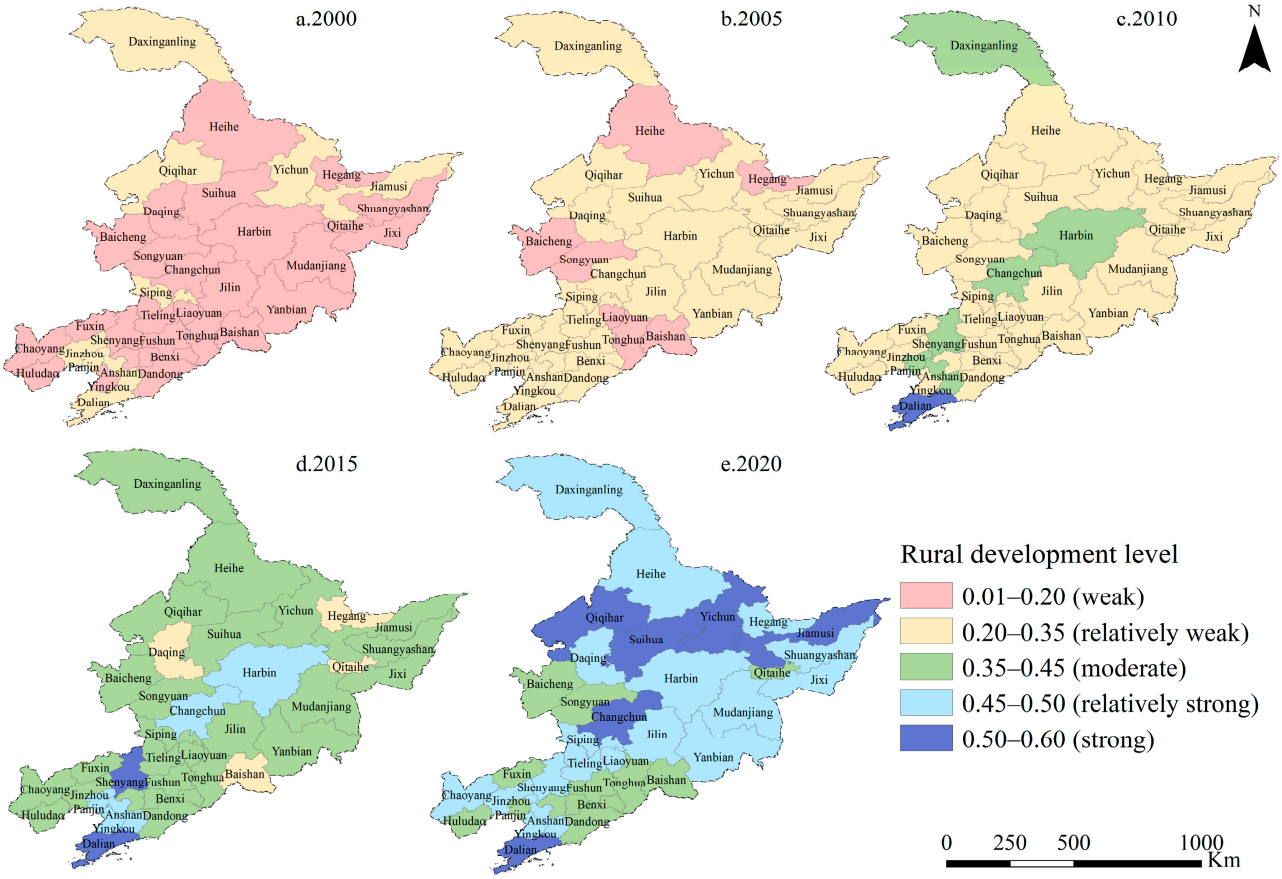

Figure 2. Spatial pattern of rural development at the city level in Northeast China from 2000 to 2020.

3.1.2. Spatial Autocorrelation Analysis of Rural Development at City Level in Northeast China

(1) Global autocorrelation analysis

In order to explore the spatial agglomeration and differentiation characteristics of the rural development levels of cities in Northeast China, Moran's I was further calculated (Table 2). The Moran's I values for the rural development level in Northeast China in 2000, 2005, 2010, 2015 and 2020 are all positive, and the Z(I) values are all greater than 2.58 at the

99% confidence level. This indicates a general tendency towards a spatial agglomeration of rural development in Northeast China. The year with the highest degree of agglomeration was 2015, and the year with the lowest degree of agglomeration was 2000. On the whole, the Moran's I values for the five time periods show an increasing trend, reflecting the gradual strengthening of the overall degree of spatial agglomeration.

Table 2. Global Moran's I value for the rural development level in Northeast China from 2000 to 2020.

Year	2000	2005	2010	2015	2020
Moran's I	0.154	0.219	0.309	0.322	0.194
Z(I)	3.337	4.461	6.129	6.308	4.106

According to the changes in Moran's I value over the years, the rural development level in Northeast China can be divided into two stages. The first stage was from 2000 to 2005, when the degree of aggregation of the rural development level in Northeast China showed an increasing trend. In this period, the rural development in Northeast China was relatively slow, and the degree of integration of urban and rural areas was low. The second stage was from 2010 to 2020, when the concentration of the rural development level in Northeast China showed a declining trend. This may be due to the development of industrialization and urbanization in this period, as well as the vigorous development of local characteristic tourism, which promoted rural development and drove the non-agricultural transformation of surrounding villages.

(2) Local autocorrelation analysis

The G_i^* index of rural development in Northeast China was analyzed, based on which the region was classified into five types, including a cold spot zone, sub-cold spot zone, mild zone, sub-hot spot zone and hot spot zone, according to the Jenks natural breaks method (Figure 3). Except for 2000 and 2020, most of the clusters with high rural development levels in Northeast China were concentrated in the southern region, while the clusters with low rural development levels were mostly concentrated in the northern and central regions. In 2000, hot spots and sub-hot spots were mainly distributed in the northern part of Northeast China and some central areas, such as Harbin, Qiqihar, Heihe and other cities (Figure 3a). In 2005, 2010 and 2015, mild areas decreased compared with the year 2000, and the decreased areas were replaced by cold spots and sub-cold spots (Figure 3c–d). Overall, cities with high and low rural development levels were clustered together. Revealing hot and cold areas helps the government formulate differentiated rural development strategies. For example, for hot spots, rural financial support should be strengthened, and local resources should be fully tapped to develop characteristic industries on the basis of guaranteeing traditional advantageous agriculture so as to enhance rural prosperity. For a cold spot area, we should support the development of diversified and new industries while consolidating rural modernization and encouraging farmers' entrepreneurship and technological innovation.

3.2. Effective Factor Analysis of Rural Development at the City Level in Northeast China

3.2.1. Comparison of Model Test Results

This paper quantitatively analyses the driving factors of rural development differentiation in Northeast China. The explanatory variables were screened using three models, i.e., the OLS model, the GWR model and the GTWR model, and the results of the three models were compared. As shown in Table 3, the coefficient of determination R^2 and the corrected coefficient of determination R^2 of the GTWR model were 0.954 and 0.951 respectively, which showed an overall enhanced explanatory power compared to the OLS and GWR models. The Akaike Information Criterion (AIC) value of the GTWR model was −186.257, which was smaller than that of the OLS and GWR models, indicating that the GTWR model was a better fit.

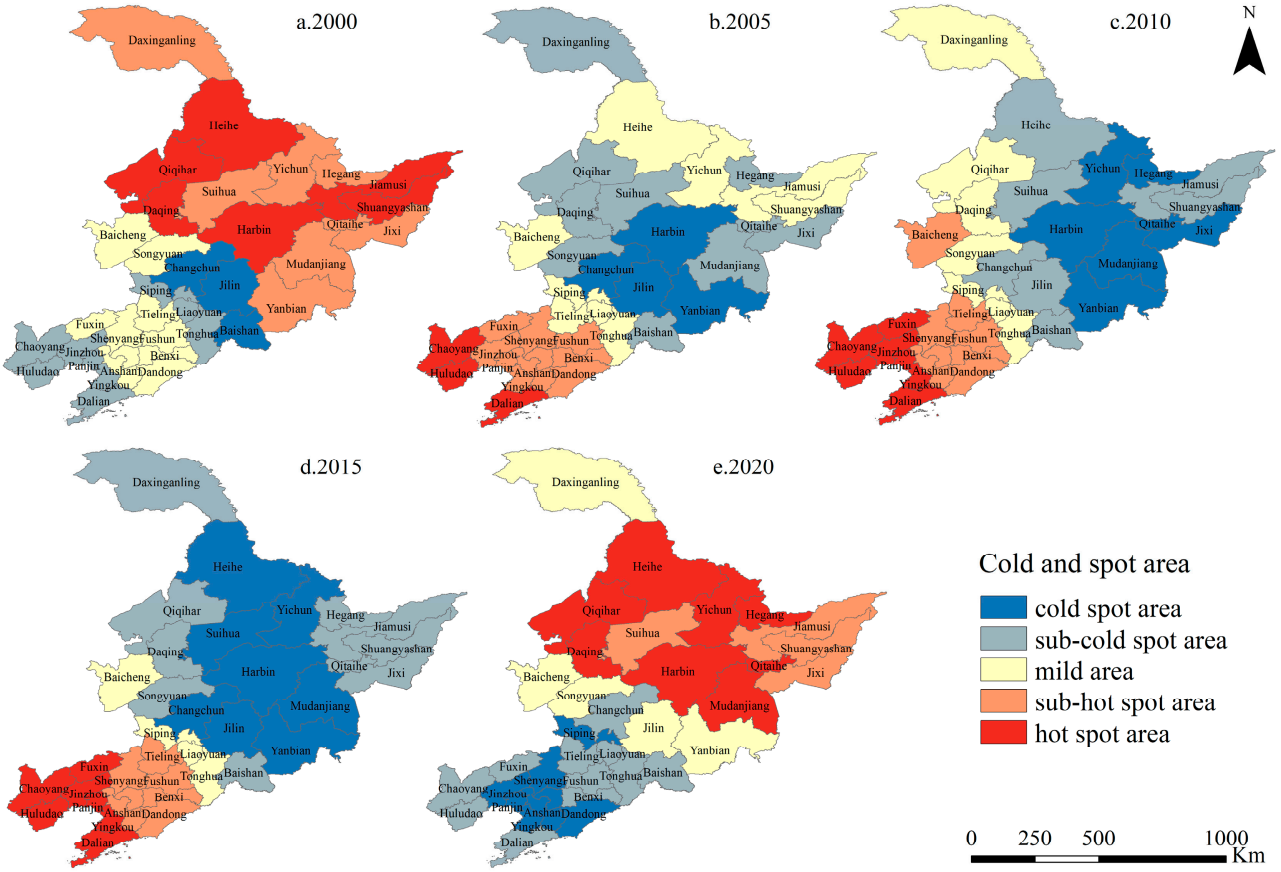

Figure 3. Spatial pattern of cold and hot spots of rural development at the city level in Northeast China from 2000 to 2020.

Table 3. Comparison of GWR model, GTWR model and OLS model fits.

Model Fitting Parameters	OLS Model	GWR Model	GTWR Model
R^2	0.842	0.911	0.954
Calibration R^2	0.813	0.905	0.951
Akaike Information Code (AICc)	−153.496	−177.007	−186.257

3.2.2. Driving Factor Analysis Based on the GTWR Model

(1) Analytical results of the GTWR model

Taking each factor in 2020 as an example, the average of the absolute value and the proportion of positive and negative values of the regression coefficients of each variable in the GTWR model were calculated, as shown in Table 4. The results showed that there were great differences in the degree of influence of each variable, which reflected the different influences of different factors on the rural development level. Among them, the proportion of primary industry added value to the GDP, the general public budget expenditure per capita, public finance revenue and population density had positive impacts on rural development for the whole region. This indicates that overall, the urbanization process and environmental protection had trade-off relationships with rural development. On the other hand, the more important the role of agriculture in economic production and the higher the government budget, the higher the level of rural development in Northeast China. This indicated that the region should coordinate the relationship between urban and rural development, upgrade the status of agricultural production and ensure a sound financial situation for the government. From the perspective of the positive and negative ratios of the regression coefficients, the natural environment (average elevation, average slope, annual precipitation, average temperature and average NDVI) and local economic

conditions (urbanization level and social fixed asset investment) had both positive and negative effects, indicating that these factors both limited and promoted rural development and transformation in different regions; thus, the government needs to formulate strategies to promote rural development in accordance with local conditions.

Table 4. Regression coefficient statistics of the GTWR model for the driving factors analysis of rural development in Northeast China.

Driving Factors	Explanatory Variables	Average of Absolute Values	Positive %	Negative %
Natural factors	Average elevation	0.063	5.6	94.4
	Average slope	0.128	69.4	30.6
	Annual precipitation	0.043	36.1	63.9
	Average temperature	0.107	58.3	41.7
	Average NDVI	0.345	88.9	11.1
Socioeconomic factors	Proportion of primary industry added value to the GDP	0.105	100	0
	Urbanization level	0.028	16.7	83.3
	Population density	0.107	100	0
	General public budget expenditure per capita	0.231	100	0
	Public financial revenue	0.047	100	0
	Social fixed asset investment	0.022	69.4	30.6

(2) Spatial–temporal pattern of driving factors affecting rural development level at the city level in Northeast China

In order to observe the spatial distribution of the fitting coefficients of each driving factor more intuitively and reflect the spatial influence difference of each factor, taking the fitting results of each index in 2020 as an example, the regression coefficients of each variable in the GTWR model were visually expressed and analyzed (Figure 4).

The positive and negative effects of these natural environment indicators are different in space. Among them, the annual precipitation and average elevation have strong negative effects on most rural areas, while the average temperature, average NDVI and average slope have strong positive effects on most rural areas. From the perspective of spatial differences in influence, different regions play different roles. Relatively speaking, 94.4% of the rural development in the central, eastern and western regions of Northeast China is more susceptible to the negative impact of altitude. The central, eastern and western regions mainly include mountains, hills and large areas of plain. In the Songnen Plain in the west and Sanjiang Plain in the northeast, the main grain-producing areas, the per capita cultivated land area is five times that of the national per capita cultivated land area. The change in altitude may affect the local agricultural production situation to some extent. The average NDVI can promote the rural development levels of most villages in Northeast China. The increase in vegetation is conducive to increasing biodiversity. It can combine the construction of an ecological environment and the protection of rare animals and plants with eco-tourism agriculture to form a unique sightseeing agriculture, which is conducive to promoting the development of villages. An increase in annual precipitation caused a decline in rural development of 36.1% in the southern region, indicating that rural development in the southern region was more vulnerable to temperature constraints than in other regions.

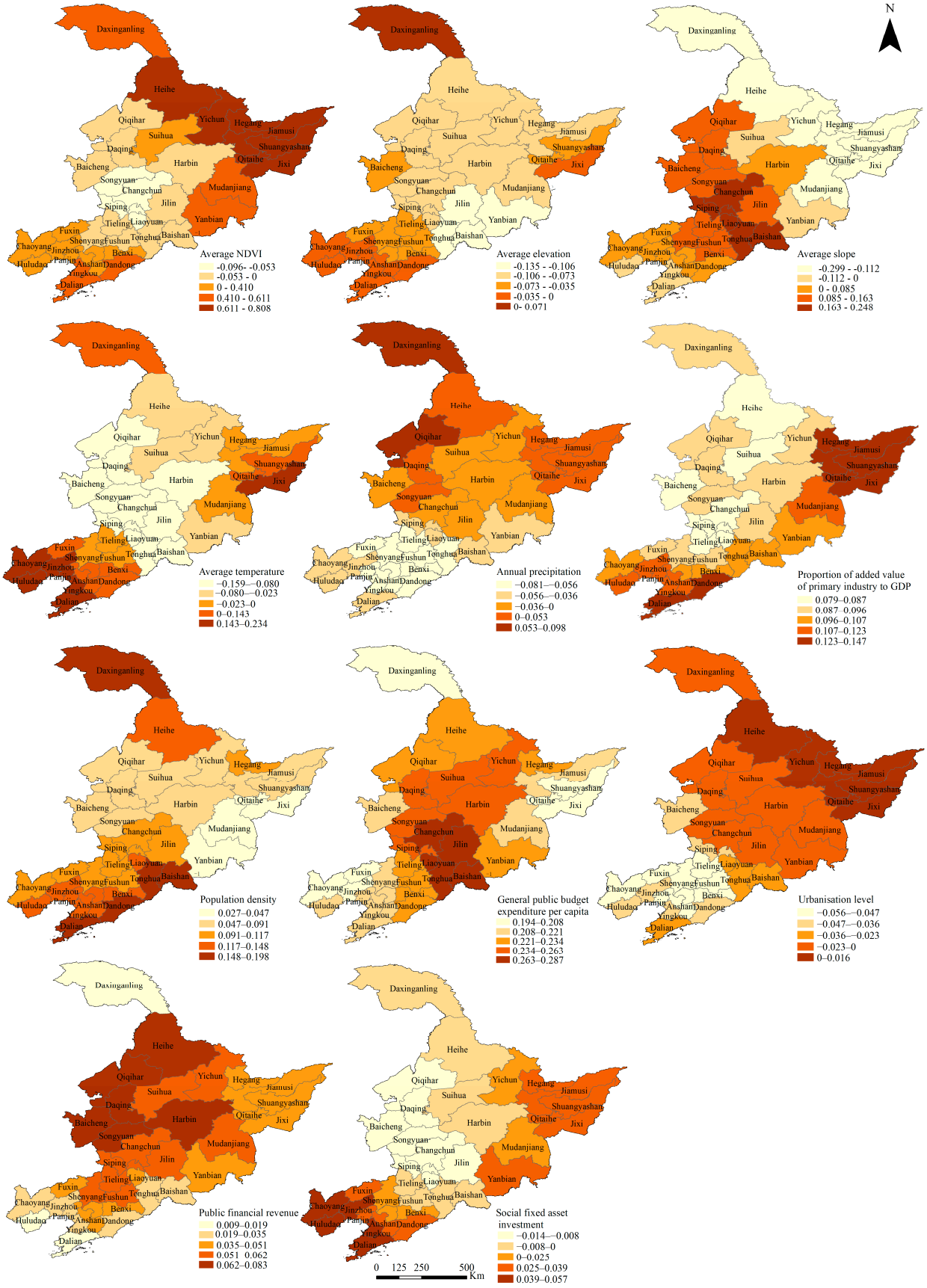

Figure 4. Spatial distribution of the coefficients of the driving factors of rural development in Northeast China, based on a GTWR model.

Slope has a negative effect on the level of rural development in 30.6% of the areas in Northeast China, reflecting the restricting effect of remote location conditions on rural development and transformation. Among them, the central and southern regions have the strongest restricting effects on local rural development and transformation, which gradually weaken to the north and show the lowest values in the eastern and northeastern regions. The central and southern regions have complex and diverse landforms with low hills, and the distribution of farmland is scattered and fragmented. These conditions are not conducive to large-scale and mechanized agricultural farming. In summary, the different effects of different natural factors on different regions highlight the regional differences in the impact of natural environment and also indicate that the natural conditions suitable for agricultural development vary from place to place.

Regarding the spatial–temporal heterogeneity of economic factors' influence on rural areas, it showed that the proportion of the primary industry added value to the GDP, population density, per capita expenditure of general public budget and public financial revenue all had positive effects on the level of rural development, reflecting the important roles of these indicators in promoting rural development and transformation. The level of urbanization has an inhibitory effect on the rural development of 83.3% of Northeast China. Liaoning Province's industrial development started early, and with the deepening of industrialization, the speed of urban outward expansion is increasing, which further increases the urban population. At the same time, Liaoning Province, as a large industrial province, provides more jobs, resulting in a loss of the rural population. There is a limiting effect on local rural development.

The influence of public finance revenue on rural development is strong in the central and eastern parts of Northeast China. This is related to the backward development of traditional agricultural areas in the east and west. This region has long suffered from problems such as weak infrastructure, backward agricultural technology, inefficient industrial management and a lack of talent. It is difficult to provide sufficient power support for local rural development and transformation. Compared with the abundant, high-quality resources in the south, its own development is more dependent on government support. Therefore, the government should continue to strengthen its financial tilt to the central, eastern and western regions in the future. The level of investment in fixed social assets has a promoting effect of 69.4% on the rural development level of Northeast China. It is mainly concentrated in the southern and eastern regions, perhaps because these areas have better basic conditions but lack human and technical resources. Increased social investment in these areas will contribute to rural development in these areas.

4. Conclusions and Discussion

4.1. Conclusions

Based on the theoretical analysis of the connotation, evolutionary logic and driving factors of the rural development level, this paper discusses the spatio-temporal characteristics of rural development in Northeast China in the years 2000, 2005, 2010, 2015 and 2020. In this study, the indicators were selected from three aspects, "agriculture", "rural" and "farmers", which makes the research more comprehensive and convincing. The research was set in Northeast China, which is an important grain base in China and has a large gap between urban and rural development. The findings of this study can provide important information for policy and planning decisions. Moreover, in the influencing factor analysis, an OLS model, GWR model and GTWR model were used for regression analyses. According to the analysis results from the three models, the model with the highest degree of fitting was selected to analyze the influencing factors. It showed that the spatial distribution of the level of rural development in different stages was different during 2000–2020. The rural development level in Northeast China had been enhanced overall and showed a spatial pattern of "high in the central, low in the east and west" in most periods. The level of rural development in Northeast China tended to demonstrate spatial agglomeration features. Overall, the Moran's I value for the five time periods showed an

increasing trend, reflecting the gradual strengthening of the overall spatial agglomeration degree of rural development in Northeast China. The rural development agglomeration in Northeast China presented the spatial characteristics of "cold in the north and hot in the south", and it was relatively stable from 2005 to 2015. The theoretical driving mechanism of the rural development level and the empirical results of the GTWR model show that the urbanization process, elevation, annual precipitation and other natural factors have weakened the level of rural development to a certain extent, while agricultural production upgrading, an increase in general public budget expenditure per capita and the sound financial situation of the government can promote rural development in Northeast China. The effects of the natural environment and local economic conditions rural development were different in different regions.

In the future, to enhance sustainable rural development in Northeast China, the government should implement development strategies according to specific regional needs and potentials to address the unique challenges and opportunities of each region. Second, policies and initiatives that focus on sustainable resource management to mitigate the negative impacts of natural factors on rural development should be developed. This can include measures to protect water resources, improve soil quality, implement climate-smart agricultural practices and promote renewable energy. At the same time, local rural economies can be encouraged to diversify away from agriculture. It is also necessary to explore opportunities to support the development of other sectors such as tourism, eco-tourism, manufacturing and services. This can be achieved by providing infrastructure, market access and necessary support services. Cooperation between the public and private sectors can be promoted to accelerate rural development and construction. Finally, the government should also ensure effective governance and policy coordination at all levels of government to promote rural development. This includes streamlining administrative procedures, improving coordination among government departments, establishing a clear regulatory framework, and promoting transparency and accountability in resource allocation. Strengthening governance mechanisms will help ensure the effective implementation of rural development policies and programs.

4.2. Discussion

This paper explores the spatial–temporal patterns and driving mechanism of the level of rural development in Northeast China. Studying the rural development level can provide a comprehensive analysis of regional differences in local rural development. By identifying the areas with the greatest development gaps, researchers can advise on targeted interventions to reduce disparities and promote balanced rural development. Against the background of rural revitalization, rural development has a comprehensive scientific connotation. To promote rural development, it is not only necessary to accelerate the modernization of agriculture and rural areas but also to fully tap local characteristics and actively explore diversified rural functions and values. The most arduous and onerous task in building a modern socialist country in a well-rounded way still lies in the rural area. By addressing the challenges posed by natural factors and harnessing the potential of local economic conditions, the government and relevant departments have the potential to improve the livelihoods of rural residents, reduce regional disparities, promote sustainable development and contribute to the overall socio-economic growth of the region. In addition, a successful rural development strategy can provide important learning experiences and models for the rest of China, potentially boosting rural development across the country and creating a more balanced and inclusive development landscape. Research on the evaluation of the level of rural development =in Northeast China in this paper focuses on the discussion of the spatial–temporal differentiation characteristics and driving factors of the level of rural development, though there are still some limitations in revealing the differences in rural development levels in different rural development types in the region. In the future, this aspect of the research can be strengthened. In addition, rural development involves many aspects. As it is difficult to quantify rural planning, form, government

restrictions and other factors, these factors must be abandoned in the construction of the index system. Future research will further improve the index system to promote rural development research.

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