

# The Spatial Distribution Characteristics of Economic Growth Rates in Henan Province

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## Abstract

The economic growth rate is a core indicator for measuring the pace of regional economic growth, reflecting dynamic economic changes over a specific period and serving as a critical foundation for macroeconomic analysis and policy formulation. Based on the 2009-2025 economic statistical data of counties (districts) in Henan Province, China, this paper first applies the logistic economic growth regression model to calculate the economic growth rate of each research unit, then analyzes the overall spatial pattern of economic growth rates, identifies the distribution of economic growth hot and cold spots, examines the radiation characteristics of economic growth through semivariogram analysis, and further explores the spatial distribution features of economic growth rates via Kriging interpolation analysis. The research results show that there are significant disparities in the county-level economic growth rate, with the coefficient of variation (ratio of standard deviation to mean) standing at 0.44. Geographically, northeastern Henan demonstrates relatively higher economic growth rates, and significant positive correlation exists between economic growth rate and economic aggregate. In terms of spatial agglomeration, the economic growth rate forms two major hot spot agglomerations centered on the urban built-up areas of Zhengzhou and Luoyang, as well as two major cold spot agglomerations—one centered on Anyang's urban built-up area, and the other distributed zonally along the boundary of China's second and third topographic steps. Regions with relatively high economic growth rates exert an outward radiation effect with a linear decreasing trend, with a radiation radius of approximately 254.10 km, and no significant correlation is observed between radiation intensity and topographic features. Specifically, interpolation analysis reveals that high-speed, medium-speed, and low-speed economic growth regions in the province account for 34.56%, 56.60%, and 8.84% of the total administrative area, respectively.

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## Keywords

Economic Growth Rate, Logistic Regression Model, Cold and Hot Spot Analysis, Semivariogram, Economic Radiation, Interpolation Analysis, Henan Province

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## 1. Introduction

From a spatial perspective, the study of inter-regional relationships in macroeconomic growth serves as a vital component of theoretical research on regional development, with its core focusing on exploring the issues of regional economic differences, convergence (i.e., convergent growth and balanced growth), and divergence (i.e., divergent growth and unbalanced growth) (Hu et al., 2002; Zhang & He, 2007; Xu, 2023).

Economic radiation refers to the transfer of production factors from economically developed regions to the surrounding underdeveloped regions, aiming to raise the economic development level of the latter. In this way, it could realize a more optimal allocation of resources across the entire region and better exert the overall regional functions. A regional growth pole, as the core of a region, promotes the agglomeration of leading, innovative and related industries, forming an economic development core whose development advantages radiate outward and drive the economic development of the surrounding regions (Chen et al., 2019a; Feng & Zhang, 2019).

Economic growth rate is a core indicator for measuring the speed of regional economic aggregate expansion, which reflects the dynamic changes of the economy over a certain period, and serves as an important basis for macroeconomic analysis and policy formulation (Hu & Wang, 2025; Yan et al., 2023). Differences in regional economic growth rates are influenced not only by the internal factors inherent to each region but also significantly by their geographical locations. Regions with high economic growth exert a crucial driving effect on the surrounding areas through economic radiation (Zhang & He, 2007; Chen et al., 2019a; Hu & Wang, 2025; Hu et al., 2025).

In recent years, along with the rapid economic growth of Henan Province, the spatial imbalance in economic development levels among its various regions—attributed to disparities in natural environment, resource endowments, economic foundations, and socio-cultural factors—has attracted extensive attention from researchers. These scholars have adopted statistical analysis methods (including factor analysis, cluster analysis, principal component analysis, the Gini coefficient, and the Theil coefficient), as well as technical tools such as ESDA and GIS to comprehensively evaluate the economic development levels of cities in Henan Province. They have also conducted quantitative analyses on the spatiotemporal differences, dynamic evolution of spatial structures, and driving mechanisms of city economic development, thereby yielding numerous results with practical value

(Feng & Zhang, 2019; Li & Wu, 2007; Yang, 2012; Zhang et al., 2017; He et al., 2016; Kong & Feng, 2023; Xu, 2023; Zhang et al., 2022).

At present, relatively few studies have focused on the spatial relationships of regional economic growth rates, yet the mutual influence between regional economic growth rates is also a key driver of regional economic growth differences. In existing research, economic growth rates are often calculated using a time-series segmentation method, wherein economic increment data over a given period is divided by the length of that period to derive the economic growth rate. While this method is simple and straightforward to compute, it completely overlooks the process of economic changes within the period, thereby exhibiting certain limitations.

Taking 157 county-level units in Henan Province as the research objects, this study selects GDP data from 2009 to 2025 as indicators. To explore the economic change process and grasp the overall regional economic growth during the study period, the Logistic regression model is employed to estimate the economic growth rate of each unit. Furthermore, this study analyzes the overall spatial pattern of economic growth rates in Henan Province, identifies the spatial distribution of cold and hot spots of economic growth, examines the radiation characteristics of economic growth rates based on semivariograms, and reveals their spatial distribution features through interpolation analysis. The purpose is to accurately judge the economic development status of the entire region and provide scientific reference for the formulation and implementation of government policies.

## 2. Data and Research Methods

### 2.1. Research Area Overview

Henan Province (31°23'N - 36°22'N, 110°21'E - 116°39'E) is located in the transition zone between the second and third steps of China's topographic relief, with a total area of  $1.67 \times 10^5$  km<sup>2</sup>. The province administers 18 prefecture-level cities, 21 county-level cities, 82 counties, and 54 municipal districts, featuring complex landform types and a terrain that slopes from west to east. The northern, western, and southern parts of Henan are surrounded by the Taihang Mountains, Funiu Mountains, Tongbai Mountains, and Dabie Mountains, which form a semi-circular distribution along the provincial boundaries. The central and eastern regions belong to the alluvial plain of the Huang-Huai-Hai River Basin (Zhang et al., 2020).

Data on GDP and the GDP deflator for 157 county-level units are obtained from the Henan Statistical Yearbook (2009-2025). Using 2005 as the base year, the nominal GDP of each county from 2009 to 2025 is deflated by applying the provincial GDP deflator for each corresponding year. All values are thus uniformly converted into a real GDP series based on 2005 comparable prices (in 100 million yuan). Meanwhile, the spatial data are obtained from the Henan Basic Geographic Information Database and its metadata database, WGS 1984 UTM Zone 49N projected coordinate system, unit: meter. To eliminate the impact of county-level ad-

ministrative division adjustments on the analysis results, the GDP data are disaggregated and aggregated using the area-weighted average method, ensuring comparability across spatial scales.

## 2.2. The Growth Rate of Economic

Theoretically, economic activities within a specific region constitute a self-organized evolutionary process, shaped by factors such as the regional geographical environment, natural resource endowments, industrial structure, geographical location, socio-economic development level, and development policies. Correspondingly, regional economic growth basically conforms to the characteristics of a Logistic curve.

$$P_t = \frac{P_0}{1 + \exp\{a - r(t - 2009)\}} \quad (1)$$

where,  $P_t$  (100 million yuan) is as the discrete variable of GDP data.  $t$  is the time series of years,  $a$  (100 million yuan) is a regional constant,  $r$  represents the natural growth rate of GDP (100 million yuan per year),  $P_0$  (100 million yuan) is as the environmental load capacity.  $a$  and  $r$  are the regression coefficient of the linear regression equation,

$$y = \ln(P_0 - P) - \ln(P) = a - rt \quad (2)$$

The significance level of the equation is tested using the test,

$$F = \frac{SSR/1}{SSE/(n-1)} \quad (3)$$

where SSR and SSE are the regression squared sum and residual squared sum of Equation (2),  $n$  is the number of observed years. Giving a significance level  $\alpha$ , based on the critical value  $F_\alpha$  of the  $F$  distribution, as  $F > F_\alpha$ , the regression model and its parameters  $a$  and  $r$  are significant (Zhang et al., 2024).

The environmental load force  $P_0$  is the function of the regional environment. For ease of calculation, the inflection point of Equation (1) is used, for where the tangent slope reaches the maximum, the curve changes from concave to convex. Its value is fitted with the maximum slope of the measured curve (Li et al., 2019; Yang et al., 2022; Yin, 2002).

$$P_0 = 2 \max\{P_2 - P_1, P_3 - P_2, \dots, P_n - P_{n-1}\} \quad (4)$$

## 2.3. The Cold and Hot Spot Analysis of Economic Growth Rate

Cold and hot spot analysis is an effective method for exploring the local spatial agglomeration characteristics of economic growth rates. A strong spatial correlation among economic growth rates indicates that the spatial process factors of economic growth are influencing economic growth. Studying regions with strong spatial correlation and exploring the significant agglomeration characteristics of economic growth rates in spatial patterns could help rationalize the allocation of social resources and ensure the balanced development of the regional economy

(Awuh, 2026; Xu et al., 2022; Zhang et al., 2024; Muriuki et al., 2023; Lu et al., 2023).

Under the second-order stationarity assumption (Zhang et al., 2020, Awuh, 2026; Xu et al., 2022), cold and hot spot analysis employs the Getis-Ord  $G_i^*$  statistical model.

$$G_i^* = \frac{\sum_{k=1}^n w_{ik} (r_k - \bar{r})}{S \sqrt{\frac{n \sum_{k=1}^n w_{ik}^2 - \left(\sum_{k=1}^n w_{ik}\right)^2}{n-1}}} \quad (5)$$

where,  $\bar{r}$  and  $S$  represent the mean and the standard deviation of the economic growth rate, respectively.  $W = (w_{ij})_{n \times n}$  denotes the spatial relationship matrix of the county (district) units, defined by first-order rook contiguity, where  $w_{ij} = 1$  if two spatial units  $i$  and  $j$  share a common border, and  $w_{ij} = 0$  otherwise.  $G_i^* > 0$  indicates that the weighted average of the economic rates in the surrounding  $i$  county (districts) is greater than the overall mean, corresponding to a hot spot region with higher economic growth rates. The larger the  $G_i^*$ , the more prominent the hot spots are. Conversely,  $G_i^* < 0$  indicates the weighted average of the economic growth rates in the surrounding  $i$  county (district) is less than the overall mean, corresponding to a cold spot region with lower economic growth rates. The smaller  $G_i^*$ , the more prominent the cold spots is.

The overall spatial aggregation characteristics are described by the deviation multiple between the sample mean and the overall theoretical mean relative to the overall theoretical standard deviation

$$Zscore = \frac{\bar{r} - \mu_0}{\sigma/n} \quad (6)$$

The significance level of the aggregation characteristics is determined based on hypothesis testing, since  $r$  and  $\bar{r}$  converge in probability to a normal distribution, the significance of the agglomeration characteristics could be verified accordingly, as  $\alpha = 0.05$ ,  $Zscore = 1.96$  (Zhang et al., 2024; Lu et al., 2023; Huang & Xu, 2020; Awuh, 2026; Xu et al., 2022).

#### 2.4. Spatial Heterogeneity Characteristics of the Economic Growth Rate

The economic growth rate is a location-based random variable  $r(P) = r(x, y)$  that follows a specific probability distribution, with its values being random and dependent on both its location  $P$  and the observation time (Zhang et al., 2020; Zhang et al., 2024; Chen et al., 2019b; Taharin & Roslee, 2021).

The economic growth rate has two significant characteristics: randomness and structural. Firstly, it is a random variable, having the characteristics of locality, randomness, and abnormality; secondly, it has average structural properties, which not only reflects the natural economic growth level in the location, but also reflects the radiating influence of economic growth in other regions, resulting in

the spatial correlation characteristics between the economic growth rate  $r(P)$  at  $P$  and  $r(P')$  at  $P'$ . These spatial correlations depend on the distance  $h$  between the two points and the characteristics of the economic growth rate itself (Zhang et al., 2024; Chen et al., 2019b; Taharin & Roslee, 2021; Jiao et al, 2023; Asal, 2023; Margaritidis, 2024).

Under the second stationarity assumption (Zhang et al., 2020), the covariance between two points is defined as

$$c(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [r(P_i) - \bar{r}(P_i)] [r(P_i + h) - \bar{r}(P_i + h)] \quad (7)$$

where  $N(h)$  is the number of observation value pairs with the distance of  $h$ ,  $\bar{r}(P_i)$  is the sample mean of  $r(P)$  which is independent of the position  $P$ .

To facilitate the study of the overall changes in the economic growth rate, the differences in the economic growth rate at different distances, its distribution at specific distances, and the relationship between the economic growth rate and distance changes, the semivariogram function of the economic growth rate is defined as half of its covariance.

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(P_i) - Z(P_i')]^2 \quad (8)$$

which reflects the economic growth rate variation of all point pairs at the specified distance  $h$  in the discrete point group, as well as their spatial distribution characteristics.

$\gamma(h)$ , calculated based on the observed values of discrete economic growth rate, is a discrete function, in order to study the overall characteristics of regional changes in economic growth rate, using curve fitting method to transform it into a continuous function to obtain a mathematical model of semivariogram function. Commonly used fitting functions include Exponential model, Spherical model, Gaussian model, and Linear model, etc. These continuous semivariogram function could be described by four parameters, namely, the localized discontinuity value or nugget  $C_0 = \lim_{h \rightarrow 0} \gamma(h)$ , which reflects the spatial variation caused by random observation factors, is determined by the variance of observed values at a single location; As the interval distance  $h$  increases,  $\gamma(h)$  from  $C_0$  gradually tends to a constant  $\lim_{h \rightarrow \infty} \gamma(h) = C + C_0$ , called the sill value, which reflects the largest variation in economic growth rate; when  $\gamma(h)$  reaches tends to stabilize at the sill value, the corresponding value  $h$  is called the range ( $a$ ), which reflects when  $h \geq a$ , the spatial correlation of economic growth rate disappears (Zhang et al., 2020; Zhang et al., 2024; Taharin & Roslee, 2021; Jiao et al, 2023; Asal, 2023; Margaritidis, 2024).

As the semivariogram function  $\gamma(h)$  is calculated based on observed values of the discrete economic growth rate, it is inherently a discrete function. To examine the overall characteristics of regional changes in the economic growth rate, the curve fitting method is employed to convert this discrete function into a continuous one, thereby deriving a mathematical model of the semivariogram func-

tion. Commonly used fitting functions include the Exponential model, Spherical model, Gaussian model, and Linear model, etc. (Asal, 2023; Zhang et al., 2024). These continuous semivariogram functions could be described by four key parameters, namely: the localized discontinuity value (or nugget)  $C_0 = \lim_{h \rightarrow 0} \gamma(h)$ , which reflects spatial variation caused by random observation factors, and is determined by the variance of observed values at a single location; as the interval distance  $h$  increases,  $\gamma(h)$  gradually converges to a constant  $\lim_{h \rightarrow \infty} \gamma(h) = C + C_0$ , referred to as the sill value, which represents the maximum variation in the economic growth rate; when  $\gamma(h)$  reaches the stabilized value, the corresponding  $h$  is termed the range  $a$ , which indicates the distance beyond which the spatial correlation of the economic growth rate disappears (Zhang et al., 2024; Taharin & Roslee, 2021; Jiao et al, 2023; Asal, 2023; Margaritidis, 2024).

Based on the fitted semivariogram model, spatial interpolation analysis could be applied to calculate the economic growth rate at unknown points, thereby presenting the overall spatial distribution and variation characteristics of the economic growth rate across the entire region.

Specifically, the Kriging interpolation method relies on data from known points within the finite neighborhood of an unknown point, incorporates their spatial positional relationships and the structural information provided by the fitted semivariogram model, and employs unbiased optimal estimation to calculate the value of the unknown point.

$$Z^*(P) = \sum_{i=1}^n \lambda_i Z(P_i), \lambda = K_{n \times n}^{-1} D_{n \times 1} \quad (9)$$

where  $\lambda_i$  is the contribution of the economic growth rate  $Z(P_i)$  of the known point  $P_i$  to the unknown point  $P$ ,  $n$  is the number of points within the specified distance neighborhood of  $P$ ,  $K$  is the augmented matrix of the semivariogram values at the known points,  $D$  is an augmented column vector of the semivariogram values from the known points to the unknown point (Zhang et al., 2024; Liao et al., 2016; Taharin & Roslee, 2021; Jiao et al, 2023; Asal, 2023; Margaritidis, 2024).

### 3. The Spatial Distribution Characteristics of Economic Growth Rates in Henan Province

#### 3.1. Growth Rate of Economic in Henan Province

Using Equation (1), (2) and (4) to calculate the economic growth rate of the counties (districts), cities and province, under the confidence level of 90%, by the test of  $F$ , all economic growth rates show significant characteristics. The calculation results for the province and cities are shown in **Table 1** and **Figure 1**, while the calculation results for counties (districts) are shown in **Figure 2**.

**Table 1.** The characteristic of economic growth rate from 2009-2025 in Henan.

City	$a$	$r \times 10^2$	City	$a$	$r \times 10^2$
Province	242.63	11.41			

Continued

AnYang	178.04	8.81	ZhengZhou	321.49	15.92
PuYang	220.99	10.94	ShangQiu	291.66	14.44
HeBi	234.88	0.74	XuChang	271.77	13.46
XinXiang	257.59	12.74	ZhouKou	289.89	14.36
JiaoZuo	156.66	7.74	PingDingShan	201.93	9.99
Jiyuan	220.24	10.90	LuoHe	284.08	14.07
KaiFeng	284.55	14.09	NanYang	219.65	10.87
SanMenXia	165.65	8.20	ZhuMaDian	275.38	13.62
LuoYang	230.15	11.39	XinYang	262.82	13.00

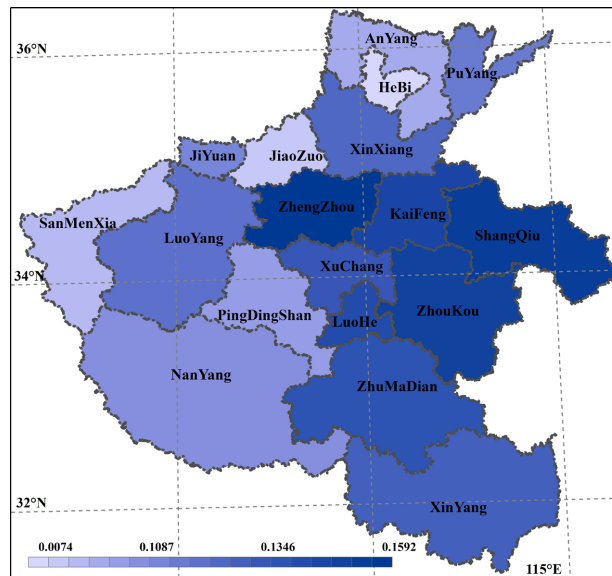


Figure 1. The distribution of city economic growth rates in Henan

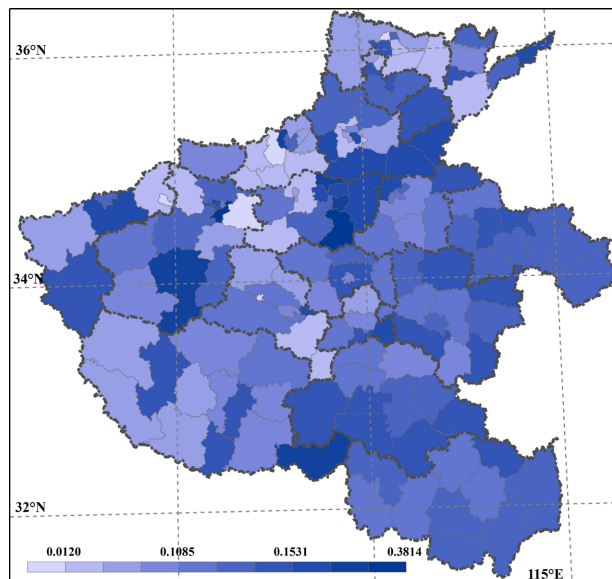


Figure 2. The distribution of county (district) economic growth rates in Henan.

The economic growth rate in the province is about  $86.5 \times 10^{-4}$ . In the city level, 9 cities have economic growth rates higher than the provincial mean, namely Zhengzhou, Shangqiu, Zhoukou, Kaifeng, Luohe, Zhumadian, Xuchang, Xinyang and Xinxiang in the descending order. Luoyang, the second-largest economy of the province, registered a growth rate of  $11.39 \times 10^{-2}$ , slightly below the provincial mean. Geographically (Figure 1), all these cities are located in the central and southeastern parts of the province. Except for Zhengzhou, the other 8 cities are major traditional agricultural cities. This indicates that over the past 17 years, with the advancement of agricultural modernization, the agricultural sector has achieved rapid development compared with other industries in the province.

At the county (district) level (Figure 2), there are significant differences in economic growth rates. The weighted mean center of economic growth rates ( $113.8072^\circ\text{E}$ ,  $34.2468^\circ\text{N}$ ) is located 44.41 km to the northeast of the province's geographic center ( $113.6175^\circ\text{E}$ ,  $33.8763^\circ\text{N}$ ) with an azimuth of  $22.0633^\circ$ , indicating that the economic growth rate is relatively higher in the northeastern part of the province overall.

Specifically, Xinzheng City, which recorded the fastest growth ( $38.14 \times 10^{-2}$ ), is 2.79 times that of Yima City, which has the slowest growth ( $1.20 \times 10^{-2}$ ). The sample standard deviation stands at  $5.06 \times 10^{-2}$ , the ratio of standard deviation to mean is about 0.44, and the range to mean ratio is about 2.70. Among the 157 counties (districts), 113 counties (districts) see their economic growth rates outpace the provincial mean, of which 38 units are urban built-up areas, accounting for 33.62%, slightly higher than the overall urban built-up areas proportion (31.84%). Geographically, excluding urban built-up areas, the distribution pattern of county-level economic growth rates is basically consistent with that at the city level.

Correlation analysis and regression analysis shows that at a 99% confidence level, there is a significant positive correlation between the average total GDP of counties (districts) (Figure 3) and the economic growth rate (Figure 2) with a correlation coefficient of 0.23, and  $R^2 = 0.08$ ,  $F = 13.482 \gg F_{0.99}(1, +\infty) \approx 6.81$ . This indicates that county-level economic development in Henan Province presents a significant "scale effect": a larger economic scale implies stronger resource agglomeration capacity, a more complete industrial chain, and higher production efficiency. These factors jointly support higher growth rates, enabling these regions to become regional growth poles that drive the development of surrounding areas through radiation.

### 3.2. Hotspot Analysis of Economic Growth Rate in Henan Province

Based on Equations (5) and (6), the Getis-Ord  $G_i^*$  index and its corresponding significance values  $Zscore_i$  for each county (district) are calculated, with the results presented in Figure 4 and Figure 5. The economic growth rates across the province exhibit a distinct spatial pattern of cold and hot spots.

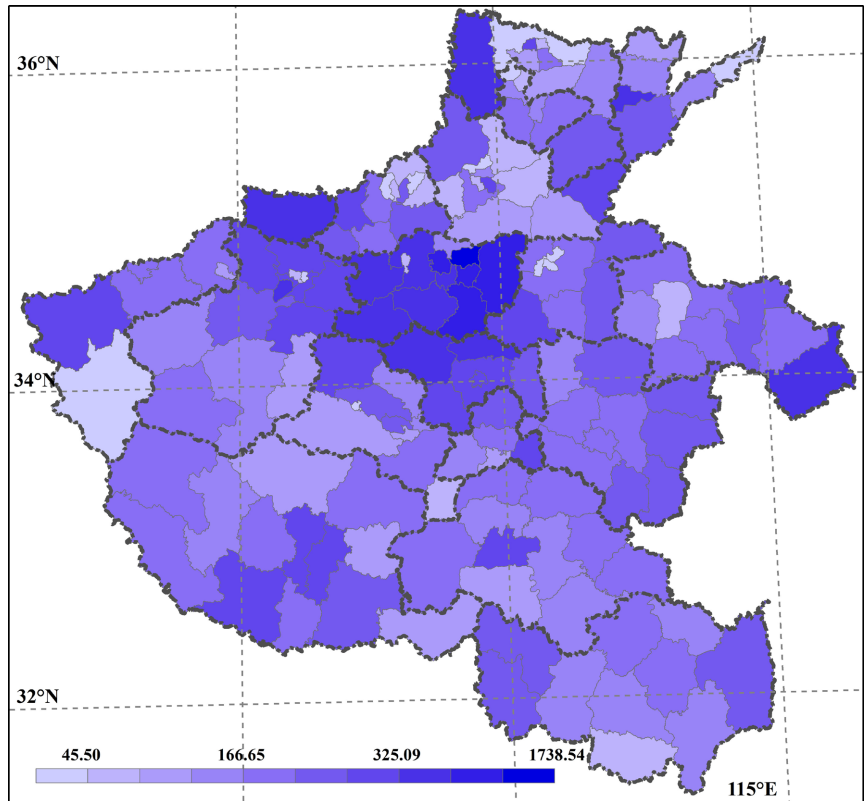


Figure 3. The distribution of the average total GDP of counties (districts) in Henan.

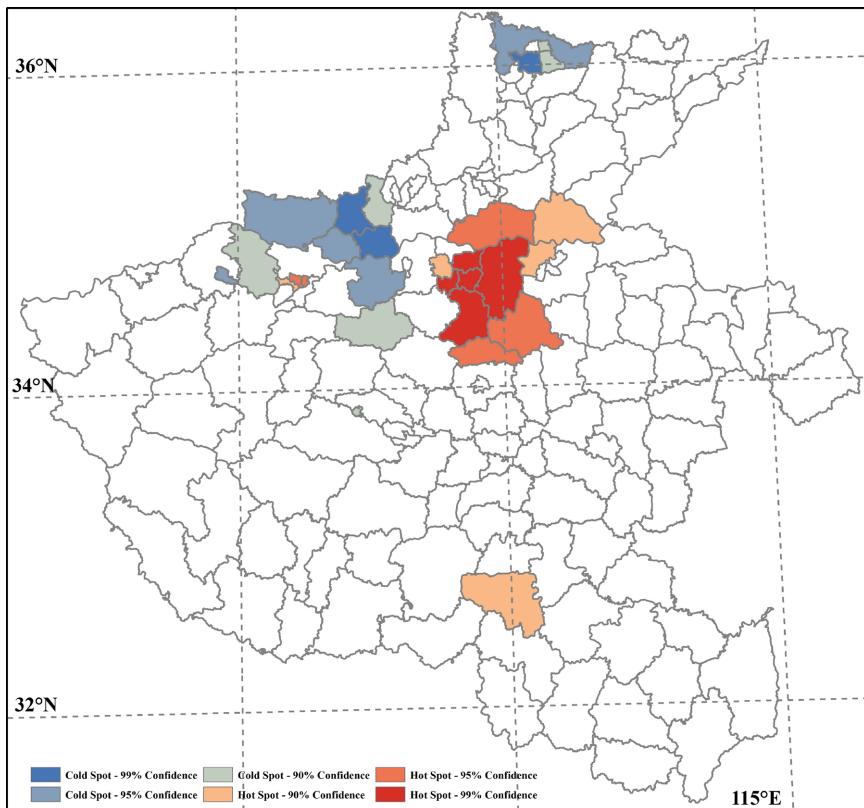
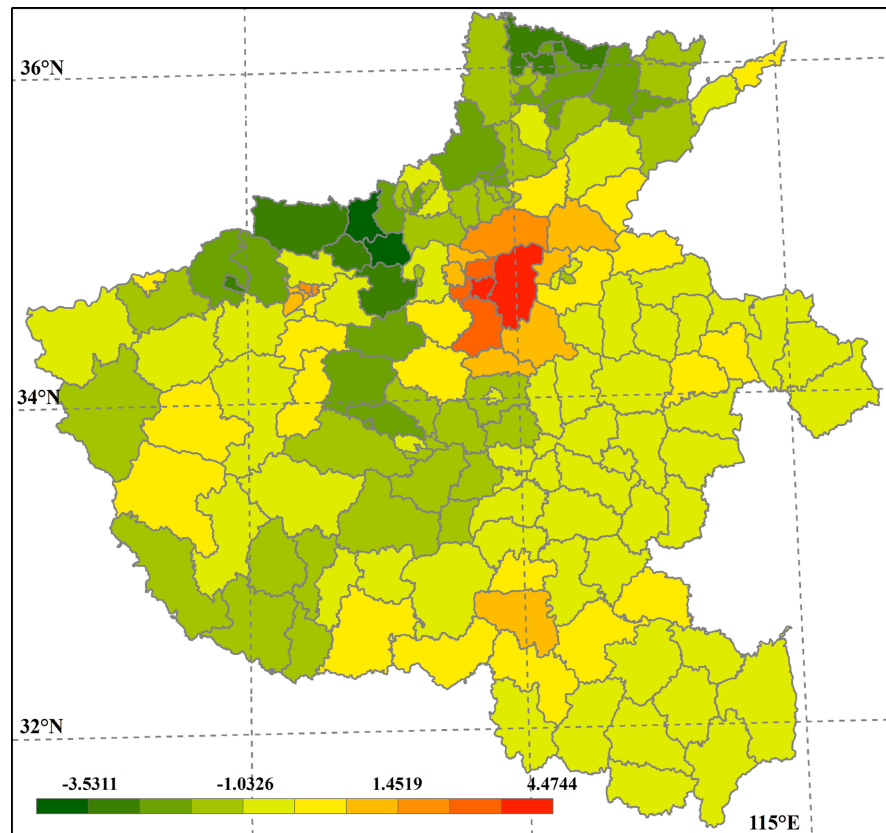


Figure 4. The hot spot and cold spot distribution of county growth rates in Henan.



**Figure 5.** The Z-scores distribution of county growth rates in Henan.

At the 90% confidence level, hot spots form two major agglomerations, each centered on the urban built-up areas of Zhengzhou and Luoyang respectively. These hot spot zones cover 15 counties (districts), accounting for 5.8719% of the total provincial area. The first agglomeration is centered on Zhengzhou's urban built-up area and encompasses 4 of its built-up districts (as Jinshui District, Zhongyuan District, Guancheng District, and Erqi District), as well as Zhongmu County and Xinzheng City. Notably, Xinzheng City emerges as the province's fastest-growing region, a trend likely attributable to the development of the Zhengzhou Airport Economy Zone; in contrast, Zhongmu County benefits from its adjacency to the newly developed Zhengdong New District. Driven by the economic radiation effect of Zhengzhou's built-up area, Yuanyang County and Fengqiu County in southern Xinxiang City, Longting District and Weishi County in western Kaifeng City, and Change City in northern Xuchang City are also incorporated into this agglomeration, amounting to a total of 11 counties (districts). The second agglomeration is centered on Luoyang's urban built-up area and covers a smaller spatial scope than the first, encompassing primarily 3 of Luoyang's built-up districts (as Chanhe District, Laocheng District, and Xigong District). Additionally, Queshan County, adjoining the southern part of Zhumadian's urban built-up area, also displays the spatial characteristic of hot spot distribution with  $r = 0.1537$  and  $ZScore = 1.7629$ .

At the 95% confidence level, the core spatial locations of hot spots within the two major agglomerations remain largely unchanged, whereas their coverage areas have contracted, encompassing 10 counties (districts) in total, which account for 3.7604% of the province's total area. The first agglomeration, anchored by Zhengzhou's urban built-up area, comprises 3 core built-up districts of the city (as Jinshui, Guancheng and Erqi Districts), along with Zhongmu County, Xinzheng City, Yuanyang County (Xinxiang), Weishi County (Kaifeng) and Changge City (Xuchang). The second agglomeration, centered on Luoyang's urban built-up area, includes two key built-up districts of Luoyang: Laocheng District and Xigong District.

At the 99% confidence level, hot spot areas are concentrated in the vicinity of Zhengzhou's urban built-up area, comprising 5 counties (districts) – Jinshui District, Guancheng District, Erqi District, Zhongmu County, and Xinzheng City – and accounting for 1.7552% of the province's total area.

Cold spot areas are concentrated primarily in two major regions: the first is situated in the northern part of the province, in the vicinity of Anyang's urban built-up area, and the second is in the northwestern part, distributed in a zonal pattern along the boundary of China's second and third topographic steps.

At the 90% confidence level, cold spot areas comprise 14 counties (districts), accounting for 5.5648% of Henan Province's total area. The first region includes 3 built-up districts of Anyang City (as Beiguan District, Wenfeng District, and Long'an District) and Anyang County. The second region consists of 4 counties (cities) of Jiaozuo City (as Bo'ai County, Qinyang City, Mengzhou City, and Wen County), 2 county-level cities of Zhengzhou City (as Gongyi City and Dengfeng City), Jiyuan City, Xinan County of Luoyang City, and Yima City of Sanmenxia City. Additionally, Shilong District of Pingdingshan City also exhibits cold spot distribution characteristics with  $r = 0.0120$  and  $ZScore = -1.6611$ .

At the 95% confidence level, cold spot areas comprise 8 counties (districts), accounting for 3.6793% of Henan Province's total area. The first region covers Long'an District and Anyang County in Anyang City, while the second includes Qinyang City and Wen County in Jiaozuo City, Gongyi City in Zhengzhou City, Jiyuan City, Xinan County in Luoyang City, and Yima City in Sanmenxia City.

At the 99% confidence level, cold spot areas cover 3 counties (districts) in total, accounting for 0.8253% of Henan Province's total area. The former encompasses Long'an District in Anyang City, while the latter comprises Qinyang City and Wen County in Jiaozuo City.

Overall, the number and coverage of spatial units in the economic growth hot spot zones exceed those of the cold spot zones, which to a certain extent indicates a notable radiation and driving effect of economic growth across the province.

### 3.3. Spatial Heterogeneity Analysis of Economic Growth Rate in Henan Province

The results of hotspot analysis indicate that the economic growth rate of Henan Province has significant spatial correlation, and spatial process factors are playing

an important role in regional economic development. To further explore the spatial correlation structure of Henan Province's economic growth rate, the formation mechanism of hotspot regions, as well as the radiation capacity, radiation direction and radiation scope of hot spot regions, we conduct a systematic analysis on the spatial variation characteristics of Henan Province's economic growth rate next.

To ensure the validity of analyzing the spatial variability of economic growth rates, this study assumes that the economic growth of counties (districts) follows the second-order stationarity hypothesis. The geographic centroid of each county (district) is used as its regional representative, and the economic growth of the corresponding administrative unit is aggregated at this point.

Based on the semivariogram models in Equations (7) and (8), semivariogram values for the economic growth rate are calculated. Four widely used semivariogram models (exponential, spherical, Gaussian, and linear) are applied to fit the empirical semivariogram curve, and the optimal linear model is determined by maximizing the coefficient of determination ( $R^2 = 0.531$ ) and minimizing the residual sum of squares ( $SSR = 2.68 \times 10^{-6}$ ),

$$\gamma(h) = \begin{cases} 2.850 \times 10^{-3} & h = 0 \\ 2.850 \times 10^{-3} + 4.254 \times 10^{-3} \times \left( \frac{h}{2.541 \times 10^5} \right) & 0 < h \leq 2.541 \times 10^5 \\ 7.104 \times 10^{-3} & 2.541 \times 10^5 < h \end{cases} \quad (10)$$

The parameters corresponding to the semivariogram are the nugget value  $C_0 = 2.850 \times 10^{-3}$ , sill value  $C + C_0 = 7.104 \times 10^{-3}$ , and range  $a = 2.541 \times 10^5$  m, respectively. The principal axis direction exerts a negligible effect on the model; the range of residuals is less than  $1 \times 10^{-8}$ , and the range of all model parameters is less than  $1 \times 10^{-6}$ .

The average distance among the 157 counties (districts) in the province is approximately 124.75 km, with an average nearest neighbor distance of about 20.20 km. A comparison of the nugget and sill values reveals significant dispersion in economic growth rates. Within the spatial autocorrelation range  $h \leq 2.541 \times 10^5$  m, the variability of economic growth rates  $C/(C + C_0) = 59.88\%$  changes markedly with increasing distance. The slight discrepancy between the semivariogram range and the provincial regional radius indicates that high-growth areas exert a strong radiation effect on low-growth areas—one that exhibits a linear decreasing trend, is unaffected by topographic factors, and shows no directionality.

The radiation scope covers 87.57% of the province (**Figure 6**), with the uncovered 23 counties (districts) concentrated in the western and southeastern parts, spanning Sanmenxia, Nanyang and Xinyang cities in particular. Notably, Gushi, Shangcheng and Xinxian counties in Xinyang City are entirely outside this scope; over 80% of the administrative area of Huangchuan, Guangshan, Luoshan counties (Xinyang City), Xichuan County (Nanyang City), Lushi County, Lingbao City (Sanmenxia City), and Taiqian County (Puyang City) falls outside the radiation range.

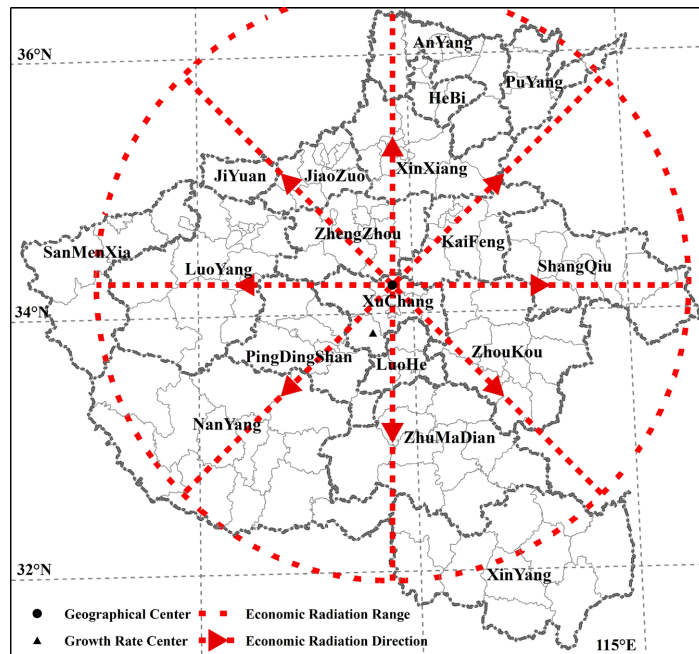


Figure 6. The economic radiation range in Henan.

Based on this linear model, Kriging interpolation (Equation (9)) is implemented for interpolative analysis, with results presented in Figure 7. Correlation analysis and regression analysis shows at a 99% confidence level, the interpolation results have good fitting accuracy, with a Mean error of  $ME = 0.27 \times 10^{-2}$ , a Root Mean Square Error of  $RMSE \approx 0.15 \times 10^{-2}$ , and  $F = 157.54 \gg F_{0.99}(1, +\infty) \approx 6.81$ . The corresponding contour distribution of economic growth rates at a 0.01 interval is illustrated in Figure 8.

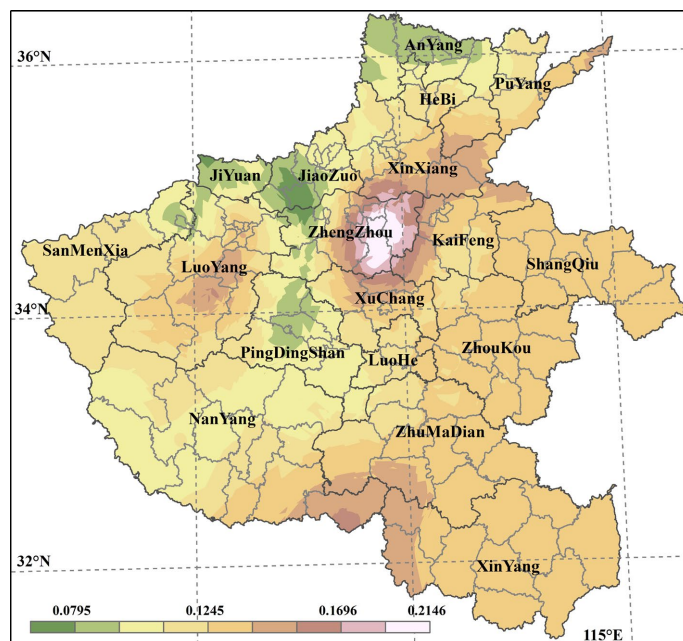
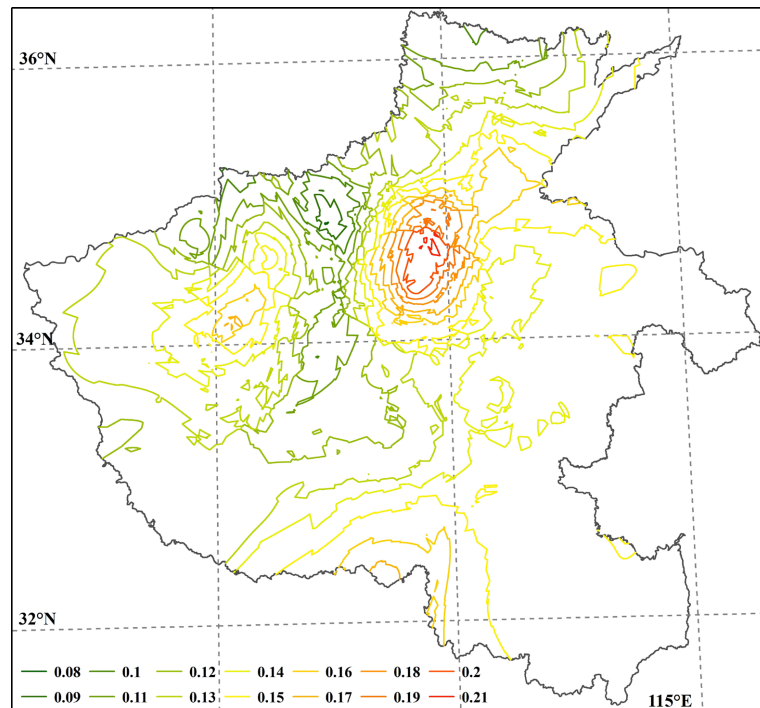
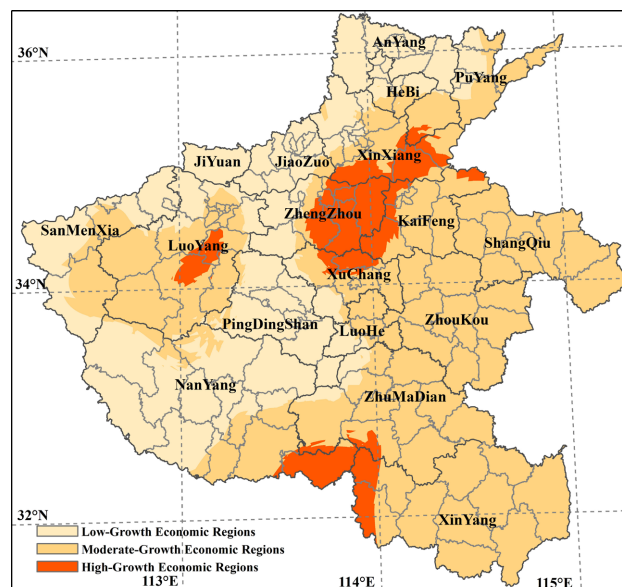


Figure 7. The interpolation distribution of economic growth rates in Henan.



**Figure 8.** The contour distribution of economic growth rates in Henan.

The interpolation results are classified using the natural breaks method, and divided into three types: high-growth zones, medium-growth zones, and low-growth zones, as presented in **Figure 9**. The high-growth zones cover 34 counties (districts), accounting for 34.56% of the total provincial area; the medium-growth zones exhibit a distinct block-like spatial structure, encompassing 118 counties (districts) and making up 56.60% of the total area; the low-growth zones comprise 86 counties (districts), accounting for 8.84% of the total area.



**Figure 9.** The interpolation distribution of county growth rates classification in Henan.

## 4. Conclusion

Based on the 2009-2025 economic statistical data of counties (districts) in Henan Province, China, this paper first employs the logistic economic growth regression model to calculate the economic growth rate of each spatial unit, and then adopts spatial analysis methods including hot spot analysis and semivariogram analysis to systematically examine the spatial distribution characteristics of economic growth rates across the province. The research results indicate that: 1) The evolution of Henan Province's regional economy is generally consistent with the logistic natural growth model. County-level economic growth rates demonstrate significant disparities, with the coefficient of variation (ratio of standard deviation to mean) reaching 0.44. Geographically, northeastern Henan exhibits relatively higher economic growth rates, and significant positive correlation exists between economic growth rate and economic aggregate. 2) Economic growth rates in Henan Province exhibit distinct hot and cold spot agglomeration characteristics. At the 90% confidence level, two major hot spot agglomerations are centered on the urban built-up areas of Zhengzhou and Luoyang respectively, with two major cold spot agglomerations: one centered on Anyang's urban built-up area, and the other distributed zonally along the boundary of China's second and third topographic steps. 3) Regions with relatively high economic growth rates exert an outward radiation effect with a linear decreasing trend, and the radiation radius stands at approximately 254.10 km. Areas not fully covered by the radiation are concentrated in the western and southern parts of the province, with no significant correlation between radiation intensity and topographic features. Interpolation analysis reveals that high-growth regions across the province cover 34 counties (districts), accounting for 34.56% of the total area; medium-growth regions exhibit a distinct block-like spatial structure, encompassing 118 counties (districts) and making up 56.60% of the total area; low-growth regions comprise 86 counties (districts), accounting for 8.84% of the total area.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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