Evolutionary Characteristics and Driving Mechanisms of the Spatial Distribution Pattern of Township Population in the Yellow River Basin

Luo Qing, Zang Yongting, Wang Yunlong, Wang Shanbing, Liu Le

2026-08-24

ChinaRxiv

Abstract

Fine-scale analysis of population change is of great theoretical and practical significance for deepening the understanding of the coupling mechanisms of human-land systems and optimizing regional development policies. Based on data from the fifth, sixth, and seventh national population censuses, this study comprehensively applies GIS spatial analysis, standard deviation ellipse, and GeoDetector methods to systematically examine the evolutionary characteristics and driving mechanisms of the spatial distribution pattern of township-level population in the Yellow River Basin from 2000 to 2020. The results show that: (1) The distribution of township-level population density in the Yellow River Basin presents a pattern of higher density in the east and lower density in the west, consistent with the distribution pattern of economic development levels. During the study period, township-level population shrinkage was pronounced, with 5530 townships experiencing population decline, accounting for 59.89% of the total number of townships. (2) Population distribution exhibits a strong spatial autocorrelation effect. During the study period, there were 935 "high-high" townships and 2406 "low-low" townships; hotspots of population growth showed an expansion trend "from north to south and from east to west" ; coldspots of population growth formed a stable pattern of "central collapse." The center of gravity of population distribution was located in Jincheng City, Shanxi, and showed a slow northward migration. (3) GeoDetector analysis reveals that the synergistic effects of physical geography, socioeconomic conditions, and geographical location are the key mechanisms shaping the township-level population distribution pattern in the Yellow River Basin, with stronger synergistic effects between physical geography factors and geographical location factors. The dominant influencing factors differ across regions, and per capita cultivated land area has the most significant constraining effect on population distribution.

Full Text

Evolutionary Characteristics and Driving Mechanisms of the Spatial Distribution Pattern of Township Population in the Yellow River Basin

Luo Qing ^1,2,3, Zang Yongting ^1,2,3, Wang Yunlong ^1,2,3, Wang Shanbing ^1,2,3, Liu Le ^1,2,3

(1. School of Urban and Rural Planning, Henan University of Economics and Law, Zhengzhou 450046, Henan, China; 2. Research Center for Coordinated Economic Development of the Yellow River Basin, Henan University of Economics and Law, Zhengzhou 450046, Henan, China; 3. Laboratory for Evolutionary Analysis and Simulation of Urban-Rural Socioeconomic Systems, Henan University of Economics and Law, Zhengzhou 450046, Henan, China)

Abstract: Fine-scale analysis of population change is of important theoretical and practical significance for deeply understanding the coupling mechanisms of human-land systems and optimizing regional development policies. Based on data from the fifth, sixth, and seventh national population censuses, this study comprehensively applies GIS spatial analysis, standard deviational ellipse, and geographical detector methods to systematically analyze the evolutionary characteristics and driving mechanisms of the spatial distribution pattern of township population in the Yellow River Basin from 2000 to 2020. The results show that: (1) The distribution of township population density in the Yellow River Basin presents a pattern of high values in the east and low values in the west, which is consistent with the pattern of economic development levels. During the study period, township population contraction was evident: 5,530 townships were in a state of population contraction, accounting for 59.89% of the total number of townships. (2) Population distribution exhibits a relatively strong spatial autocorrelation effect. During the study period, there were 935 "high-high" type townships and 2,406 "low-low" type townships; population growth hot spots showed an expansion trend "from north to south and from east to west," while population growth cold spots formed a stable "central collapse" pattern. The center of gravity of population distribution was located in Jincheng City, Shanxi Province, and showed the characteristic of slowly migrating northward. (3) Geographical detector analysis reveals that the synergistic effects of natural geography, socioeconomic conditions, and geographical location factors are the key mechanisms shaping the population distribution pattern of townships in the Yellow River Basin, among which the synergistic effect between natural geographical factors and geographical location factors is stronger. The dominant influencing factors differ among regions, and per capita cultivated land area has the most significant constraining effect on population distribution.

Keywords: influencing factors; geographical detector; spatial distribution of population; evolution of spatial pattern; Yellow River Basin

Article ID: 1000-6060(2026)08-1711-13(1711~1723)

The Yellow River Basin is an important ecological barrier and ecological corridor in China. Its ecological protection and high-quality development constitute an important component of ecological civilization construction in China and even globally[1]. However, the basin faces multiple challenges, including prominent contradictions between population, resources, and the environment, as well as unbalanced regional development. On September 12, 2024, at a symposium on comprehensively promoting ecological protection and high-quality development in the Yellow River Basin, General Secretary Xi Jinping emphasized the need to promote ecological protection across the entire basin to a new level, achieve new results in high-quality development, bring new improvements to people's lives, and open up a new situation for ecological protection and high-quality development in the Yellow River Basin. Population is the core element of regional development[2]; its spatial distribution pattern directly affects the efficiency of resource allocation, environmental carrying capacity, and the quality of economic and social development[3]. Scientifically grasping the evolutionary laws of population distribution can not only provide a basis for current regional policymaking, but also offer an important reference for future urban-rural development planning and population management strategies[4]. Especially against the background of integrated urban-rural development, in-depth study of population distribution characteristics at the township scale is of great significance for solving the problem of "rural hollowing" and promoting rural revitalization.

As a comprehensive representation of the state of regional development, the spatial distribution of population has always been a core topic in human geography research. Existing studies have achieved abundant results in measuring population distribution patterns, identifying spatiotemporal evolution laws, and exploring driving mechanisms[5-8]. Studies at the macro scale show that since Hu Huanyong proposed the Hu Line, the basic pattern of China's population distribution has remained stable, but southeastern regions have displayed significant spatial restructuring characteristics internally[9-11]. This spatial heterogeneity originates from the coupling effects of multiple factors, among which natural geographical factors—especially topographic conditions—establish the basic framework of population distribution[12-15], while economic factors have played an increasingly prominent leading role in modern population agglomeration[16-17]. With socioeconomic development, the influence of new driving factors such as geographical location and public services on population redistribution has continuously increased[18-22]. Overall, although existing studies have revealed macro-level patterns relatively well, the following two limitations remain[23-25]: research scales are mostly concentrated at the national and provincial (regional) levels, with insufficient fine-scale depiction of micro administrative units such as townships and subdistricts; and research on the response of new characteristics of population distribution under the background of urban-rural transformation still needs to be deepened.

Received: 2025-08-21; **Revised:** 2025-09-04

Funding: General Project of Humanities and Social Sciences Research of the Ministry of Education (25YJA790046); Henan Provincial Philosophy and Social Sciences Planning Project (2023BSH002); Major Basic Research Project of Philosophy and Social Sciences in Henan Universities (2025-JCZD-11); Key Scientific Research Project of Henan Higher Education Institutions (25A790004)

Author profile: Luo Qing (1981-), male, PhD, professor, doctoral supervisor, mainly engaged in research on urban-rural development and planning. E-mail: luoqing518@163.com

Townships are the basic units of coordinated urban-rural planning and integrated development, and the evolution of their population distribution patterns has unique research value. In the process of traditional urbanization, the "urban-biased" development strategy led to rural population outflow and weakening development momentum[^26]. However, with the in-depth implementation of a series of major strategies such as rural revitalization, integrated urban-rural development, and village merger and cohabitation[^27-28], rural land-resource allocation has been optimized to a certain extent, infrastructure conditions have improved, and localized population agglomeration in townships has been promoted, resulting in more complex population migration patterns in urban–rural regions. As the cradle of Chinese civilization, the Yellow River Basin has a process of population agglomeration and diffusion in its riparian townships that profoundly reflects the internal laws of regional development. Based on this, this study takes 9,234 townships in the Yellow River Basin as the research objects, integrates multi-period population census data, and systematically analyzes the spatiotemporal evolution characteristics and multi-factor synergistic driving mechanisms of the spatial pattern of township population in the basin from 2000 to 2020. The results will provide a scientific basis for promoting coordinated population–economy–environment development in the Yellow River Basin, and have important practical value for advancing high-quality regional development.

1 Data and Methods

1.1 Overview of the Study Area

As an important ecological barrier and economic belt in China, the Yellow River Basin flows through nine provinces (autonomous regions): Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong. Its main stream is 5,464 km long; the average elevation of the source region is above 4,000 m; and the basin covers a vast area of 79.5×10^4 km^2. The population distribution in the Yellow River Basin is uneven: most of the population is concentrated in the middle and lower reaches of the basin, especially in megacities such as Zhengzhou and Xi' an, forming densely populated core areas. From 2000 to 2020, the resident population of townships in the Yellow River Basin decreased by 4.56×10^7, with this decline particularly prominent in the traditional plain agricultural areas of the middle and lower reaches of the Yellow River Basin, exerting a considerable impact on ecological protection and high-quality development in the basin[^29]. As the influence of various new factors becomes increasingly evident, the region will show a more complex population distribution pattern in the future. In view of this, this study takes the 9,234 townships of 85 prefecture-level cities along the Yellow River as the basic analytical units. Their spatial extent covers the main population agglomeration areas while also fully retaining the urban–rural transition zones. The study area has typical geographic gradient characteristics and prominent human–land relationship contradictions, providing an ideal sample for exploring the laws governing the evolution of population distribution.

1.2 Research Methods

1.2.1 Spatial Autocorrelation Analysis

This study uses the global Moran' s I index to reflect the overall trend of spatial correlation in township population in the Yellow River Basin[^30]. Global Moran' s I ranges from -1 to 1. The closer the value is to 1, the stronger the spatial agglomeration of the population; the closer it is to -1, the stronger the negative spatial autocorrelation; when it equals 1, the population space exhibits a random distribution pattern. Its calculation formula is as follows:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - x_z)(x_j - x_z)}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \sum_{i=1}^{n} (x_i - x_z)^2} \qquad (1)$$

$$x_z = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad (2)$$

where I is the global Moran' s index; n is the number of research units; w_{ij} is the spatial weight; x_i and x_j are the observed values of the i-th and j-th research units, respectively; and x_z is the mean value of x_i.

Local spatial autocorrelation (LISA) analysis reflects the association of population distribution between each township unit and neighboring township units, as well as the degree of spatial clustering; it is generally characterized using LISA maps. The calculation formula is as follows:

$$I_i = \frac{1}{S^2} \sum_{j \neq i}^{n} w_{ij}(x_j - x_z)(x_i - x_z) \qquad (3)$$

$$S^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - x_z)^2 \qquad (4)$$

where I_i is the local Moran' s I value of the i-th research unit; S^2 is the sample variance.

1.2.2 Standard Deviational Ellipse Analysis

The standard deviational ellipse describes and visualizes the spatial distribution characteristics of research objects in terms of centrality, extent, distribution direction, and distribution shape[^31]. This study uses the standard deviational ellipse to reveal the spatial morphology of population distribution in the Yellow River Basin and its evolutionary characteristics. The calculation formula is:

$$\bar{x}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}, \qquad \bar{y}_w = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}$$

$$\sigma_x = \sqrt{\sum_{i=1}^{n} \frac{(w_i\bar{x}_i \cos\theta - w_i\bar{y}_i \sin\theta)^2}{\sum_{i=1}^{n} w_i^2}}, \qquad (5)$$

$$\sigma_y = \sqrt{\sum_{i=1}^{n} \frac{(w_i\bar{x}_i \sin\theta - w_i\bar{y}_i \cos\theta)^2}{\sum_{i=1}^{n} w_i^2}}$$

where $\bar{x}_w$ and $\bar{y}_w$ are the coordinate deviations from research unit i to the mean center, respectively; x_i, y_i, and $\bar{x}_i$, $\bar{y}_i$ are the longitude-latitude coordinates and weighted mean-center coordinates of research unit i, respectively; σ_x and σ_y are the standard deviations of the X and Y coordinate axes; θ is the azimuth angle of the ellipse; and w_i is the population size of research unit i.

1.2.3 Geographical Detector

The geographical detector can effectively identify spatial heterogeneity characteristics and analyze their formation mechanisms, including factor detection, interaction detection, risk-area detection, and ecological detection[^32]. This study uses the geographical detector to examine the influencing factors of township population distribution in the Yellow River Basin from 2000 to 2020. The calculation formula is as follows:

$$q = 1 - \frac{1}{N\sigma^2} \sum_{h}^{x} N_h \sigma_h^2 \qquad (6)$$

where q is the statistic of the influence factor, with a value ranging from 0 to 1. The larger the value of q, the greater the influence of the independent variable on the dependent variable. N and N_h are the numbers of units in the whole region and in stratum h, respectively; σ^2 is the variance of township population density; σ_h^2 is the variance of population density in stratum h; and x is the classification of the independent variable.

1.3 Data Sources and Processing

This study adopts a multi-source data fusion method. The data sources include: (1) township-level population data from the fifth, sixth, and seventh national population censuses of 2000–2020; (2) 30 m-resolution elevation data and 1 km-resolution precipitation and temperature data provided by the Resource and Environment Science Data Platform of the Chinese Academy of Sciences; (3) road network and river data extracted from the OpenStreetMap platform; and (4) the global nighttime light dataset (GHNTL) published by Li et al. [33]. Through radiometric calibration and resampling (1 km resolution), this dataset integrates DMSP-OLS nighttime light data for 2000–2013 and NPP-VIIRS nighttime light data for 2013–2020, resolving the temporal comparability problem between data from different sensors. All data were subjected to unified spatial registration and standardization to ensure that data quality met the needs of the study.

Because some township administrative divisions were adjusted during 2000-2020, this study processed them accordingly. The specific processing steps are as follows: (1) The data from the fifth, sixth, and seventh national population censuses for 2000–2020 were matched. Information on changes in township administrative divisions over the three periods was collected from the National Bureau of Statistics, the website of the Place Name Network of Administrative Divisions, and county- and municipal-level government websites. Changed townships were corrected and processed; among them, renamed townships were queried for their names before and after renaming and the two were matched. For townships that were canceled, merged, or newly established, manual correction was conducted according to their administrative divisions, and precise matching was carried out with township-level census data for the three periods. (2) Spatialization of township-level census data. To ensure consistency between census data and spatial boundaries, the complete township name (province name + city name + county name + township name) was used as the linking field, and the census data for the three periods were spatially joined with the township vector boundaries. Deviations found during the matching process were corrected using a combination of manual correction and GIS techniques.

2 Results and Analysis

2.1 Spatial Distribution Pattern of Township Population in the Yellow River Basin

2.1.1 Spatial differentiation characteristics of population density This paper selects population density as the key indicator for measuring the spatial distribution characteristics of township population in the Yellow River Basin. It is calculated as the ratio of the resident population of a township to the township land area. Based on relevant research results [34] and the characteristics of population distribution in the basin, it is divided into seven levels: agglomeration core areas (population density $\geq$ 1000 persons $\cdot$ km^{-2}), highly agglomerated areas (500-1000 persons $\cdot$ km^{-2}), relatively highly agglomerated areas (200-500 persons $\cdot$ km^{-2}), moderately agglomerated areas (100-200 persons $\cdot$ km^{-2}), relatively low-density agglomerated areas (50-100 persons $\cdot$ km^{-2}), low-density agglomerated areas (25-50 persons $\cdot$ km^{-2}), and relatively sparse areas ($\leq$ 25 persons $\cdot$ km^{-2}), and spatial visualization was conducted (Fig. 1). From the perspective of spatial pattern evolution, population density in the Yellow River Basin shows stable and significant differentiation characterized by being high in the east and low in the west. High-density agglomerated areas ($\geq$ 500 persons $\cdot$ km^{-2}) remain persistently concentrated in

Fig. 1 Distributions of township population density in the Yellow River Basin from 2000 to 2020

(a) 2000

(b) 2010

(c) 2020

Legend: national boundary; provincial boundary; municipal boundary; county boundary.
Population density / persons $\cdot$ km^{-2}: $\leq$ 25, 25–50, 50–100, 100–200, 200–500, 500–1000, $\geq$ 1000.
Scale: 0–500 km.

Note: The map is compiled based on the standard map with review number GS(2024)0650 from the Standard Map Service website of the Ministry of Natural Resources; the base-map boundaries have not been modified. The same applies below.

Figure 1. Distributions of township population density in the Yellow River Basin from 2000 to 2020

Shandong and Henan, and follows a distance-decay pattern of diffusion toward the periphery; medium-density clusters (100–500 persons$\cdot$km^-2) are distributed in Shaanxi and Shanxi; low-density clusters (( )50 persons $\cdot$ km^-2) are concentrated in remote areas such as Qinghai and Sichuan, where the sparse population is constrained by remoteness, inconvenient transportation, and harsh natural background conditions. Overall, the high- and medium-density clusters across the basin are mostly distributed along major roads and overlap with areas of high road-network density and flat terrain.

From the perspective of population-change trends, during 2000–2010 the township population within the basin was mainly increasing. There were 5,206 growth-type townships, mainly distributed in central Shandong, Inner Mongolia, and northern Qinghai; there were 4,028 shrinking townships, concentrated in Henan and Gansu (Fig. 2). In 2010–2020, however, population transformation and mobility intensified. In economically lagging areas, the population continuously flowed and concentrated toward central cities, township populations decreased, and shrinkage intensified. The number of shrinking townships increased to 6,690 (72.45%), forming contiguous population-shrinkage zones in Gansu, Shanxi, and Henan; there were only 2,544 growth-type townships (27.55%), scattered in Ngawa Prefecture of Sichuan, Shaanxi, and southeastern Qinghai. From a longitudinal perspective over 2000–2020, the overall township population in the basin showed a shrinking trend. Among them, 1,342 townships had population shrinkage exceeding 40% (24.27% of shrinking townships), and 2,230 townships had shrinkage of 20%–40% (40.33% of shrinking townships).

2.1.2 Spatial clustering characteristics of population distribution

The spatial autocorrelation analysis results show that township population distribution in the Yellow River Basin presents significant spatial clustering char-

Fig. 2 Distributions of township population growth in the Yellow River Basin from 2000 to 2020

Figure 1: Fig. 2 Distributions of township population growth in the Yellow River Basin from 2000 to 2020

acteristics. Based on the ArcGIS 10.8 platform, global spatial autocorrelation analysis was conducted on township population census data for 2000, 2010, and 2020. The results show that the global Moran' s I values were 0.355, 0.298, and 0.254 (P=0.000), respectively, indicating that population distribution in the study area has a significant positive spatial correlation; that is, township population exhibits a non-random clustered pattern in space. Notably, the global Moran' s I decreased over time, reflecting that the degree of spatial clustering of population in the Yellow River Basin gradually weakened and that the distribution pattern tended toward more balanced development.

To further reveal the spatial heterogeneity of population clustering, this study used the LISA cluster analysis method to identify specific clustering areas (Fig. 3). "High-high" clusters reflect contiguous areas with substantial population growth. During 2000-2010, they were mainly distributed in Inner Mongolia and northeastern Shandong, with 616 townships in total, accounting for 6.67% of all townships; during 2010-2020, they were mainly distributed in Shandong, northeastern Henan, central Shaanxi, and townships under the jurisdiction of Huangnan Tibetan Autonomous Prefecture and Guoluo Tibetan Autonomous Prefecture in Qinghai, with 2,526 townships in total, accounting for 27.36% of all townships; during 2000-2020, they were most evident in Inner Mongolia, northeastern Shandong, Linyi City, and Huangnan Tibetan Autonomous Prefecture of Qinghai, with 935 townships in total, accounting for 10.13% of all townships. "Low-low" clusters characterize concentrated contiguous areas of population decline. During 2000-2010, they were mainly distributed in Henan and Gansu, with 2,839 townships in total, accounting for 30.76% of all townships; during 2010-2020, they were most prominent in Shanxi, Gansu, and northern Inner Mongolia, with 2,165 townships in total, accounting for 23.45% of all townships; during 2000-2020, they were most prominent in Shanxi, southeastern Henan, and Wuwei City of Gansu Province, with 2,406 townships in total, accounting for the total number of townships

(a) 2000-2010

(b) 2010-2020

(c) 2000-2020

Legend: national boundary; provincial boundary; municipal boundary; township boundary.
Population change rate/%: ≤ -40; -40–-20; -20–0; 0-20; 20-40; ( )40.
Scale: 0-500 km.

图 2 2000—2020 年黄河流域乡镇人口增长分布

Fig. 2 Distributions of township population growth in the Yellow River Basin from 2000 to 2020

(a) 2000-2010

(b) 2010-2020

(c) 2000-2020

Legend
Boundaries: national boundary; provincial boundary; municipal boundary; township boundary
Cluster type: not significant; high-high; high-low; low-high; low-low

Fig. 3 LISA cluster maps of township population distribution in the Yellow River Basin from 2000 to 2020

···accounted for 26.06%. The LISA cluster analysis results reveal that, during the study period, the township population distribution in the Yellow River Basin was undergoing a transition from "core-periphery" differentiation to "multi-center-networked" restructuring.

2.1.3 Evolutionary characteristics of the spatial distribution of population

To further analyze the spatial evolutionary characteristics of township population distribution in the Yellow River Basin, this study further employed the standard deviational ellipse to explore the dynamic evolution process of township population distribution in the Yellow River Basin (Fig. 4). This method intuitively shows the spatial displacement trajectory of population agglomeration areas and, in combination with the population distribution centroid, systematically reveals the evolutionary trend and directional characteristics of the population spatial pattern. From 2000 to 2020, the spatial distribution structure of township population in the Yellow River Basin remained relatively stable, and the standard deviational ellipse was consistently located in the southeastern part of the basin. This spatial orientation is highly consistent with the pattern of regional economic development and the spatial alignment of major transportation corridors, reflecting the close association between population distribution and economic development as well as infrastructure layout. During the study period, the centroid of population distribution was always located within the territory of Jincheng City, Shanxi Province, and showed a trend of slow migration toward the north. This phenomenon indicates that the imbalance of population distribution within the basin persisted, and the eastern region consistently maintained a relatively high level of population concentration. Relying on its superior locational conditions, the eastern region formed a well-developed infrastructure network, abundant employment opportunities, and relatively high income levels; together, these advantages promoted the sustained agglomeration of resource factors.

(a) Population centroid migration map

(b) Enlarged map of the ellipse local area

(c) Enlarged map of population centroid migration

Legend
Boundaries: national boundary; provincial boundary; municipal boundary; township boundary
Standard deviational ellipse: 2000; 2010; 2020
Population centroid: 2000; 2010; 2020
Population centroid migration trajectory

Fig. 4 Migration characteristics of township population distribution in the Yellow River Basin from 2000 to 2020

2.2 Analysis of Factors Influencing Township Population Distribution in the Yellow River Basin

2.2.1 Selection and processing of influencing factors

From a theoretical perspective, the spatiotemporal heterogeneity of population spatial distribution originates from the combined effects of natural geographical factors and socioeconomic factors. Among them, natural geographical factors shape the basic framework of population distribution through long-term cumulative effects, whereas socioeconomic factors, because of their dynamism, significantly change the population distribution pattern in the short term. With reference to related studies

35–37

, the influencing factors selected in this study include the following three aspects (Table 1): (1) natural geographical factors. Elevation, temperature, precipitation, and river-network density are used to measure natural geographical factors. (2) Socioeconomic factors. The nighttime light index is used to characterize the level of economic development; village density and road-network density reflect the degree of infrastructure improvement; and per capita cultivated land area measures agricultural resource endowment. (3) Geographical location factors. Distance to the county government and distance to the municipal government are used to characterize locational advantages and to analyze their potential influence on population agglomeration.

Table 1 Construction of influencing factor indicators for township population distribution in the Yellow River Basin

Variable type	No.	Indicator name	Indicator meaning
Explained variable	Y	Population density	Permanent township population / township land area
Natural geography	X_1	Elevation	Average elevation of the township area
Natural geography	X_2	Temperature	Annual average land-surface temperature of the township
Natural geography	X_3	Precipitation	Annual average land-surface precipitation of the township
Natural geography	X_4	River-network density	Total length of trunk and tributary rivers within the township / township area
Socioeconomic	X_5	Nighttime light index	Brightness of lights within the township
Socioeconomic	X_6	Village density	Kernel density value of villages within the township
Socioeconomic	X_7	Road-network density	Total length of all roads within the township / township area
Socioeconomic	X_8	Per capita cultivated land area	Cultivated land area within the township / total population within the area
Geographical location	X_9	Distance to county government	Distance from each township to the nearest county government

Variable type	No.	Indicator name	Indicator meaning
Geographical location	X_{10}	Distance to municipal government	Distance from each township to the nearest municipal government

2.2.2 Analysis of factors influencing population spatial distribution

This study uses the geographical detector to measure the influence of factors affecting the population spatial distribution of 9,234 township units in the Yellow River Basin (Table 2), so as to analyze changes in the magnitude of the effects of influencing factors in different periods. According to the factor-detection results, the population distribution in the Yellow River Basin is greatly affected by socioeconomic and geographical location factors. Among them, per capita cultivated land area, distance to the municipal government, distance to the county government, road-network density, and village density are the dominant factors influencing township population distribution in the Yellow River Basin, whereas river-network density, temperature, and precipitation have relatively small effects on township population distribution in the Yellow River Basin. The specific analysis is as follows:

Table 2 Detection results of influencing factors on township population distribution in the Yellow River Basin

Indicator	2000 q value	2000 Rank	2010 q value	2010 Rank	2020 q value	2020 Rank
Elevation	0.407^{***}	7	0.363^{***}	6	0.250^{**}	6
Temperature	0.338^{***}	9	0.335^{**}	7	0.152^{**}	9
Precipitation	0.354^{*}	8	0.276^{*}	9	0.239^{*}	8
River-network density	0.110^{*}	10	0.114^{*}	10	0.079^{*}	10
Nighttime light index	0.493^{**}	6	0.277^{**}	8	0.240^{**}	7
Village density	0.494^{*}	5	0.575^{**}	4	0.688^{**}	4
Road-network density	0.514^{*}	4	0.435^{**}	5	0.744^{***}	2

Indicator	2000 q value	2000 Rank	2010 q value	2010 Rank	2020 q value	2020 Rank
Per capita cultivated land area	0.786***	1	0.698***	1	0.821***	1
Distance to county government	0.584***	3	0.578***	3	0.591***	5
Distance to municipal government	0.662***	2	0.695***	2	0.735***	3

Note: The q value is explanatory power; *, *, and indicate significance at the 1%, 5%, and 10% confidence levels, respectively.

(1) Per capita cultivated land area. During the study period, per capita cultivated land area consistently had the greatest influence on township population distribution in the Yellow River Basin. The explanatory powers (q values) in 2000, 2010, and 2020 were 0.786, 0.698, and 0.821, respectively, all above 0.6. The size of per capita cultivated land area directly determines the population that a given region can support, and to some extent explains the formation of high-density population clusters in Henan and Shandong within the Yellow River Basin. (2) Road-network density. During the study period, road-network density increased from 0.514 in 2000 to 0.744 in 2020, indicating that the economic core zones and main transportation networks of the Yellow River Basin are highly coupled in space. This has made the effect of "transportation-led development" increasingly prominent, and the spatial association between population distribution and transportation infrastructure as well as the level of economic development has continuously strengthened. (3) Distance to the municipal government and distance to the county government. Geographical proximity has a significant influence on population mobility and distribution. The q value of distance to the municipal government is generally higher than that of distance to the county government, showing a clear "central-place" hierarchical effect. This proves that high-level administrative centers, relying on their strong radiation capacity in economic, cultural, and public-service

resources, exert a stronger attraction on population. (4) Village density. During the study period, the influence of village density on population distribution gradually increased. As a comprehensive representation of regional natural resource endowment and historical settlement suitability, areas with high village density generate sustained population attraction through existing settlement foundations and convenience of life, forming a self-reinforcing positive feedback mechanism of "population agglomeration –regional development" in regions such as Henan, Shandong, and Shanxi.

2.2.3 Analysis of the interaction among factors influencing population distribution

Using the geographical detector method, this study further analyzed the population distribution in the Yellow River Basin.

…a multi-factor synergistic mechanism in the distribution. The results show that the q values of all two-factor combinations are significantly higher than those of single-factor effects, indicating that the formation of the population spatial pattern is the result of nonlinear synergistic effects among multiple factors (Fig. 5). From 2000 to 2020, the interactions among factors were dominated by two-factor enhancement. Among them, the explanatory power of the interactions between per capita cultivated land area, road-network density, distance to the county government, distance to the municipal government, and other factors was markedly stronger than that of interactions among the other factors. By comparison, the interactions between factors such as temperature and river-network density and other factors were relatively weak. The synergy-effect analysis reveals that there are synergistic effects among the influencing factors of population distribution in the towns of the Yellow River Basin, among which the synergistic effects between geographical-location factors and natural-geographical factors are stronger. This also verifies the applicability of the "human–land system synergy theory" in the Yellow River Basin. Specifically, geographical-location factors form a "location–environment" synergistic effect through spatial coupling with the background conditions of natural-geographical factors; socioeconomic factors generate a "development–governance" synergistic effect through spatial superposition of infrastructure networks and administrative resources. In addition, as a fundamental condition, natural-geographical factors continuously influence the suitability pattern of population distribution through interactions with geographical location and socioeconomic factors.

2.2.4 Spatial heterogeneity analysis of the factors influencing population distribution

Based on the natural-geographical characteristics and administrative divisions of the Yellow River Basin, this study divides the basin into three typical sections. The upper reaches extend from the source of the Yellow River to the river mouth in Togtoh County, Inner Mongolia, and are dominated by plateau and mountainous natural-geographical characteristics; the middle reaches extend from the

Fig. 5 Interaction effects of influencing factors on population distribution in the Yellow River Basin from 2000 to 2020

Figure 2: Fig. 5 Interaction effects of influencing factors on population distribution in the Yellow River Basin from 2000 to 2020

Fig. 6. Heat map of contribution rates of influencing factors. Vertical axis: influencing factors X_1-X_{10}; horizontal groups: upper reaches, middle reaches, lower reaches; columns in each group: 2000, 2010, 2020, average value; color bar: q value.

Figure 3: Fig. 6. Heat map of contribution rates of influencing factors. Vertical axis: influencing factors X_1-X_{10}; horizontal groups: upper reaches, middle reaches, lower reaches; columns in each group: 2000, 2010, 2020, average value; color bar: q value.

river mouth to Taohuayu in Zhengzhou, Henan, and are dominated by transitional plains in natural geography; the lower reaches extend from Taohuayu to the estuary in Shandong, and their natural-geographical characteristics are those of an alluvial plain. Based on the geodetector model, this study detects the factors influencing population distribution separately for the upper, middle, and lower reaches of the Yellow River Basin, indicating that these factors have significant spatial heterogeneity (Fig. 6). In the plateau and mountainous areas of the upper reaches, a "natural–social compound driving" characteristic is shown, with road-network density ($q = 0.751$),

Note: X_1 is elevation; X_2 is temperature; X_3 is precipitation; X_4 is river-network density; X_5 is nighttime light index; X_6 is village density; X_7 is road-network density; X_8 is per capita cultivated land area; X_9 is distance to county government; X_{10} is distance to municipal government; q value is explanatory power. The same below.

Fig. 5 Interaction effects of influencing factors on population distribution in the Yellow River Basin from 2000 to 2020

Fig. 6 Contribution rates of influencing factors in the upper, middle, and lower reaches of the Yellow River Basin from 2000 to 2020

River-network density ($q = 0.460$) and the nighttime light index ($q = 0.411$) jointly dominate the population distribution. Among them, topographic constraints cause the population to concentrate in valley basins; the arid climate (annual precipitation < 400 mm) makes river-network areas key population carriers; and the difficulty of transportation construction makes road-network density an important limiting factor. The middle-reach transitional plain zone shows the characteristics of a "socioeconomic-dominated" type: road-network density ($q = 0.481$), distance to the municipal government ($q = 0.465$), and per capita cultivated land area ($q = 0.450$) have the most significant influence. Flat terrain promotes the formation of high-density road networks, municipal administrative-resource radiation forms a 15–30 km population aggregation circle, and cultivated-land resources influence population distribution through urbanization transformation. The downstream alluvial plain area presents the characteristics of an "agriculture-location coordinated" type: the q value of per capita cultivated land area ($q = 0.561$) is the strongest, followed by distance to the municipal government ($q = 0.518$); fertile soils support high-density agricultural populations. Overall, the basin exhibits an obvious "environment-development" gradient: from upstream to downstream, the q value of natural-geographical factors decreases by 68%, the q value of socioeconomic factors increases by 15%, and the q value of geographical-location factors also increases by 25%. This finding provides a scientific basis for formulating differentiated regional development policies. It is suggested that the upper reaches should focus on constructing development axes along river valleys, the middle reaches should coordinate urban expansion with cultivated-land protection, and the lower reaches should rely on agricultural advantages to promote rural revitalization.

2.3 Driving mechanisms of the evolution of the population distribution pattern

Based on factor detection and interaction detection of the spatial distribution pattern of township populations in the Yellow River Basin, the results show that the spatial distribution of population in the Yellow River Basin is the result of the combined action of multiple factors (Fig. 7), and that the relationships among these factors and their degrees of influence show characteristics of strong-weak transformation in different regional types. On this basis, the driving mechanisms of the evolution of township population distribution patterns are analyzed in depth.

(1) **Foundational constraint mechanism of natural-geographical factors.** The Yellow River Basin spans the three major geomorphic units of the Qinghai–Tibet Plateau, the Loess Plateau, and the North China Plain. In the upper reaches, constrained by a fragile ecological environment and low agricultural carrying capacity, population continues to flow outward, causing township distribution to tend toward "low density and decentralization." By contrast, the middle and lower alluvial plains, relying on superior natural conditions, have formed strong population attraction; they not only maintain high-density concentration of the local population, but also absorb populations from the upper reaches and from outside the basin, thereby forming large-scale, densely distributed township settlements. This directional flow of population from naturally disadvantaged areas to enrichment areas, driven by differences in natural endowments, is ultimately amplified under the superimposed effects of urban-rural resource flows, forming a polarized pattern of township population distribution within the basin.

(2) **Gradient transmission mechanism of socioeconomic factors.** So-

Fig. 7 Driving mechanism of the evolution of the spatial distribution pattern of the population in the Yellow River Basin

Figure 4: Fig. 7 Driving mechanism of the evolution of the spatial distribution pattern of the population in the Yellow River Basin

cioeconomic factors reshape township population distribution through the gradient potential energy generated by uneven development and through transmission mechanisms. From 2000 to 2010, dominated by a core-periphery structure, population showed a large-scale one-way flow from rural areas to towns; after 2010, with industrial transfer and county-level economic development, population flows showed a new trend of "return and concentration" toward county seats and central towns.

Fig. 7 Driving mechanism of the evolution of the spatial distribution pattern of the population in the Yellow River Basin

In this process, improvements in transportation facilities reduced spatial resistance and accelerated urban–rural flows; meanwhile, the advance of scaled agricultural operations released a large amount of labor from agricultural production. These factors acted together, guiding population flow to shift from single-direction mobility to diversified mobility, and forming a new regional population distribution pattern with urban clusters and county seats as pivots and towns as nodes.

(3) Mechanism of strengthened interaction in geographical location. Strengthened interaction in geographical location dominates the spatial restructuring of population flows and the evolution of town distribution forms. In the upper reaches, constrained by natural conditions, urban–rural linkages are weak, the population is mainly characterized by out-migration and dispersion, and the distribution presents a dispersed pattern. In downstream urban clusters, tight urban–rural economic linkages have promoted high-frequency, networked population mobility and created a highly agglomerated form. From 2000 to 2010, transportation accessibility mainly strengthened the population agglomeration effect of central cities; after 2010, through population diffusion and redistribution within the driving region, the distribution of town populations in the Yellow River Basin evolved from the traditional "concentric-circle" model toward a "point-axis" model, forming population agglomeration belts along main transportation corridors.

3 Conclusions and Suggestions

3.1 Conclusions

(1) Population density shows a significant differentiated pattern of being high in the east and low in the west. The population distribution of the Yel-

low River Basin has marked spatial imbalance. High-density agglomeration areas ($\geq$ 500 persons $\cdot$ km^{-2}) are concentrated in downstream plain areas such as Shandong and Henan, forming stable population agglomeration cores supported by superior geographical conditions and economic development advantages. Medium-density agglomeration areas (100–500 persons $\cdot$ km^{-2}) are distributed in midstream provinces such as Shaanxi and Shanxi. Low-density agglomeration areas ($\leq$ 50 persons $\cdot$ km^{-2}) are concentrated in upper-reach plateau areas such as Qinghai and Sichuan, where the population has long been sparse because of natural constraints. Population density is significantly positively correlated with terrain flatness and transportation-network density, and high- and medium-density agglomeration areas are mostly distributed along major transportation arteries.

(2) The trend of population shrinkage has intensified, and spatial polarization is prominent. From 2000 to 2020, the township population in the Yellow River Basin as a whole showed a shrinking trend. The proportion of shrinking towns rose from 43.62% in 2000–2010 to 72.45% in 2010–2020, and contiguous population-loss areas formed in Gansu, Shanxi, Henan and other regions. Growth-type towns are scattered sporadically in ecological resettlement areas or policy-supported areas such as Aba Prefecture in Sichuan and southeastern Qinghai. This pattern of "central collapse and marginal sporadic growth" indicates that, in the process of urbanization, the vast majority of towns in the Yellow River Basin face severe challenges of population outflow.

(3) The degree of spatial agglomeration has weakened, but local polarization continues to intensify. The global Moran' s I decreased from 0.355 in 2000 to 0.254 in 2020, reflecting that the overall population distribution tends toward equalization. Local agglomeration

The typological analysis further reveals that population distribution is undergoing a transformation process from "core-periphery" differentiation to "multi-center-networked" restructuring. Hot spots of population growth have expanded from Inner Mongolia and Shandong toward Shaanxi and Qinghai, while cold spots of population contraction have remained consolidated in central provinces. The center of gravity of population distribution is mainly located in Jincheng City, Shanxi Province, and during the study period it showed the characteristic of slowly migrating northward.

(4) The spatial distribution pattern of township population in the Yellow River Basin is affected by multiple factors, among which socioeconomic and geographical-location factors play the most significant roles. Per capita cultivated land area, road-network density, and distance to county governments and municipal governments are the core driving factors, respectively reflecting agricultural carrying capacity, traffic-guiding effects, and the radiating role of central places. During the study period, per capita cultivated land area was consistently the strongest influencing factor, the

effect of road-network density continued to increase, while the impacts of distance to county governments and municipal governments showed hierarchical differences, with the effect of distance to municipal governments stronger than that of distance to county governments. Interaction analysis indicates that the influencing factors of township population distribution in the Yellow River Basin have synergistic effects; among them, the synergy between geographical-location factors and physical-geographical factors is stronger. Spatial heterogeneity analysis shows that population distribution in the upstream region is mainly constrained by road-network density and river-network density; the midstream region is dominated by transportation and administrative resources; and the downstream region shows collaborative driving by agriculture and location, forming an overall gradient from natural-constraint type to socioeconomic-dominant type.

3.2 Suggestions

In view of the above research conclusions, in the process of promoting regional coordinated development in the Yellow River Basin, local characteristics should be fully considered and optimal development paths explored. All regions need to attach importance to cultivating population agglomeration areas, and to deeply understand the influence of physical geography, socioeconomic conditions, and geographical-location factors (especially their synergistic effects) on population distribution so as to maximize agglomeration effects. For example, the upstream region may build a coordinated development model of "ecological protection–specialty industries"; the midstream region may strengthen a dual-wheel drive of "transport hub–energy base"; and the downstream region may advance integrated development of "urban agglomeration–rural revitalization." Based on the existing population-density pattern, growth poles can be developed in high-density agglomeration areas, the level of regional economic development can be improved, and radiating and driving effects can be brought into play. Specific strategies include: (1) starting from geographical-location and socioeconomic factors, strengthening the construction of transportation, communications, and other infrastructure, improving accessibility within the basin, and promoting population mobility and agglomeration over a broader scope. (2) Guiding various townships to explore development paths suited to local conditions, enhancing regional economic vitality, improving development levels, actively creating employment opportunities, attracting population inflow, and promoting the formation and development of population agglomeration areas.

This study preliminarily analyzed the evolutionary characteristics and influencing factors of township population distribution in the Yellow River Basin from 2000 to 2020, and focused on the roles of factors such as physical geography, socioeconomic conditions, and geographical location; however, deficiencies remain. Future research can proceed from the following two aspects. On the one hand, demographic factors such as population transition, natural growth, and migration may be integrated to construct a more complete mechanism-analysis framework and deepen the discussion of the mechanisms influencing spatial differentiation of population. On the other hand, from the perspective of multi-factor interactions, social factors such as education, medical care, marriage, and fertility attitudes, as well as policy factors such as family planning and ecological migration, should be incorporated; these are crucial for understanding changes in population distribution.

References

[1] Sun Yingqi, Zhang Zilong, Chen Xingpeng, et al. Size-hierarchy and network structure analysis of urban system in the Yellow River Basin using multi-source data[J]. Scientia Geographica Sinica, 2024, 44(2): 268–277. [Sun Yingqi, Zhang Zilong, Chen Xingpeng, et al. Size-hierarchy and network structure analysis of urban system in the Yellow River Basin using multi-source data[J]. Scientia Geographica Sinica, 2024, 44(2): 268–277.]

[2] Fan Zhengde, Yi Chengdong, Lü Xuezheng, et al. Spatial-temporal pattern evolution and driving factors of population distribution in Metropolitan Area: Empirical evidence from the three metropolitan areas of Beijing, Shanghai and Guangzhou[J]. Urban Development Studies, 2023, 30(9): 97–105. [Fan Zhengde, Yi Chengdong, Lü Xuezheng, et al. Spatial-temporal pattern evolution and driving factors of population distribution in Metropolitan Area: Empirical evidence from the three metropolitan areas of Beijing, Shanghai and Guangzhou[J]. Urban Development Studies, 2023, 30(9): 97–105.]

[3] Wang Hua, Zhang Wei, Song Hui, et al. Spatial evolution of urban population in Changsha and its simulation: Based on the multi-source data[J]. Economic Geography, 2023, 43(8): 49–61. [Wang Hua, Zhang Wei, Song Hui, et al. Spatial evolution of urban population in Changsha and its simulation: Based on the multi-source data[J]. Economic Geography, 2023, 43(8): 49–61.]

[4] Chen Weimin, Ren Yuqing. Population aging, income distribution and household consumption in China[J]. Population Journal, 2025, 47(4): 82–97. [Chen Weimin, Ren Yuqing. Population aging, income distribution and household consumption in China[J]. Population Journal, 2025, 47(4): 82–97.]

[5] Tang Shuangshuang, Zhou Jing, Xu Qiqi, et al. Population distribution evolution and influencing factors of city-town-rural area in Jiangsu Province from 2010 to 2020[J]. Progress in Geography, 2024, 43(5): 993-1007. [Tang Shuangshuang, Zhou Jing, Xu Qiqi, et al. Population distribution evolution and influencing factors of city-town-rural area in Jiangsu Province from 2010 to 2020[J]. Progress in Geography, 2024, 43(5): 993–1007.]

[6] Liu Tao, Peng Rongxi, Zhuo Yunxia, et al. China' s changing population distribution and influencing factors: Insights from the 2020 census data[J]. Acta Geographica Sinica, 2022, 77(2): 381–394. [Liu Tao, Peng Rongxi, Zhuo Yunxia, et al. China' s changing population distribution and influencing factors: Insights from the 2020 census data[J]. Acta Geographica Sinica, 2022, 77(2): 381–394.]

[7] Deng Yu, Liu Shenghe, Cai Jianming, et al. Spatial pattern and its evolution of Chinese provincial population and empirical study[J]. Acta Geographica Sinica, 2014, 69(10): 1473-1486. [Deng Yu, Liu Shenghe, Cai Jianming, et al. Spatial pattern and its evolution of Chinese provincial population and empirical study[J]. Acta Geographica Sinica, 2014, 69(10): 1473-1486.]

[8] Hugo G. Population geography[J]. *Progress in Human Geography*, 2007, 31(1): 77-88.

[9] Qi Wei, Liu Shenghe, Liu Zhen. The novel pattern and driving factors of population spatial distribution on both sides of the "Hu Line" based on the seventh census in China[J]. *Acta Geographica Sinica*, 2022, 77(12): 3023-3040. [Qi Wei, Liu Shenghe, Liu Zhen. The novel pattern and driving factors of population spatial distribution on both sides of the "Hu Line" based on seventh census in China[J]. *Acta Geographica Sinica*, 2022, 77(12): 3023-3040.]

[10] Ding Jinhong, Cheng Chen, Zhang Weijia, et al. The ideological origins and geographical demarcation significance of Hu Huanyong Line[J]. *Acta Geographica Sinica*, 2021, 76(6): 1317-1333. [Ding Jinhong, Cheng Chen, Zhang Weijia, et al. The ideological origins and geographical demarcation significance of Hu Huanyong Line[J]. *Acta Geographica Sinica*, 2021, 76(6): 1317-1333.]

[11] Zhou Hao. The stability of migration pattern in China and related issues: Consideration based on the data of seventh national census bulletin[J]. *Chinese Journal of Population Science*, 2021(3): 28-41, 126-127. [Zhou Hao. The stability of migration pattern in China and related issues: Consideration based on the data of seventh national census bulletin[J]. *Chinese Journal of Population Science*, 2021(3): 28-41, 126-127.]

[12] Xu Di, Xu Yan. Spatio-temporal pattern of registered population in Nanjing from 1928 to 2017[J]. *Acta Geographica Sinica*, 2022, 77(10): 2439-2456. [Xu Di, Xu Yan. Spatio-temporal pattern of registered population in Nanjing from 1928 to 2017[J]. *Acta Geographica Sinica*, 2022, 77(10): 2439-2456.]

[13] Zhang Yingna, Wang Yue, Hu Haoyu, et al. Analysis of population spatial-temporal distribution and mobility in Beijing-Tianjin-Hebei urban agglomeration based on mobile phone trajectory big data[J]. *Areal Research and Development*, 2023, 42(3): 161-167, 180. [Zhang Yingna, Wang Yue, Hu Haoyu, et al. Analysis of population spatial-temporal distribution and mobility in Beijing-Tianjin-Hebei urban agglomeration based on mobile phone trajectory big data[J]. *Areal Research and Development*, 2023, 42(3): 161-167, 180.]

[14] Li Bo, Jin Shuting, Chen Xingpeng, et al. The population spatial distribution characteristics of China since the reform and opening up: Analysis of the four national census data based on 1982-2010[J]. *Economic Geography*, 2016, 36(7): 27-37. [Li Bo, Jin Shuting, Chen Xingpeng, et al. The population spatial distribution characteristics of China since the reform and opening up: Analysis of the four national census data based on 1982-2010[J]. *Economic Geography*, 2016, 36(7): 27-37.]

[15] Zhao Tongtong, Song Bangguo, Chen Yuansheng, et al. Analysis of population distribution and its spatial relationship with terrain elements in the Yarlung Zangbo River, Nyangqu River and Lhasa River region, Tibet[J]. *Journal of Geo-Information Science*, 2017, 19(2): 225-237. [Zhao Tongtong, Song Bangguo, Chen Yuansheng, et al. Analysis of population distribution and its spatial relationship with terrain elements in the Yarlung Zangbo River, Nyangqu River and Lhasa River region, Tibet[J]. *Journal of Geo-Information Science*, 2017, 19(2): 225-237.]

[16] Jiang Tuanbiao, Zhu Benhui, Liu Yixiao. Analysis on the spatial and temporal evolution of population distribution and its influencing factors in the Pearl River-Xijiang River economic belt[J]. *South China Population*, 2020, 35(4): 57-67. [Jiang Tuanbiao, Zhu Benhui, Liu Yixiao. Analysis on the spatial and temporal evolution of population distribution and its influencing factors in the Pearl River-Xijiang River economic belt[J]. *South China Population*, 2020, 35(4): 57-67.]

[17] Ma Xiaomin, Zhang Zhibin, Guo Qianqian, et al. Spatial and temporal evolution and driving factors of population in Lanzhou City from 2000 to 2020[J]. *Arid Land Geography*, 2025, 48(1): 168-178. [Ma Xiaomin, Zhang Zhibin, Guo Qianqian, et al. Spatial and temporal evolution and driving factors of population in Lanzhou City from 2000 to 2020[J]. *Arid Land Geography*, 2025, 48(1): 168-178.]

[18] Liu Aihua. Analysis on the spatial agglomeration and its influence factors of the floating population in Beijing-Tianjin-Hebei[J]. *Population & Economics*, 2017(6): 71-78. [Liu Aihua. Analysis on the spatial agglomeration and its influence factors of the floating population in Beijing-Tianjin-Hebei[J]. *Population & Economics*, 2017(6): 71-78.]

[19] Wang Lu, Feng Zhiming, Yang Yanzhao, et al. The change of population density and its influencing factors from 2000 to 2010 in China on county scale[J]. *Acta Geographica Sinica*, 2014, 69(12): 1790-1798. [Wang Lu, Feng Zhiming, Yang Yanzhao, et al. The change of population density and its influencing factors from 2000 to 2010 in China on county scale[J]. *Acta Geographica Sinica*, 2014, 69(12): 1790-1798.]

[20] Wu Rongwei, Zhang Jiali, Zhou Liang, et al. Population aging in Chinese counties: Change of regional types and influencing factors from the population mobility perspective[J]. *Progress in Geography*, 2025, 44(6): 1213-1226. [Wu Rongwei, Zhang Jiali, Zhou Liang, et al. Population aging in Chinese counties: Change of regional types and influencing factors from the population mobility perspective[J]. *Progress in Geography*, 2025, 44(6): 1213-1226.]

[21] Zhu Huxiao, Tang Shuangshuang, Xu Qiqi. Spatial distribution and influencing factors of four types of floating population in urban and rural areas: A case study of Jiangsu Province[J]. *Geographical Research*, 2025, 44(6): 1655-1673. [Zhu Huxiao, Tang Shuangshuang, Xu Qiqi. Spatial distribution and influencing factors of four types of floating population in urban and rural areas:

A case study of Jiangsu Province[J]. *Geographical Research*, 2025, 44(6): 1655–1673.]

[22] Wang Zhenbo, Xu Jiangang, Zhu Chuangeng, et al. The county accessibility divisions in China and its correlation with population distribution[J]. *Acta Geographica Sinica*, 2010, 65(4): 416–426. [Wang Zhenbo, Xu Jiangang, Zhu Chuangeng, et al. The county accessibility divisions in China and its correlation with population distribution[J]. *Acta Geographica Sinica*, 2010, 65(4): 416–426.]

[23] Tong Yufen, Han Jiabin, Yang Yanfei. Evaluation of rationality of population distribution of urban agglomerations in China: Based on the analysis of economic benefits of urban agglomerations[J]. *Population Research*, 2024, 48(3): 52–64. [Tong Yufen, Han Jiabin, Yang Yanfei. Evaluation of rationality of population distribution of urban agglomerations in China: Based on the analysis of economic benefits of urban agglomerations[J]. *Population Research*, 2024, 48(3): 52–64.]

[24] Li Qingpeng, Zhou Hongwei. Evolution of village-level population in north China in 1920–2010: A case of Pingyao County in Shanxi Province[J]. *Economic Geography*, 2025, 45(2): 91–102. [Li Qingpeng, Zhou Hongwei. Evolution of village-level population in north China in 1920–2010: A case of Pingyao County in Shanxi Province[J]. *Economic Geography*, 2025, 45(2): 91–102.]

[25] Li Qin, Xie Zhi, Zhang Zihan, et al. Spatial distribution and influencing factors of the willingness of agricultural transfer population to settle in cities in Hunan Province from the perspective of new-type urbanization: Based on the 2017 national dynamic monitoring data on floating population[J]. *Economic Geography*, 2024, 44(11): 95–103. [Li Qin, Xie Zhi, Zhang Zihan, et al. Spatial distribution and influenc-

ing factors of the citizenization willingness of agricultural transfer population in Hunan Province under the perspective of new urbanization: Based on the dynamic monitoring data of the national floating population in 2017[J]. Economic Geography, 2024, 44(11): 95–103.]

[26] Li J T, Jia L R, Liu Y S, et al. Measuring model of rural transformation development path in Fuping County of Beijing-Tianjin-Hebei region[J]. Habitat International, 2018, 74(4): 48–56.

[27] Liu Tao, Zhu Yujia. Effects of main function zoning on China' s population redistribution[J]. Acta Geographica Sinica, 2025, 80(6): 1427–1445. [Liu Tao, Zhu Yujia. Effects of main function zoning on China' s population redistribution[J]. Acta Geographica Sinica, 2025, 80(6): 1427–1445.]

[28] Zhang Xueliang, Pan Ting. Accurate identification and characteristic analysis of township population shrinkage from the perspective of dual boundary: A case study of the Yellow River Basin[J]. Economic Geography, 2024, 44(3): 1–10. [Zhang Xueliang, Pan Ting. Accurate identification and characteristic analysis of township population shrinkage from the perspective of dual boundary:

A case study of the Yellow River Basin[J]. Economic Geography, 2024, 44(3): 1-10.]

[29] Fu Zhanhui, Yang Yahan, Qiao Jiajun, et al. Rural hollowing out in the Yellow River Basin and the development path of rural revitalization[J]. Progress in Geography, 2024, 43(6): 1049-1059. [Fu Zhanhui, Yang Yahan, Qiao Jiajun, et al. Rural hollowing out in the Yellow River Basin and the development path of rural revitalization[J]. Progress in Geography, 2024, 43(6): 1049-1059.]

[30] Gao Wei, Yang Liya, Zhao Xinzheng, et al. Spatiotemporal patterns and influencing factors of population shrinkage in the Yellow River Basin from the perspective of the Major Function Oriented Zone[J]. Geographical Research, 2025, 44(6): 1565-1586. [Gao Wei, Yang Liya, Zhao Xinzheng, et al. Spatiotemporal patterns and influencing factors of population shrinkage in the Yellow River Basin from the perspective of the Major Function Oriented Zone[J]. Geographical Research, 2025, 44(6): 1565-1586.]

[31] Gong Pan, Zhang Shuo, Wang Wenzhe. The evolutionary characteristics and spatial-temporal pattern of China' s urban shrinkage from the perspective of population: Based on the analysis of the seventh national census bulletin data[J]. Population & Economics, 2022(3): 1-15. [Gong Pan, Zhang Shuo, Wang Wenzhe. The evolutionary characteristics and spatial-temporal pattern of China' s urban shrinkage from the perspective of population: Based on the analysis of the seventh national census bulletin data[J]. Population & Economics, 2022(3): 1-15.]

[32] Luo Qing, Wang Yifei, Zhou Xiaoqing, et al. Spatial pattern of Chinese farmers' professional cooperatives and its influencing factors[J]. Chinese Journal of Agricultural Resources and Regional Planning, 2024, 45(5): 155-168. [Luo Qing, Wang Yifei, Zhou Xiaoqing, et al. Spatial pattern of Chinese farmers' professional cooperatives and its influencing factors[J]. Chinese Journal of Agricultural Resources and Regional Planning, 2024, 45(5): 155-168.]

[33] Li X C, Zhou Y Y, Zhao M, et al. A harmonized global nighttime light dataset 1992—2018[J]. Scientific Data, 2020(7): 168-177.

[34] Sun Pingjun, Liu Ju, Luo Ning, et al. The spatial pattern of shrinking cities in Chengdu-Chongqing economic circle and its influencing factors: Based on the analysis of the fifth, sixth, and seventh national population census data[J]. Journal of Southwest University (Natural Science Edition), 2022, 44(1): 46-56. [Sun Pingjun, Liu Ju, Luo Ning, et al. The spatial pattern of shrinking cities in Chengdu-Chongqing economic circle and its influencing factors[J]. Journal of Southwest University (Natural Science Edition), 2022, 44(1): 46-56.]

[35] Liu C L, Wang F H, Xu Y P. Habitation environment suitability and population density patterns in China: A regionalization approach[J]. Growth and Change, 2019, 50(1): 184-200.

[36] Du Zhiwei. Spatial characteristics and influencing factors on population shrinkage in city-town-rural areas of small and medium-sized cities in China[J].

Geographical Research, 2025, 44(6): 1534–1550. [Du Zhiwei. Spatial characteristics and influencing factors on population shrinkage in city-town-rural areas of small and medium-sized cities in China[J]. Geographical Research, 2025, 44(6): 1534–1550.]

[37] Yang Huimin, Xu Jiawei, Li Xiaojian. Characteristics and influencing factors of population distribution in plain agricultural areas in the process of urbanization: A case study of Zhecheng County in the eastern plain of Henan Province[J]. Geographical Research, 2023, 42(6): 1528-1544. [Yang Huimin, Xu Jiawei, Li Xiaojian. Characteristics and influencing factors of population distribution in plain agricultural areas in the process of urbanization: A case study of Zhecheng County in the eastern plain of Henan Province[J]. Geographical Research, 2023, 42(6): 1528–1544.]

Evolutionary characteristics and driving mechanisms of population distribution patterns in townships along the Yellow River Basin

LUO Qing^1,2,3, ZANG Yongting^1,2,3, WANG Yunlong^1,2,3, WANG Shanbing^1,2,3, LIU Le^1,2,3

(1. School of Urban and Rural Planning, Henan University of Economics and Law, Zhengzhou 450046, Henan, China; 2. Research Center for Coordinated Economic Development of the Yellow River Basin, Zhengzhou 450046, Henan, China; 3. Laboratory of Evolutionary Analysis and Simulation for Urban-Rural Socioeconomic Systems, Zhengzhou 450046, Henan, China)

Abstract: Fine-scale analyses of population change are of theoretical and practical significance for deepening understanding of human-land system coupling mechanisms and optimizing regional development policies. Drawing on data from the fifth, sixth, and seventh Chinese national population censuses, this study systematically analyzes the evolutionary characteristics and driving mechanisms of spatial distribution patterns of township-level populations in the Yellow River Basin from 2000 to 2020, using integrated methods such as GIS spatial analysis, the standard deviational ellipse, and geographical detection. The results indicate the following: (1) The population density distribution in the Yellow River Basin exhibits a pattern of high values in the east and low values in the west, which is consistent with the distribution pattern of economic development levels. During the study period, township population shrinkage was pronounced, with 5,530 townships experiencing population decline, accounting for 59.89% of all townships. (2) The population distribution displays strong spatial autocorrelation. During the study period, there were 935 high-high type townships and 2,406 low-low ones. Hotspots of population growth expanded from north to south and from east to west, while cold spots of population growth formed a stable pattern of central collapse. The center of gravity of the population distribution was in Jincheng City, Shanxi Province, and exhibited a slow northward migration trend. (3) Geographical detector analysis reveals that the synergistic effects of natural geographical conditions, levels of economic development, and locational factors were the key mechanisms shaping the population distribution pattern in the townships of the Yellow River Basin, with stronger synergistic effects observed between natural and locational factors. The dominant influencing factors vary across regions, and per capita arable land area exerted the most significant constraining effect on population distribution.

Keywords: influencing factors; geographical detector; population spatial distribution; spatial pattern evolution; Yellow River Basin

Note: Figure translations are in progress. See original paper for figures.