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Population evolution at the prefecture-level city scale in China:

Change patterns and spatial correlations

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Abstract: China has entered a new stage of high-quality urbanization. Therefore, it is critical to grasp the latest population distribution and dynamics. Using mean-variance grading, Moran's index, and the Theil index, this study compared the differences in population changes between 2010–2020 and 2000–2010 at the prefecture-level city scale based on census data to analyze the new trends in population evolution. We found that: (1) New growth poles of the population are inland provincial capitals, forming rapid-growing zones together with coastal urban agglomerations. Population growth in over 60% of the cities in the northern coastal urban agglomeration has slowed. (2) The scope of population loss in inland areas is constantly expanding. In the northeastern part of China, 92.7% of the cities have lost population, making this a typical population loss area. (3) Population shrinkage in the northeastern region and growth in the Pearl River Delta urban agglomeration show diffusion characteristics, while population patterns around the provincial capital are in a polarized stage. (4) The Theil index of population distribution increased, with 83.91% of differences coming from between groups, indicating that the gap between cities of different sizes has further expanded. This study provides scientific support for the coordinated promotion of nearby and remote urbanization.

Keywords: population distribution; agglomeration and decentralization; pattern change; nearby urbanization; prefecture-level city

1 Introduction

Changes in spatial population characteristics reflect population distribution laws and regional development differences, and they serve as the foundation for population regulation and regional development policies. China's entire floating population is expected to reach 376

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million by 2020, up 70% from 2010. The massive urban–rural population flux continually reshapes the population's spatial distribution pattern (Fan, 2005). According to the floating population monitoring report, China's floating population reached a tipping point in 2014, shifting from a steady increase to a decline, resulting in changes in population concentration and spatial distribution that drew widespread attention from academia and policymakers. The first round of new-type urbanization planning (2014–2020) is coming to an end, and the new-type urbanization will enter a new stage of people-oriented high-quality development, with a greater focus on the evolution of the man–land relationship (Chen *et al*., 2020). The analysis of current population evolution law is useful for the study and judgment of the population distribution pattern in the new era, the establishment of the urban system, the practice of multi-mode urbanization, and basic research on people-oriented new-era urbanization.

Census data is an accurate reflection of the population's spatial distribution, and it is commonly used in studies on population distribution, migration, and new-type urbanization (Liu *et al*., 2015a; 2015b; Fang *et al*., 2017; Chen *et al*., 2021a). For a long time, the natural environment, resource endowment, climatic conditions, and other factors significantly impacted population size, leading to a relatively consistent basic geographical pattern. In 1935, Hu proposed the geographical division line of the population from Heihe in Heilongjiang to Tengchong in Yunnan, reflecting the unequal development of the east and west (Chen *et al*., 2021b). The spatial pattern of the population divided by the Hu line maintains long-term stability, regardless of its rich geographical connotations (Gong *et al*., 2019) or the objective reflection of facts (Li *et al*., 2012; Chen *et al*., 2016; Lu *et al*., 2016; Qi *et al*., 2016; Li *et al*., 2017).

With the advancement of marketization, industrialization, and urbanization, China's population mobility has been continuously strengthened (Qiao *et al*., 2016), and economic factors have played a significant role in the reconstruction of population patterns (Li *et al*., 2019), breaking the constraints of natural geographical conditions to a certain extent. Studies have shown that China's urban scale structure has changed significantly since the implementation of the reform and opening-up policy that started in 1978 (Anderson *et al*., 2005). The level of economic development and the progress of urbanization are thought to be related to urban population growth (Storper *et al*., 2006; Liang *et al*., 2021; Liang *et al*., 2022). According to the cumulative circulation effect, the higher the population size, the faster the population growth rate (Black *et al*., 2003), thereby exacerbating population polarization. Fang *et al*. (2017) referred to Zipf's law to reveal that China's uneven spatial distribution of urban population increased from 2000 to 2012. Liu *et al*. (2015b) reported that before 2010, 1% of Chinese cities absorbed nearly half of the floating population. In recent years, studies on the redistribution of population space have shown that the Pearl River Delta, Yangtze River Delta, northern Beijing-Tianjin-Hebei region, and other eastern urban agglomerations are the main inflow areas for the country's population, mainly from the central and western provinces of China, such as Sichuan, Hunan, Hubei and Anhui (Liu *et al*., 2015a; Wang *et al*., 2016; Zang *et al*., 2016; Liu and Gu, 2020). The growth of China's floating population has gradually slowed down. However, the concentration trend in inland provincial capitals and coastal low-tier cities is becoming progressively more evident, and the urban agglomeration areas with growing populations show a multi-center trend (Lan *et al*., 2019; Wu *et al*., 2019). The willingness of the floating population to settle increases as the floating scale is reduced, and the impact of social welfare and quality of life on changes in the population size's spatial structure, steadily increases (Ding *et al.*, 2021).

Existing studies are often based on population size or density data, using statistical analysis (Chen *et al.*, 2016; Liu *et al.*, 2020), coefficient of variation (Qi *et al.*, 2016), geographic detectors (Li *et al.*, 2017), population center of gravity model (Liang *et al.*, 2021), transition matrix (Xu *et al.*, 2009), Moran index (Zhang *et al.*, 2018), Gini coefficient (Yang *et al.*, 2017), dividing line of population density (Ge *et al.*, 2010), Lorenz curve (Han *et al.*, 2007), and other methods of studying the spatial distribution pattern. In this paper, we compare the population changes of cities at different levels in different periods to analyze the evolution of population patterns, and to identify the types of population change and their evolution in different regions. In terms of data, we use the latest seventh census data, which reflects the most accurate changes in the population pattern.

Based on the data from the fifth, sixth, and seventh censuses at the prefecture-level city scale, this paper uses a variety of hierarchical classification methods to study the types of population changes in different regions. It analyzes the spatial distribution characteristics of population changes in prefecture-level cities and the changing trend of differences between cities of different sizes. It uses ArcGIS and statistical analysis tools to measure spatial correlation and variability to obtain the updated characteristics of population evolution in China's prefecture-level cities, thereby providing a reference for the new-type urbanization and regional coordinated development of multiple models such as nearby and remote urbanization.

2 Data and methods

2.1 Population data

This paper uses data from the fifth, sixth, and seventh national censuses at the prefecture-level city scale. The first two are from the national census data. The most recent census data come from the seventh national census bulletin for each province (autonomous regions, municipalities directly under the Central Government). For convenience of comparison, the data for the three years are integrated according to the administrative regions in 2020, with a total of 357 prefecture-level administrative units. Due to missing data, Hong Kong, Macao, Taiwan, and the 10 directly administered counties in Xinjiang are not included in this article.

2.2 Methods

2.2.1 The mean standard deviation classification method

The mean standard deviation approach distinguishes types by employing a combination of a variable's mean and multiple standard deviation multiples. The standard deviation reflects how the variable deviates from the mean, thereby representing the overall average of the variable. Prefecture-level cities can be divided based on the degree of population variation or change relative to the average level. The typical characteristics of prefecture-level cities with a substantial degree of deviation can be differentiated. The equations for calculating the mean and standard deviation are as follows:

$$\mu = \frac{\sum_{i=1}^{n} pop_i}{n}, std = \left[\frac{\sum_{i=1}^{n} pop_i^2 - \left(\sum_{i=1}^{n} pop_i \right)^2 / n}{n-1} \right]^{1/2} \tag{1}$$

among them, μ and std are the mean and standard deviation of the population size of the prefecture-level city or the population change in 10 years, respectively; pop_i represents the size or variation of the population of the *i*-th prefecture-level city. The categories of population change in 10 years are divided into four groups, with 0 and *std* as thresholds, according to the practical implication of population change. The prefecture-level cities of different scales are divided into five categories with μ, ±0.5 std as the dividing point (see Table 1), where *pop* denotes the population size and Δpop denotes the population change over a 10-year period.

Table 1 Population changes and scale classification methods

Type	1	2	3	4	5
pop	$>\mu+std$	$\mu+0.5std\sim\mu+std$	$\mu-0.5std\sim\mu+0.5std$	$\mu-std\sim\mu-0.5std$	$<\mu-std$
Δ*pop*	$>\mu+std$	$0.5\sim\mu+std$	$\mu-std\sim0$	$<\mu-std$	–

2.2.2 Spatial correlation of population and changes

We used the global Moran index (Moran, 1950) and the LISA agglomeration map to measure and display the geographical correlation features of population change and size in cities at the prefecture level. The global Moran index quantifies the overall degree of agglomeration, and the LISA agglomeration map based on the local Moran index can identify spatially specific regions of polarization or diffusion. The global Moran index is calculated as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)} \tag{2}$$

where *I* is the global Moran index, w_{ij} is the spatial weight of the relationship between cities *i* and *j*: a simple binary adjacency matrix is used to represent the proximity relationship (that is, adjacent is 1, non-adjacent is 0), x_i and x_j are the population size or amount of change in cities *i* and *j* respectively, $\bar{x}$ is the mean. The value of *I* ranges from –1 to 1. When *I* is more than 0, it means that similar values on the space are spatially aggregated, where high values and high values are concentrated, or low values and low values are concentrated. Conversely, when *I* is less than 0, it means that diverse values are spatially aggregated.

Global spatial autocorrelation cannot accurately represent the specific spatial location of agglomeration or anomalies. In this paper, the LISA index (I_i) is introduced to test the effects of aggregation or dispersion in local areas to reveal the degree of spatial autocorrelation of population and its changes. The function is as follows:

$$I_i = \frac{n\left(x_i - \bar{x}\right)\sum_{j=1}^{n} w_{ij}\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \tag{3}$$

The standardized statistic for its test is:

$$Z = \frac{I_i - E(I_i)}{\sqrt{VAR(I_i)}} \tag{4}$$

If Z is positive and greater than 1.96, the region has a positive spatial autocorrelation. If Z is negative and less than −1.96, the region has a negative spatial autocorrelation. Z is between −1.96 and 1.96, giving the observations an independent random distribution (Cui *et al.*, 2020).

2.2.3 Differences in population distribution

The Theil index is a special form of the generalized entropy index system, widely used to evaluate regional heterogeneity. The Theil index is decomposable, not only judging the overall difference level but also distinguishing gaps and contributions between or within groups. Bourguignon and Shorrocks decomposition techniques for overall differences, between-group differences, and intra-group differences in the Thiel index are applied in this paper (Bourguignon, 1979; Shorrocks, 1980). The Theil index is used to measure and decompose the disparity in various degrees of population size in China. The formula is as follows:

$$T_{pi} = \sum_j \left(\frac{P_{ij}}{P_i}\right) \log\left(\frac{P_{ij} / P_i}{1 / N_i}\right) \tag{5}$$

$$T_p = \sum_i \sum_j \left(\frac{P_{ij}}{P_i}\right) \log\left(\frac{P_{ij} / P}{1 / N}\right) = T_{WR} + T_{BR} \tag{6}$$

$$T_{WR} = \sum_i \frac{N_i}{N} T_{pi} \tag{7}$$

$$T_{BR} = \sum_i \left(\frac{P_i}{P}\right) \log\left(\frac{P_i / P}{N_i / N}\right) \tag{8}$$

$$Z_w = \frac{T_{WR}}{T_p}, Z_b = \frac{T_{BR}}{T_p}, Z_i = \frac{P_i}{P} Z_w \tag{9}$$

where P_{ij} is the population of the j-th prefecture-level city in group i, P_i is the total population of group i, and P is the total population of all groups. N_i is the number of prefecture-level cities belonging to group i, and N is the total number of prefecture-level cities. T_p denotes the overall Theil index, T_{pi} presents the Theil index of population size change of prefecture-level cities in different groups. T_{WR} represents the intra-group Terre Index, which reflects the difference in the spatial distribution of population in prefecture-level cities of the same scale. T_{BR} represents the Theil index between groups, reflecting the differences in the spatial distribution of population between different scale levels. Z_W indicates the intra-group contribution rate, reflecting the impact of intra-group differences on overall differences. Z_b denotes the contribution rate between groups, showing the effect of group differences on the total difference. Z_i shows each group's contribution rate, illustrating the impact of differences at each scale level on the total difference.

3 Results

3.1 Classification and pattern of population change

As Table 2 shows, 357 prefecture-level cities are grouped with 0 and $\mu \pm std$ as the thresholds, respectively: rapid population growth, Δpop > 1.10 million; slow population growth, 0 < $\Delta pop \leqslant$ 1.10 million; slow population decrease, −667,000 $\leqslant \Delta pop \leqslant$ 0; serious population loss, Δpop < −667,000. Provincial capitals and coastal cities are points of rapid population influx, and population shrinkage is typical in northeastern China (Figure 1b). There are 31 prefecture-level cities with rapid population growth, accounting for only 8.7% of the total. There are 29 provincial capitals and the three major coastal urban agglomerations, accounting for 93.5%, the main body of the population influx area. Population inflow is common in provincial capitals and open cities along the southeast coast, whereas population loss is common in the northeast (Figure 1b). Only 8.7% of all cities are concentrated in 31 prefecture-level cities with strong population growth. Among the cities, there are 29 provincial capitals and three large coastal urban agglomerations, together constituting 93.5% of the population inflow area. Several provincial capitals illustrate the extraordinary impact of the "strong provincial capitals" policy in an increasing number of provinces. Since 1978, coastal urban agglomerations have traditionally been the key destinations for population movement between provinces. According to census data, there are six prefecture-level cities in the Pearl River Delta and Yangtze River Delta urban agglomerations with rapidly growing populations. However, only Beijing (2.28 million) and Langfang (1.11 million) are located in the Beijing-Tianjin-Hebei urban agglomeration, indicating variations in the main population inflow locations. Shenzhen had the largest population rise, a 7.20 million increase, 4.75 million greater than the 2.45 million average increase in this category.

The number of prefecture-level cities with modest population growth is the highest, at 170, 47.6% of the total number of cities. They are mostly located in ethnic minority communities in the west and south and in the North China Plain, where there is a lot of agriculture. These cities are less affected by the family planning policy, making the natural population growth rate comparatively high. There are 150 prefecture-level cities with slow population reduction, accounting for 42% of all cities, of which 66.7% of the prefecture-level cities are located in Yunnan, Shanxi, Gansu, Shaanxi, and the middle reaches of the Yangtze River. The other 34 cities whose population is slowly decreasing are located in the northeastern region (including three provinces of Heilongjiang, Jilin and Liaoning, and five leagues in eastern Inner Mongolia, a total of 41 prefecture-level administrative units). Only six cities have seen significant population loss, all of which are located either near the provincial capital (e.g., Nanchong and Xianyang) or are resource-depleted cities in the northeast (e.g., Tonghua, Qiqihar, and Suihua).

Table 2 Classification results of population changes in prefecture-level cities

Grading	2000–2010	Count	2010–2020	Count
$\Delta pop > \mu + std$	Δpop>109.5	28	Δpop>110.1	31
$0 < \Delta pop \leqslant \mu + std$	0<$\Delta pop \leqslant$109.5	229	0<$\Delta pop \leqslant$110.1	170
$\mu - std \leqslant \Delta pop \leqslant 0$	–53.7$\leqslant \Delta pop \leqslant$0	87	–66.7$\leqslant \Delta pop \leqslant$0	150
$\Delta pop < \mu - std$	Δpop<–53.7	13	Δpop<–66.7	6

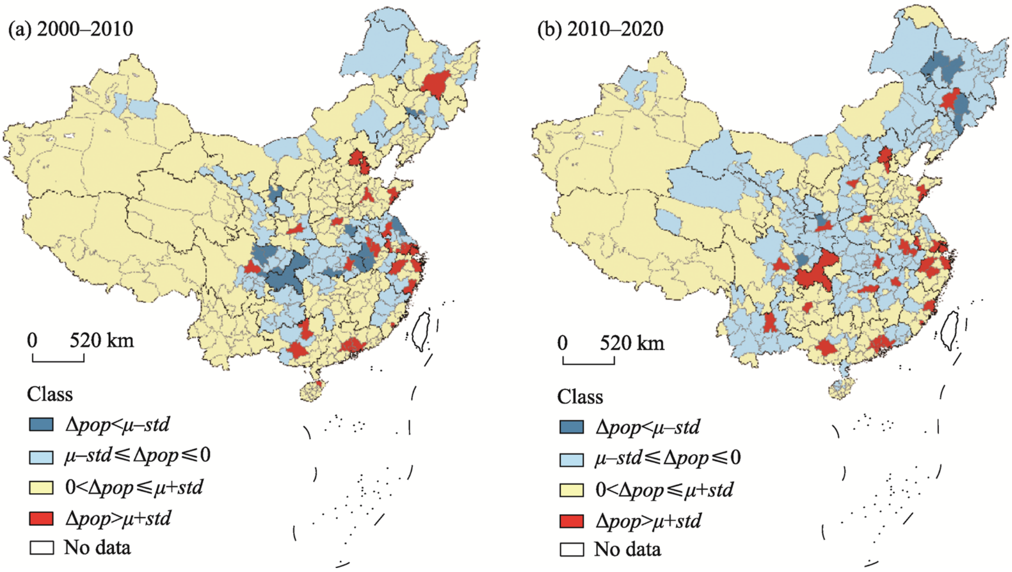

Figure 1 Classification of population changes at the prefecture-level city scale in China in 2000–2010 (a) and 2010–2020 (b)

A comparison of population changes during the last ten years with the preceding ten years indicates that the number of cities experiencing fast population expansion and shrinking has increased, and the population distribution has polarized (Figure 1). The number of prefecture-level cities with population changes of more than $\mu \pm std$ has risen from 28 to 31, and eight of the 12 new rapid population influx locations are inland provincial capitals. However, cities in coastal areas such as Jinan, Tianjin, Wuxi, and Haikou are no longer in the first rank of population increase. The number of population changes in the range of $0 \sim \mu + std$ has reduced significantly from 229 to 150, and the proportion has dropped from 64.2% to 47.6%. In the metropolitan areas of provincial capitals in the middle and western regions of China, such as Chengdu, Kunming, Wuhan, and Changsha, the population loss contrasts sharply with the large-scale population growth in central cities, indicating that, recently, the development factors of inland areas have been concentrated in provincial capitals, strengthening the regional polarization of inland urban agglomerations. The number of cities with a slowly declining population climbed from 87 to 150, mainly in slow-growing regions. The areas of severe population decrease have relocated from the middle and upper reaches of the Yangtze River to Jilin and Heilongjiang. In the last ten years, the average increment of rapid population growth rose to 2.45 million, while the average population reduction in population loss regions ($\mu - std \leqslant \Delta pop \leqslant 0$ and $\Delta pop < \mu - std$) increased by 49,000 and 133,000, respectively. This shows that the population of prefecture-level cities is polarized.

3.2 Transformation of population change types

As Figure 2 shows, comparing the population changes of each prefecture-level city in 2010–2020 with 2000–2010 shows six types of changes, where changes in the population growth trend can be identified: the scale of population loss has broadened, and the serious population shrinkage problem along the middle and upper reaches of the Yangtze River has lessened, while it has worsened in the northeastern region. There are 95 prefecture-level cit-

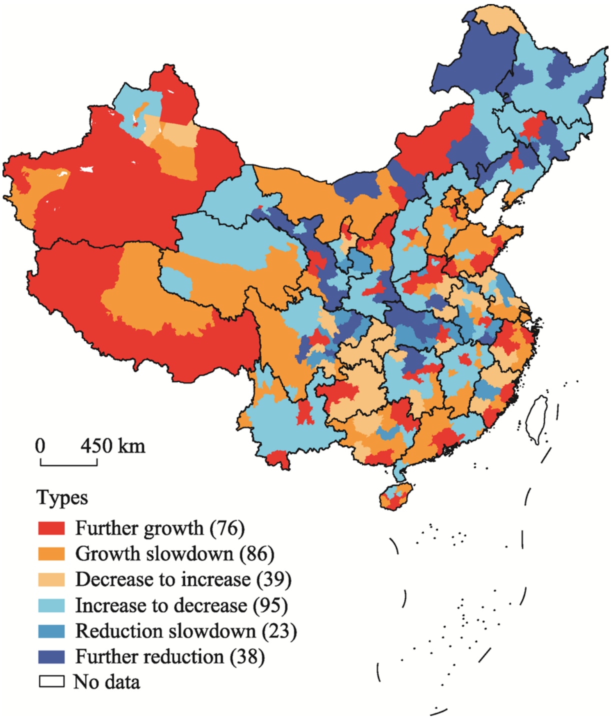

Figure 2 Transformation types of population changes in prefecture-level cities in 2000–2020

ies, accounting for 26.6% of the total, with population fluctuations from growth to reduction. Some are resource-based towns in northern China, such as Shanxi, Gansu, and other locations where heavy chemical industries are the mainstay, while others are adjacent to inland province capitals like Kunming, Changsha, Nanchang, and Xi'an. Resource-based communities have fewer employment opportunities, a low level of economic marketization, and severe environmental pollution, all of which lead to development bottlenecks and population decreases. The drop in population in the middle and upper reaches of the Yangtze River has moderated, with average losses falling from 548,000 to 166,000 in Wuhan, Chengdu, Hefei, and other provincial capital metropolitan regions. Simultaneously, Chongqing, Guizhou, and their surrounding territories have switched from being areas of population decline to becoming areas of modest growth. This might be because migrant workers returning from the eastern coast offset population losses. Nearly half of the prefecture-level cities whose population size has further decreased are located in the Northeast region. Together with the 22 newly added prefecture-level cities with shrinking populations, they illustrate the aggravation and spread of the population shrinkage problem in the Northeast. In the Northeast, 92.7% of prefecture-level cities are experiencing population decline, forming a typical population shrinkage area.

The trend of population inflow to the coastal areas north of the Yangtze River Delta slowed down, and the population of inland provincial capitals and open cities along the southern coast continued to grow. The population influx trend in 86 prefecture-level cities has decelerated; some of these cities are in coastal urban agglomerations, such as Beijing-Tianjin-Hebei, Yangtze River Delta, and Shandong Peninsula, whose growth rate has dropped significantly, accounting for 80%, 61.1%, and 85.7% of their urban agglomerations, respectively. For example, the population increment in Shanghai dropped from 6.61 million to 1.85 million, Beijing's dropped from 6.04 million to 2.28 million, and Tianjin's dropped from 3.09 million to 927,000. The other area of interest is the plateaus or deserts, such as western Sichuan, southern Qinghai, and western Inner Mongolia. These locations have a limited population, with little influence on population distribution. During 2010–2020, 76 cities had larger growth rates than before, mainly in the provincial capital, the Pearl River Delta region, and the west side of the Straits. For example, the population increase in Shenzhen increased from 3.35 million to 7.2 million, Guangzhou grew from 2.76 million to 5.98 million, and Xi'an rose from 1.19 million to 4.49 million. These prefecture-level cities are home to more than 5 million people, making them the hub of modern population expansion. There are also large areas of further population growth in the western border area. However, the population change in these cities is less than μ+std, and the population size is generally less than 100,000, which means that they have little impact on the spatial pattern of the population distribution.

3.3 Spatial correlation of population size and changes

There is a positive spatial autocorrelation between the population size change and the spatial distribution of the population in prefecture-level cities in China in 2020, with Z values of 5.71 and 7.01, respectively; that is, prefecture-level cities with massive population growth have neighbors with high population growth and vice versa (Figure 3). The result applies to the population distribution as well. In terms of population size change, the global Moran's I of population change in prefecture-level cities in China from 2010 to 2020 was 0.18, slightly higher than 0.17 in 2000–2010, and the Z value increased from 5.21 to 5.71, indicating a small increase in contiguous areas with similar population changes.

From the perspective of changes in the significance level of local autocorrelation, the proportion of cities in low-low spatial clusters increased from 9.2% in 2010 to 10.6% in

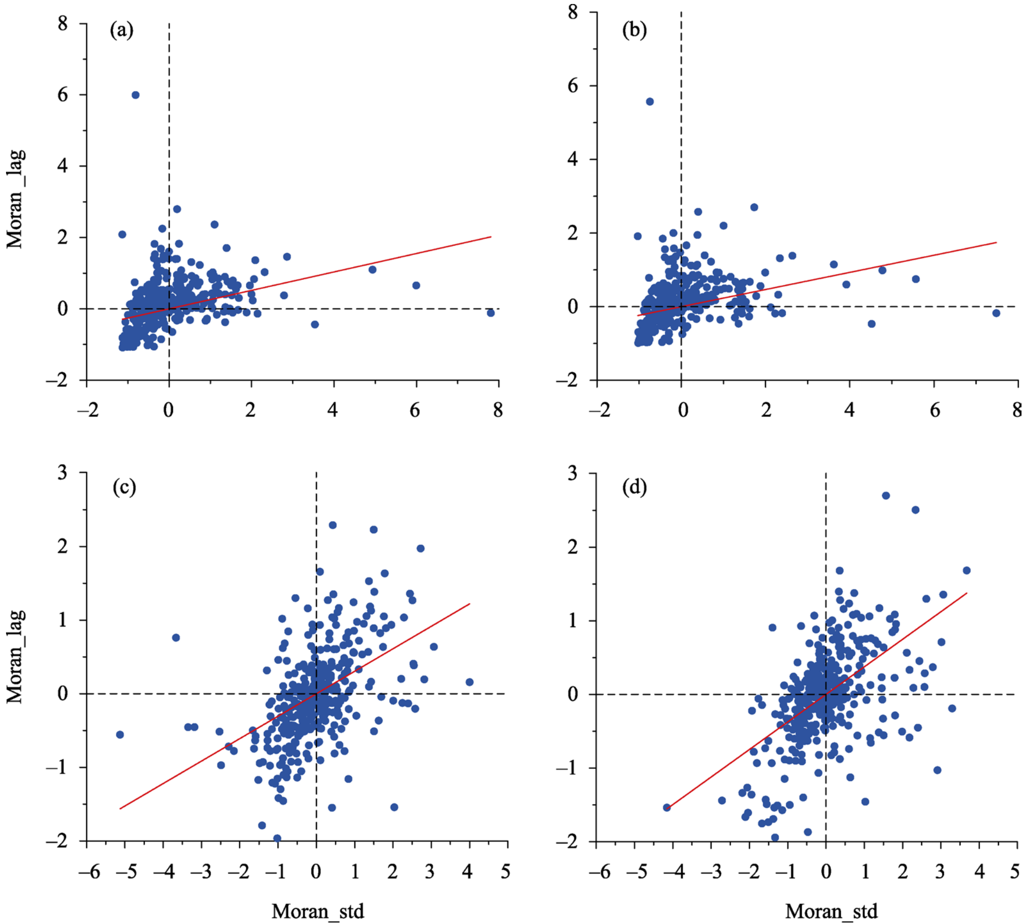

Figure 3 Moran scatter plot of population changes in 2000–2010 (a) and 2010–2020 (b), and population size of prefecture-level cities in 2010 (c) and 2020 (d)

2020. However, changes of the significance in other spatial clusters and outliers are slight, indicating that a modest rise in the global spatial autocorrelation of population change is associated with an increase in low-low spatial clusters. For population size, the global Moran's I for the population distribution in 2020 was 0.23, down from 0.26 in 2010. The proportion of prefecture-level cities with insignificant spatial autocorrelation has increased from 70% in 2010 to 70.9% in 2020, while the proportions of high-high and low-low clusters have dropped from 8.7% and 16% in 2010 to 7.3% and 15.7% in 2020, respectively. This shows that the spatial correlation of population distribution between prefecture-level cities in China is gradually decreasing.

Only the population growth trends of the Pearl River Delta urban agglomeration have the characteristics of diffusion, whereby the difference in population attractiveness between the three major urban agglomerations has gradually expanded (Figures 4a and 4b). For popula-

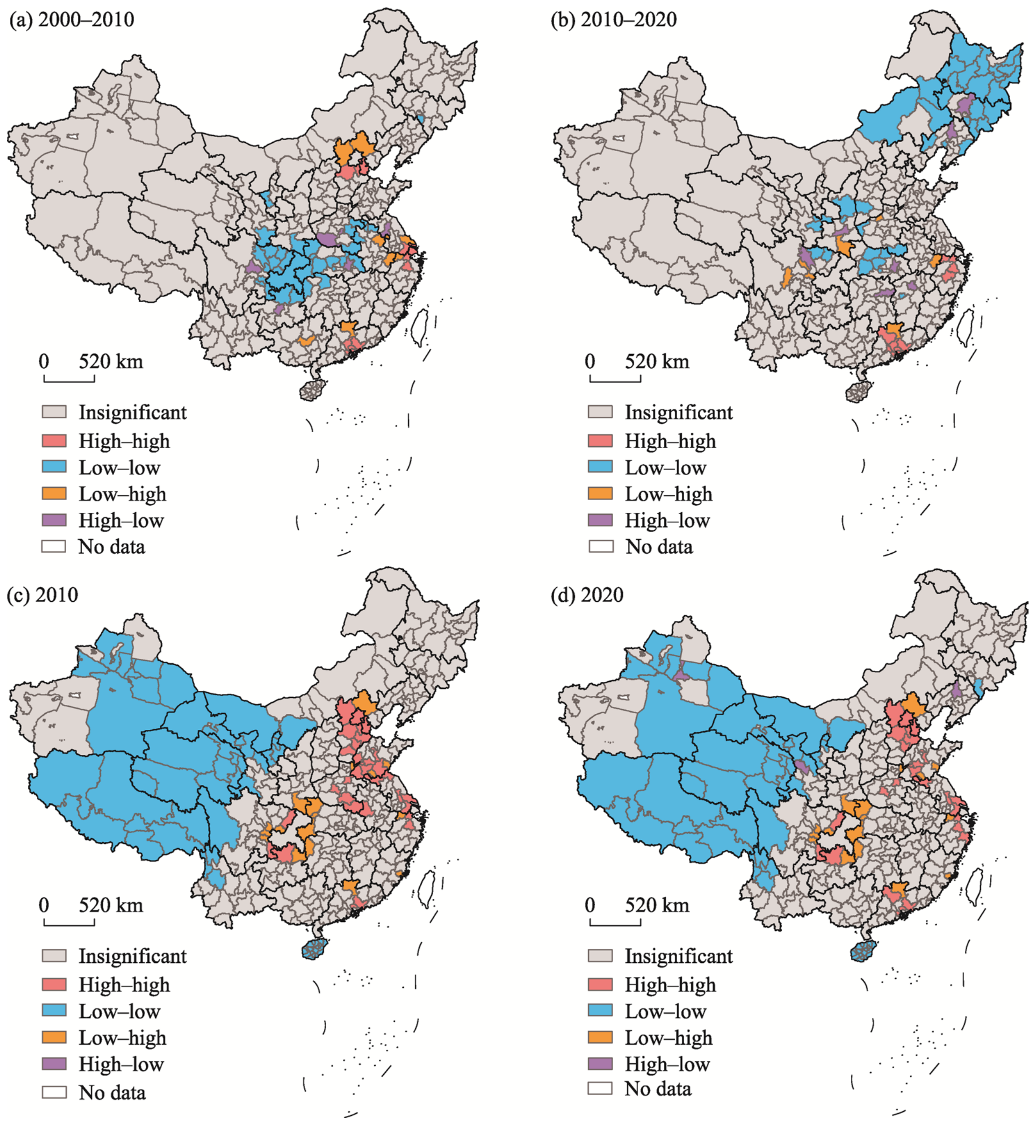

Figure 4 LISA agglomeration map of population changes in 2000–2010 (a) and 2010–2020 (b), and that of the population size in 2010 (c) and 2020 (d)

tion change, high-high spatial clusters were distributed in the three major coastal urban agglomerations from 2000 to 2010, namely, three in the Beijing-Tianjin-Hebei, four in the Yangtze River Delta, and five in the Pearl River Delta. However, in the past 10 years, only the Yangtze River Delta (4) and the Pearl River Delta (7) have high-high spatial clusters. The low-low spatial clusters shifted from the middle and upper reaches of the Yangtze River in 2000–2010 to the Northeast region in 2010–2020. Northeast China has 28 low-low values, accounting for 75.7% of all low-low clusters. From 2010 to 2020, there were only seven high-low outliers and seven low-high outliers. The former are mainly around inland provincial capitals such as Xi'an, Wuhan, Changsha, and Shenyang, reflecting the polarization of inland provincial capitals, while the latter are distributed around the high-high spatial clusters.

The population agglomeration structure of prefecture-level cities has changed little: low-low spatial clusters have decreased from 57 in 2010 to 56 in 2020, and high-high spatial clusters have diminished from 31 to 26. The reduced high-high spatial clusters became insignificant, mainly for cities in the central part of the North China Plain (Figures 4c and 4d). Northwest China is a low-low agglomeration area, and the population of these cities is generally lower than the population average, showing a low value correlation; high-high spatial clusters are mainly concentrated in the Yellow-Huaihe-Haihe rivers plain, the Yangtze River Delta, and the Pearl River Delta, displaying a high-value correlation. Low-high spatial outliers are affected by the polarization effect, mainly distributed around Chongqing.

3.4 The changing trend of population distribution difference

The gaps in population distribution are calculated according to the grading method in 2.2.1. The population gap between prefecture-level cities in China has progressively widened, as Table 3 shows. The Theil index (T_p) rose from 0.306 in 2010 to 0.351 in 2020. The difference between groups is responsible for the greater part of the overall variance, accounting for 83.91%. In 2020, the distinction between groups (T_{BR}) was significantly larger than the gap within the group (T_{WR}), with indexes of 0.294 and 0.056. The contribution rate of the difference between the groups was 67.82% higher than the amount within the group, proving that the imbalance between large, medium, and small cities is the main reason for the uneven distribution. Moreover, the gaps within the different scale classes are relatively small. The disparity between T_{BR} and T_{WR} continued to grow, rising from 0.215 in 2010 to 0.238 in 2020, demonstrating that polarization is intensifying.

Table 3 Theil index of prefecture-level cities grouped by population size

Grouping	2010			2020		
	Proportion (%)	T_{pi}	Z_i (%)	Proportion (%)	T_{pi}	Z_i (%)
$pop>\mu+std$	13.73	0.069	2.04	12.04	0.075	1.94
$\mu+0.5std<pop\leqslant\mu+std$	8.68	0.003	1.29	6.72	0.003	1.08
$\mu-0.5std\leqslant pop\leqslant\mu+0.5std$	45.94	0.034	6.83	49.86	0.043	8.02
$\mu-std\leqslant pop<\mu-0.5std$	22.69	0.068	3.37	29.41	0.132	4.73
$pop<\mu-std$	8.96	0.124	1.33	1.96	0.183	0.32
T_{WR}		0.046	14.86		0.056	16.09
T_{BR}		0.261	85.14		0.294	83.91
T_p		0.306	100.00		0.351	100.00

The Theil index contribution rate has increased, in response to intra-group distribution heterogeneity, from 14.86% in 2010 to 16.09% in 2020. Within groups with extreme large and small populations, the Theil exponents were strong, whereas they were weaker within groups with moderate population sizes. Township cities with super-large populations (pop>μ +*std*) had an intra-group difference of 0.075, up from 0.069 in 2010. Provincial capitals and significant coastal cities with a substantial influx of people rank high among them. Population mobility plays an increasingly important role in population differentiation. In 2020, the Theil index of cities with a population size of pop–*std*~*u*–0.5*std* was 0.132, an increase of 0.064 compared to 2010. The Theil index within the prefecture-level city group that belongs to *u*+0.5*std*~*u*+*std* is only 0.003 and remains stable. The contribution rate of medium-sized prefecture-level cities to the overall difference is higher than that of other grades, at 8.02%, close to half of the difference within the group, which is related to the number of prefecture-level cities it contains.

4 Discussion and conclusion

4.1 Discussion

A comparison of 2010–2020 and 2000–2010 changes in the population size of prefecture-level cities shows that the influence of economic development and income on population migration is still dominant. Large coastal cities with relatively high levels of regional economic and social development are the main influx areas of population. The central and western regions and northeastern regions are still the main sources of population migration. The imbalance of labor supply aggravates the imbalance of economic and social levels, forming a cumulative circular effect. Therefore, the differences between large cities and small and medium-sized cities continued to widen over time, and the differences between groups at different scale levels accounted for 83.91% of the overall differences.

The short-term effect of policies on the scale of population migration is evident. The central urban areas of some mega-megacities, such as Beijing and Shanghai, are highly concentrated in population and limited in space resources, resulting in a decline in the quality of the living environment and causing “urban disease.” Under these circumstances, the government implemented strict control over the size of these cities, relieving the pressure of population carrying to a certain extent. The scale of population growth in Beijing and Shanghai in the past 10 years has dropped significantly compared with the previous decade. However, the policy could focus on developing resources in less-developed areas and quickly cultivating a group of emerging population growth poles. According to the seventh census data, Chengdu, Xi’an, Zhengzhou, Wuhan, and other inland provincial capitals are developing rapidly, and the growth in population size continues to expand. During the “14th Five-Year Plan (2021–2025) for National Economic and Social Development,” many regions continued to promote the strategy of strengthening the provincial capital, thereby promoting the concentration and upgrading of political, economic, cultural, and other elements in provincial capital cities, and improving the competitiveness of labor production. In addition, the central and western regions enjoy national strategic support for new urbanization, the Silk Road Economic Belt, the Yangtze River Economic Belt, and rural revitalization. The construction of infrastructure and public services has been continuously improved, and they have benefited from the opportunities presented.

The siphon effect of population pattern evolution in the new period is remarkable, especially in the capital metropolitan area or urban agglomeration in the central and western regions. With the trend of migrant workers returning, consideration should be given to how to encourage the radiating and driving role of central cities, promote the urbanization of nearby cities, establish a linkage mechanism between large, medium, and small cities and county towns around the provincial capital, and combine with the rural revitalization strategy to form urban and rural co-governance in order to break regional development bottlenecks and guarantee the employment and settlement of returning migrant workers (Ye *et al*., 2020; Ye *et al*., 2021).

In 2020, the urbanization rate of China's permanent resident population was 18.49 percentage points higher than that of the registered population, which shows that the urbanization of the floating population lags behind in relative terms. The fair treatment and social welfare of the floating population without household registration may not be effectively guaranteed. Metropolitan areas are still the main focus of the influx of population. The stricter settlement policies make it difficult for migrants to settle in these cities to varying degrees and increase the cost of skills influx. The transformation of new urbanization planning from quantitative control to qualitative improvement is more practical for sustainable social development. Improving the urbanization policy and governance system of the agricultural transfer population is an issue that needs to be considered in the new stage of urbanization (Chen *et al*., 2019; Ye *et al*., 2022).

In 2020, the Northeast region replaced the middle reaches of the Yangtze River, an original population-shrinking area, and became the most prominent and concentrated population-losing region. From 2010 to 2020, 36 prefecture-level cities in the Northeast region experienced a massive population loss. The population decreased by an average of 325,000 people, accounting for 92.7% of the total number of cities in the region. Compared with 2000–2010, the population loss in Northeast China continued to accelerate, and the total population loss increased from 2.37 million to 14.383 million. From 2010 to 2020, the scope of population loss has been further expanded. The population status of 22 prefecture-level cities has shifted from slow growth to reduction, and only one city with population loss has shifted to slow population growth. As a result of resource depletion and long-term path dependence formed around heavy industry, the difficult reform of the economic system in Northeast China has led to population migration to areas with rapid economic development. Population loss leads to changes in population structure, further aggravating the problem of social aging and the economic burden in Northeast China. The revitalization of the Northeast region needs to focus on the needs of people, enriching industrial formats, improving public service facilities, and coordinating the relationship between economic transformation, social development, and urban construction.

Due to data limitations, this article does not expand on some topics. First, the functional types of cities with negative population growth are not classified in detail, and accurate statistics are not presented. The reasons for population loss vary with the function or location of prefecture-level cities. Therefore, research on the population evolution mechanism of different types of prefecture-level cities will facilitate the refinement of population policies and urban planning in areas with shrinking populations. Second, based on the total census data, this paper analyzes the population changes without distinguishing between urban and rural population, floating population and resident population, natural growth rate, and mechanical growth rate. These limitations suggest important directions for future research on new-type urbanization and population mobility patterns.

4.2 Conclusion

The seventh census data reflects the latest population distribution. This paper analyzes the differences and spatial characteristics of population changes in China's prefecture-level cities from the fifth to the seventh census. According to the mean standard deviation classification method, the population change of prefecture-level cities per decade is graded with 0 and $\mu \pm std$ as thresholds to compare and analyze the new spatial trend of population change. Several inland provincial capitals are the newly added population growth poles. Together with the coastal city group, they form the main rapid population growth area ($\Delta pop > u+std$). The population of a large number of resource-based cities and cities around the provincial capital has changed from increasing to decreasing, resulting in the proportion of prefecture-level cities with slow population growth ($0 \sim u+std$) decreasing from 61.4% to 47.6%, and the population slowly decreasing ($u-std \sim 0$) from 24.4% to 42%.

The extent of population loss in central and western China has widened, and many inland provincial capitals are experiencing a visible siphon effect. The major population loss problem in cities along the middle and upper reaches of the Yangtze River has lessened, but it has worsened in the Northeast, forming a typical population loss area. More than 60% of the population explosion of key cities in the coastal urban agglomeration north of the Yangtze River Delta has decelerated, while the growth of inland province capitals and open cities along the southern coast has further increased.

There is a spatial correlation between population mobility and spatial distribution. Low-low spatial clusters have relocated from the middle and upper reaches of the Yangtze River to the northeastern region. The three original major urban agglomerations have been replaced by the Yangtze River Delta and Pearl River Delta as high-value associated areas of population inflow, with only the Pearl River Delta's rapid population expansion spreading further, reflecting the differences in population attraction among these urban agglomerations. Population mobility in inland provincial capital metropolitan areas such as Xi'an, Wuhan, and Changsha is in a stage of polarization.

The population distribution gap has continually increased as the Theil index has increased from 0.306 in 2010 to 0.351 in 2020, and between groups contributed 85% of the variance. The prefecture-level cities at the top of the scale are far more attractive than small and medium-sized cities. This difference is growing due to excessive population agglomeration in some areas.

Since the implementation of the reform and opening-up policy started in 1978, China's urban-biased urbanization has invited problems such as semi-urbanization and the separation of urban–rural relations, causing people to reflect on this traditional model (Chen *et al.*, 2021b). Compared to the original large-scale inter-provincial rural-urban migration, population flow has become more diverse in recent years. Cities with different locations and scale levels have shown new typical types of population changes, and people's needs in different scenarios have generated differentiation. Therefore, starting from the special national conditions and people's development needs, promoting people-oriented new urbanization and coordinating the development of nearby and remote urbanization have significance in discussion and practice.

References

Anderson G, Ge Y, 2005. The size distribution of Chinese cities. *Regional Science and Urban Economics*, 35(6): 756–776.

Black D, Henderson V, 2003. Urban evolution in the USA. *Journal of Economic Geography*, 3(4): 343–372.

Bourguignon F, 1979. Decomposable income inequality measures. *Econometrica*, 47(4): 901–920.

Chen M, Gong Y, Li Y *et al*., 2016. Population distribution and urbanization on both sides of the Hu Huanyong Line: Answering the Premier's question. *Journal of Geographical Sciences*, 26(11): 1593–1610.

Chen M, Huang X, Huang G *et al*., 2021a. New urbanization and informal employment: Scale, pattern, and social integration. *Progress in Geography*, 40(1): 50–60. (in Chinese)

Chen M, Ye C, Lu D *et al*., 2019. Cognition and construction of the theoretical connotations of new urbanization with Chinese characteristics. *Journal of Geographical Sciences*, 29(10): 1681–1698.

Chen M, Zhou Y, Huang X *et al*., 2021b. The integration of new-type urbanization and rural revitalization strategies in China: Origin, reality and future trends. *Land*, 10(2): 1–17.

Chen M, Zhou Y, Tang Q *et al*., 2020. New-type urbanization, well-being of residents, and the response of land spatial planning. *Journal of Natural Resources*, 35(6): 1273–1287. (in Chinese)

Cui Y, Liu X, Li D *et al*., 2020. Urban spatial correlation characteristics and intrinsic mechanism in the Yangtze River Delta region. *Acta Geographica Sinica*, 75(6): 1301–1315. (in Chinese)

Ding Y, Lin L, Zhu Y *et al*., 2021. Spatial pattern and determinants of floating population's permanent settlement intention between prefecture-level cities in China. *Progress in Geography*, 40(11): 1888–1899. (in Chinese)

Fan C, 2005. Interprovincial migration, population redistribution, and regional development in China: 1990 and 2000 census comparisons. *The Professional Geographer*, 57(2): 295–311.

Fang L, Li P, Song S, 2017. China's development policies and city size distribution: An analysis based on Zipf's law. *Urban Studies*, 54(12): 2818–2834.

Ge M, Feng Z, 2010. Classification of densities and characteristics of curve of population centers in China by GIS. *Journal of Geographical Sciences*, 20(4): 628–640.

Gong S, Chen Y, 2019. The historical change, mathematical fitting and geographical significance of demographic borderlines in China. *Acta Geographica Sinica*, 74(10): 2147–2162. (in Chinese)

Han J, Zhang Z, Qi Q, 2007. Analysis and visualization of the uneven distribution of population in China. *Geo-information Science*, 9(6): 14–19. (in Chinese)

Lan F, Da H, Wen H *et al*. 2019. Spatial structure evolution of urban agglomerations and its driving factors in mainland of China: From the monocentric to the polycentric dimension. *Sustainability*, 11(3): 610.

Li J, Lu D, Xu C *et al*., 2017. Spatial heterogeneity and its changes of population on the two sides of Hu Line. *Acta Geographica Sinica*, 72(1): 148–160. (in Chinese)

Li J, Xu C, Chen M *et al*., 2019. Balanced development: Nature environment and economic and social power in China. *Journal of Cleaner Production*, 210: 181–189.

Li L, Clarke K C, 2012. Cartograms showing China's population and wealth distribution. *Journal of Maps*, 8(3): 320–323.

Liang L, Chen M, Lu D, 2022. Revisiting the relationship between urbanization and economic development in China since the reform and opening-up. *Journal of Geographical Sciences*, 32(1): 1–15.

Liang L, Chen M, Luo X *et al*., 2021. Changes pattern in the population and economic gravity centers since the reform and opening up in China: The widening gaps between the South and North. *Journal of Cleaner Production*, 310: 127379.

Liu J, Yang Q, Liu J *et al*., 2020. Study on the spatial differentiation of the populations on both sides of the "Qinling-Huaihe Line” in China. *Sustainability*, 12(11): 4545.

Liu T, Qi Y, Cao G, 2015a. China’s floating population in the 21st century: Uneven landscape, influencing factors, and effects on urbanization. *Acta Geographica Sinica*, 70(4): 567–581. (in Chinese)

Liu T, Qi Y, Cao G *et al.*, 2015b. Spatial patterns, driving forces, and urbanization effects of China’s internal migration: County-level analysis based on the 2000 and 2010 censuses. *Journal of Geographical Sciences*, 25(2): 236–256.

Liu Z, Gu H, 2020. Evolution characteristics of spatial concentration patterns of interprovincial population migration in China from 1985 to 2015. *Applied Spatial Analysis and Policy*, 13(2): 375–391.

Lu D, Wang Z, Feng Z *et al.*, 2016. Academic debates on Hu Huanyong population line. *Geographical Research*, 35(5): 805–824. (in Chinese)

Moran P A, 1950. Notes on continuous stochastic phenomena. *Biometrika*, 37(1/2): 17–23.

Qi W, Liu S, Zhao M *et al.*, 2016. China’s different spatial patterns of population growth based on the “Hu Line”. *Journal of Geographical Sciences*, 26(11): 1611–1625.

Qiao L, Li Y, Liu Y *et al.*, 2016. The spatio-temporal change of China’s net floating population at county scale from 2000 to 2010. *Asia Pacific Viewpoint*, 57(3): 365–378.

Shorrocks A F, 1980. The class of additively decomposable inequality measures. *Econometrica*: *Journal of the Econometric Society*, 613–625.

Storper M, Manville M, 2006. Behaviour, preferences and cities: Urban theory and urban resurgence. *Urban Studies*, 43(8): 1247–1274.

Wang G, Pan Z, 2016. The robustness of China’s migration and Heihe-Tengchong Line. *China Population Today*, 33(4): 39.

Wu J, Yu Z, Wei Y D *et al.*, 2019. Changing distribution of migrant population and its influencing factors in urban China: Economic transition, public policy, and amenities. *Habitat International*, 94: 102063.

Xu Z, Zhu N, 2009. City size distribution in China: Are large cities dominant? *Urban Studies*, 46(10): 2159–2185.

Yang Q, He L, 2017. Spatiotemporal changes in population distribution and socioeconomic development in China from 1950 to 2010. *Arabian Journal of Geosciences*, 10(22): 1–16.

Ye C, Liu Z, 2020. Rural-urban co-governance: Multi-scale practice. *Science Bulletin*, 65(10): 778–780.

Ye C, Yang D, Zhao J, 2022. An empirical research of the registered population transformation in China’s megacities. *Acta Geographica Sinica*, 77(2): 369–380. (in Chinese)

Ye C, Yu J, Zhang Q *et al.*, 2021. From governance to rural-urban co-governance: Research frontiers, trends, and the Chinese paths. *Progress in Geography*, 40(1): 15–27. (in Chinese)

Zang Y, Zhou S, Wu Y, 2016. The volume changes and spatial pattern dynamics of China’s interprovincial migration: A perspective of social network analysis. *Human Geography*, 31(4): 112–118. (in Chinese)

Zhang G, Huang W, Zhou C *et al.*, 2018. Spatio-temporal characteristics of demographic distribution in China from the perspective of urban agglomeration. *Acta Geographica Sinica*, 73(8): 1513–1525. (in Chinese)