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Spatiotemporal Distribution Characteristics and Evolutionary Trends of Population Structure in the Pearl River Delta Region: A Comparative Analysis Based on Census Data from 2010 to 2020

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ABSTRACT

As the foundational support for socioeconomic progress, regional population structure shapes long-term sustainable development. Using 2010 and 2020 census data for the Pearl River Delta, this study applies a spatiotemporal comparative framework to trace a decade of change in three dimensions: (1) The region is experiencing both declining birth rates and accelerated aging—marked by a shrinking workforce and higher dependency ratios. Worsening gender imbalance reflects delayed effects of past birth policies, selective labor migration, and enduring cultural preferences. (2) Industrial upgrading and rising education levels drive a dual shift. Guangzhou and Shenzhen have become service- and innovation-led post-industrial hubs, while outlying cities remain tied to low-end industries and lagging education, creating a clear development gap. (3) A “core-polarization, periphery-collapse” pattern dominates. Guangzhou and Shenzhen’ s pull on innovation factors intensifies population inflow, whereas peripheral areas like Zhaoqing face outmigration and stagnation. These findings highlight urgent needs to mitigate impending labor and eldercare shortages by refining fertility incentives and care systems; to align industry and education to break structural bottlenecks; and to develop regional coordination policies that ease core-city crowding and invigorate peripheral growth. This evidence underpins a nuanced understanding of multidimensional population-structure dynamics and guides tailored policy design.

KEYWORDS

Population structure; Population distribution; Spatiotemporal pattern; Spatial autocorrelation; Pearl River Delta Region

1. INTRODUCTION

Data from the Seventh National Population Census reveal a fundamental shift in China’s population development challenges—from pressures of quantitative expansion to those of structural optimization [1]. As a populous nation, changes in China’s population structure exert profound and long-term influences on socioeconomic transformation, public policy formulation, and sustainable development processes. Investigating the spatiotemporal evolution of population structure is both a strategic response to the diminishing “demographic dividend” and an essential pathway toward harmonizing population, resources, and environment. Urban agglomerations serve as the core engines of China’s economic growth: although they house 78% of the population, they contribute over 80% of the nation’s GDP [2]. Their population structural characteristics thereby determine regional innovation capacity and economic resilience. The Pearl River Delta (PRD), as an early pilot of China’s reform and opening-up, has, over more than forty years, formed a globally competitive urban cluster. The deep implementation of the Guangdong–Hong Kong–Macao Greater Bay Area strategy has further amplified its population agglomeration effects. Thus, elucidating the spatiotemporal evolution of population structure in this region holds exemplary significance for constructing a new paradigm of population governance in mega-urban agglomerations.

In recent years, interdisciplinary research paradigms have deepened studies of population structure, with frontiers including spatiotemporal evolution [3-4], driving mechanisms [5-6], and forecasting models [7-9]. Prior work on the PRD (Greater Bay Area) has concentrated on: aging characteristics of age structure [10-11], risks of gender imbalance[12], spatial allocation of high-tech talent [13], migration patterns of the floating population [14], and measurement of agglomeration effects [15]. However, existing studies exhibit notable limitations: (1) spatial analyses are often lacking an urban-agglomeration coordination perspective [16-21]; (2) analytical dimensions focus on single structural indicators [10-15], without establishing a three-dimensional framework encompassing natural, social, and spatial aspects; (3) the application of spatial visualization and geographically weighted regression techniques has been insufficient [7, 16, 19]. In response, this study integrates full-dimensional census data from 2010 and 2020, adopts the United Nations' population structure analytical framework [22], and applies GIS-based spatial analysis—combined with hot-spot analysis and spatial econometric models—to systematically deconstruct the spatiotemporal differentiation of population structure in the PRD and reveal its reciprocal mechanisms with regional development. The findings will provide quantitative support for balanced population development in the Greater Bay Area and theoretical reference for transforming population governance paradigms in mega-urban agglomerations.

2. STUDY AREA AND DATA SOURCES

The Pearl River Delta urban agglomeration lies in south-central Guangdong Province and includes nine prefecture-level cities: Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Huizhou, Jiangmen, and Zhaoqing. The total administrative area covers 54,700 km². According to the *2020 Seventh National Population Census Bulletin*, the region's resident population reached 78.0145 million—5.4% of the national total—and its GDP was RMB 8.95 trillion, accounting for 8.81% of China's economic output. These figures underscore the PRD's strategic importance in national development.

This study relies on the sixth and seventh national census data (2010–2020) for Guangdong Province and the nine PRD cities, supplemented by the corresponding statistical yearbooks. All data adhere strictly to the resident-population definition. Analytical dimensions encompass core demographic structural elements: (1) Natural structure, focusing on age and gender distribution; (2) Social structure, examining spatial disparities in employment and education; (3) Spatial structure, quantifying dynamics of population agglomeration and dispersion. By constructing a three-dimensional framework—natural, social, and spatial—we precisely depict the spatiotemporal trajectory of population structure evolution in the PRD over the past decade.

3. EVOLUTIONARY CHARACTERISTICS OF THE NATURAL POPULATION STRUCTURE

The natural population structure is the fundamental dimension defined by the biological attributes of a population, with its core components including age structure, gender ratio, and ethnicity [23]. Among these, age and gender structures serve as key dimensions: they not only form the basic framework for population reproduction but also critically influence socioeconomic development processes.

3.1. Evolution of Age Structure in the PRD

Age structure refers to the proportional distribution of different age cohorts within the total population over a given spatiotemporal scope. Based on the 2010 and 2020 census data, this study divides the population into three groups: children (0–14 years), working-age adults (15–59 years), and elderly (60 years and above). As shown in Table 1, between 2010 and 2020, the PRD experienced significant shifts: the share of children rose from 13.27% to 16.41%, the elderly proportion increased from 8.12% to 10.71%, and the working-age cohort declined from 78.82% to 72.88%, indicating a clear trend toward population aging. Spatially, all nine PRD cities exhibit the common pattern of a shrinking working-age population accompanied by rising dependency ratios, though the intensity of this structural transition varies. Notably, Zhaoqing and Huizhou recorded the highest child-population shares at 16.41% and 18.26%, respectively—well above the regional average. According to the international aging threshold (elderly ≥ 7%), six cities—including Guangzhou, Zhuhai, and Foshan—surpassed 10% elderly share in 2020. Among them, Jiangmen (16.41%) and Zhaoqing (18.26%) display particularly acute aging: their working-age shares are as low as 67.3% and 65.8%, and their dependency and burden ratios significantly exceed regional norms, revealing pronounced spatial imbalances in the population structure.

Figure 1 illustrates the decadal dynamics of age structure across the nine cities. From 2010 to 2020, every city saw an increase in the child cohort, led by Shenzhen (+5.21%), Dongguan (+4.87%), and Zhongshan (+4.03%); Jiangmen (+1.82%) and Zhaoqing (+1.19%) experienced more modest gains. Concurrently, all cities endured declines in their working-age shares, most sharply in Zhongshan (–8.53%), Shenzhen (–7.62%), and Dongguan (–6.78%), while Guangzhou (–4.07%), Zhaoqing (–4.63%), and Zhuhai (–4.65%) showed softer declines. The elderly population rose across the board, with the most notable increases in Jiangmen (+4.73%), Zhongshan (+1.67%), and Zhaoqing (+1.91%), underscoring significant spatiotemporal heterogeneity in regional aging. Further analysis reveals asynchronous patterns of aging "intensity" versus "pace." In Guangzhou and Foshan, aging intensity is high in 2020 (11.41% and 10.52% elderly, respectively) but growth rates are moderate (+1.67% and +0.37%). Zhongshan exhibits a mid-level intensity (8.87%) but a rapid growth rate (+4.50%). Jiangmen and Zhaoqing demonstrate a "double-high" profile: both high intensity (18.26% and 16.41%) and rapid growth (+4.73% and +3.44%). These contrasts reflect the complex and uneven evolution of population structure within the PRD.

Table 1. Comparison of population proportion of each age group in PRD from 2010 to 2020

	2010 (%)			2020 (%)		
	0-14 years	15-59 years	Over 60 years	0-14 years	15-59 years	Over 60 years
Guangzhou	11.47	78.79	9.74	13.87	74.72	11.41
Shenzhen	9.90	87.15	2.95	15.11	79.53	5.36
Zhuhai	13.5	78.77	7.73	15.88	74.12	10.00
Foshan	11.88	80.00	10.15	15.11	74.37	10.52
Dongguan	8.25	88.19	3.56	13.12	81.41	5.47
Zhongshan	11.66	83.97	4.37	15.69	75.44	8.87
Huizhou	17.60	74.28	8.12	20.76	69.19	10.05
Jiangmen	14.20	72.17	13.53	16.02	65.72	18.26
Zhaoqing	20.97	66.06	12.97	22.16	61.43	16.41
PRD	13.27	78.82	8.12	16.41	72.88	10.71

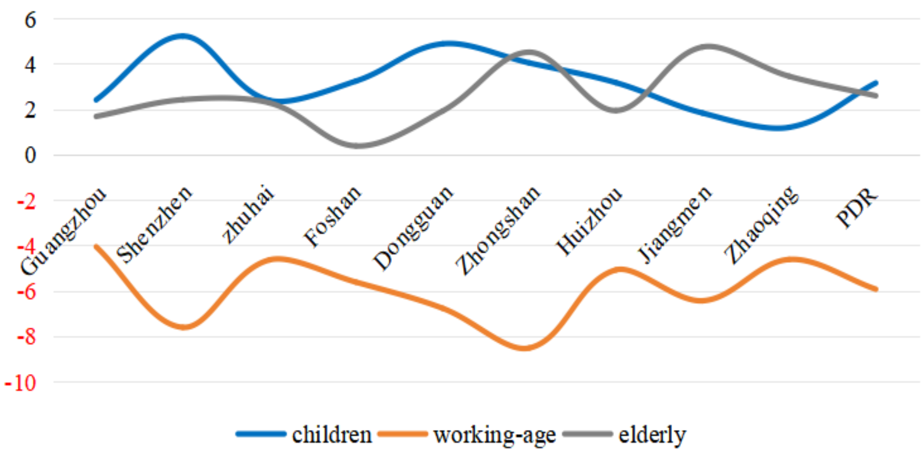

Figure 1. Change of population proportion in each age group in the PRD from 2010 to 2020

3.2. Evolution of Gender Structure in the PRD

Gender structure denotes the proportional distribution of males and females within the total population over a specified spatiotemporal scope. As a core demographic indicator, its balance fundamentally influences socioeconomic development. An imbalanced gender ratio not only undermines family formation and stability but also constrains the sustainable development of the labor market. Based on census data from 2010 and 2020 (Table 2), the male share in the PRD rose from 53.52% to 53.75%, while the female share declined from 46.48% to 46.25%, indicating a modest intensification of gender-ratio imbalance. Spatial analysis across the nine cities reveals a common upward trend in gender ratios, albeit with varying magnitudes (Figure 2). Regionally, the overall gender ratio climbed from 111.64 males per 100 females in 2010 to 116.44 in 2020, marking a historic high. Dongguan (+12.25), Zhuhai (+6.22), and Huizhou (+5.23) recorded the largest increases, whereas Jiangmen (+0.58) and Zhaoqing (+0.14) saw relatively minor changes. By 2020, Dongguan (130.06) was the only city exceeding 130, Shenzhen (122.43) fell within 120–130, Foshan (119.12), Zhongshan (117.12), Huizhou (116.32), and Zhuhai (114.87) lay in the 110–120 bracket, and Jiangmen (107.47) and Zhaoqing (108.57) remained below 110, highlighting pronounced spatial divergence. This imbalance arises from the interplay of institutional inertia, economic "pull" effects, and population migration dynamics [23]. In the PRD—China's preeminent population magnet—the proportion of male migrants significantly exceeds that of female migrants, an "economically driven gender imbalance" that intensifies regional demographic asymmetry [24]. Such a pattern reflects the lagged impact of the one-child policy on birth gender ratios and underscores deeper tensions between quantitative population agglomeration and qualitative structural coordination in mega-urban development.

Table 2. Comparison of gender ratio in PRD from 2010 to 2020

	2010 (%)		2020 (%)	
	Male	Female	Male	Female
Guangzhou	52.26	47.74	52.83	47.17
Shenzhen	54.20	45.80	55.04	44.96
Zhuhai	52.07	47.93	53.46	46.54
Foshan	53.86	46.14	54.36	45.64
Dongguan	54.09	45.91	56.53	43.47
Zhongshan	53.07	46.93	53.94	46.06
Huizhou	52.63	47.37	53.77	46.23
Jiangmen	51.16	48.84	51.80	48.20
Zhaoqing	51.18	48.82	52.05	47.95
PRD	52.72	47.28	53.75	46.25

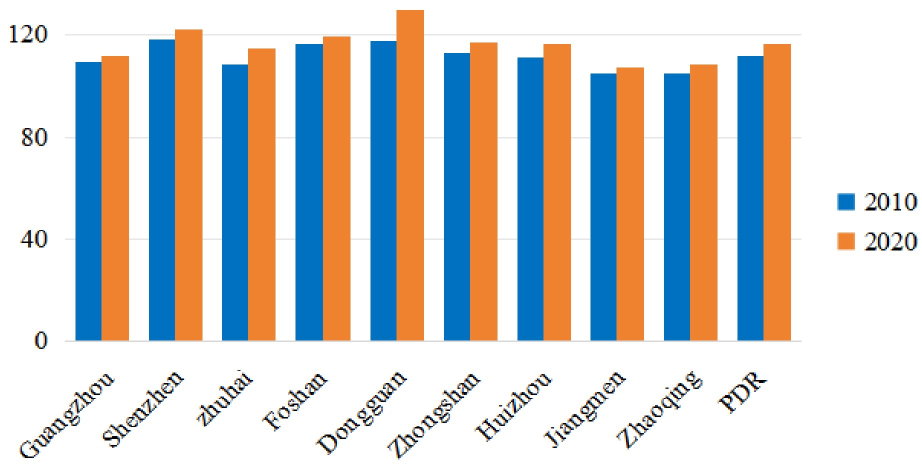

Figure 2. Gender ratio of population in PRD from 2010 to 2020

4. EVOLUTIONARY CHARACTERISTICS OF THE SOCIAL POPULATION STRUCTURE

The social population structure systematically presents the socioeconomic attributes of a population. Its core dimensions include class stratification, occupational distribution, ethnic composition, belief systems, and levels of human-capital accumulation [25]. This study focuses the analysis of social structure on two primary dimensions: industrial structure and cultural (educational) structure.

4.1. Evolution of Industrial Structure in the PRD

The industrial structure of a population reflects the organization of economic activities by sector. Adopting the three-sector classification, the employed population is divided into primary (agriculture), secondary (industry), and tertiary (services) sectors. As shown in Tables 3 and 4, between 2010 and 2020 the PRD underwent significant industrial transformation. Employment in the primary sector declined slightly to 11.37%, the secondary sector share fell by 6.75 percentage points to 41.83%, and tertiary employment rose by 6.87 points to 46.80%. Except for marginal increases in Shenzhen (+0.05%) and Dongguan (+2.70%) in traditional sectors, all other cities saw declines in primary- and secondary-sector employment, indicating a broad shift of labor toward services. Guangzhou and Shenzhen achieved service-sector leadership, with tertiary shares reaching 72.45% and 61.26%, respectively—exceeding the 60% threshold that denotes a service-dominated structure. Dongguan (66.63%) and Zhongshan (55.96%) still exhibit industrial-dominant profiles, while Jiangmen (27.44%) and Zhaoqing (44.34%) remain heavily reliant on agriculture. This asynchrony underscores uneven industrial evolution across the region. Notably, Zhaoqing’s primary-sector employment (44.34%) approaches the classic 50% threshold for traditional economies, signaling a markedly delayed transformation relative to the regional average.

According to industrial-structure theory [24], employment and output structures should exhibit “positive correlated coordination.” In the PRD, a mismatch emerges: primary-sector employment (11.37%) exceeds its output share (1.75%) by 9.62 points, while tertiary employment falls 11.49 points below its GDP contribution—reflecting both agricultural labor redundancy and service-sector productivity gains. Secondary-sector deviation is just 1.87 points, indicating a mature industrial base. Guangzhou, Shenzhen, and Zhuhai form a “golden triangle” of structural alignment with minimal mismatch. Dongguan shows narrowing discrepancies but still contends with “over-employment” in industry versus “under-employment” in services. Jiangmen and Zhaoqing face “core–periphery” dilemmas: Jiangmen’s primary-sector mismatch is pronounced, while Zhaoqing exhibits a systemic imbalance across all sectors, highlighting significant lag in industrial upgrading. Against the backdrop of global value-chain shifts, the PRD's cities simultaneously experience "leapfrogging" transformations and "path-locked" stagnation, creating structural tensions in regional development.

Table 3. The proportion of employment and GDP in the industry structure of the PRD in 2010

	Employed population (%)			GDP (%)		
	Primary Sector	Secondary Sector	Tertiary Sector	Primary Sector	Secondary Sector	Tertiary Sector
Guangzhou	9.95	39.65	50.40	1.75	37.24	61.01
Shenzhen	0.05	51.49	48.46	0.07	47.21	52.72
Zhuhai	9.55	42.67	47.78	2.68	54.77	42.55
Foshan	7.08	53.62	39.30	1.86	62.68	35.45
Dongguan	1.81	63.93	34.26	0.39	50.89	48.72
Zhongshan	6.71	67.24	26.05	2.74	58.04	39.22
Huizhou	24.25	46.95	28.80	5.92	58.94	35.15
Jiangmen	32.80	40.96	26.24	7.45	55.54	37.01
Zhaoqing	44.95	28.33	26.72	17.52	42.06	40.42
PRD	11.49	48.58	39.93	2.15	48.61	49.24

Table 4. The proportion of employment and GDP in the industry structure of the PRD in 2020

	Employed population (%)			GDP (%)		
	Primary Sector	Secondary Sector	Tertiary Sector	Primary Sector	Secondary Sector	Tertiary Sector
Guangzhou	5.04	22.51	72.45	1.15	26.34	72.51
Shenzhen	0.10	38.64	61.26	0.09	37.78	62.13
Zhuhai	3.19	40.92	55.89	1.72	43.39	54.88
Foshan	3.82	49.59	46.59	1.52	56.35	42.13
Dongguan	0.08	66.63	33.29	0.31	53.81	45.87
Zhongshan	4.22	55.96	39.81	2.27	49.40	48.33
Huizhou	14.08	45.76	40.16	5.19	50.56	44.25
Jiangmen	27.44	32.78	39.78	8.57	41.65	49.77
Zhaoqing	44.34	23.70	31.96	18.92	39.03	42.06
PRD	11.37	41.83	46.80	1.75	39.96	58.29

4.2. Evolution of Educational and Cultural Structure in the PRD

Educational attainment, as a core indicator of regional human-capital quality [26], is quantified here using two metrics: the proportion of the population with higher education and the average years of schooling. Between 2010 and 2020 (Table 5), the PRD's educational structure markedly improved: the share of higher-educated residents rose from 11.92% to 20.40%, while proportions with senior-high, junior-high, and primary education declined by 0.06, 8.96, and 0.83 percentage points, respectively. Concurrently, average years of schooling increased from 9.76 to 10.63, reflecting an overall enhancement in cultural and educational quality. All nine cities achieved growth in higher-education share, led by Shenzhen (+11.68%), Guangzhou (+8.05%), and Zhuhai (+7.36%), reaching 28.85%, 27.28%, and 25.75% in 2020—well above the regional average. Nonetheless, the overall structure remains dominated by junior-high educated cohorts. In Zhongshan, Huizhou, Jiangmen, and Zhaoqing, primary-education shares remain relatively high, indicating substantial pressure for structural upgrading.

Figure 3 illustrates average schooling gains: Zhuhai experienced a leap from 9.26 to 11.46 years, the largest increase among the cities. The averages in Guangzhou, Shenzhen, and Zhuhai all exceed the regional mean of 10.63 years, suggesting a virtuous interaction between educational advancement and industrial upgrading in these economic engines. In contrast, Huizhou (10.09 years), Jiangmen (10.02 years), and Zhaoqing (9.53 years) lag notably, underscoring how economic structure can constrain educational improvement. This "economic–educational" dual-lock effect reveals structural challenges to balanced regional development.

Table 5. Proportion of population with education in PRD in 2010 and 2020

	2010 (%)				2020 (%)			
	Univ.	Senior high	Middle	Primary	Univ.	Senior high	Middle	Primary
Guangzhou	19.23	22.92	36.12	15.72	27.28	22.00	29.48	13.78
Shenzhen	17.17	23.96	44.05	8.88	28.85	20.69	31.22	11.51
Zhuhai	18.39	24.58	33.30	16.18	25.75	21.57	28.90	15.36
Foshan	9.47	19.38	43.61	20.66	16.14	20.56	36.32	18.68
Dongguan	7.10	20.30	54.40	13.50	13.24	22.28	42.22	15.71
Zhongshan	7.78	21.00	44.98	19.65	13.36	19.60	38.57	20.02
Huizhou	5.75	15.37	48.31	21.93	12.32	16.22	40.20	21.52
Jiangmen	5.36	19.73	42.78	24.33	10.59	20.65	36.55	22.84
Zhaoqing	4.33	11.88	43.54	29.04	8.79	14.86	39.90	25.24
PRD	11.92	20.57	43.68	17.12	20.40	20.51	34.72	16.29

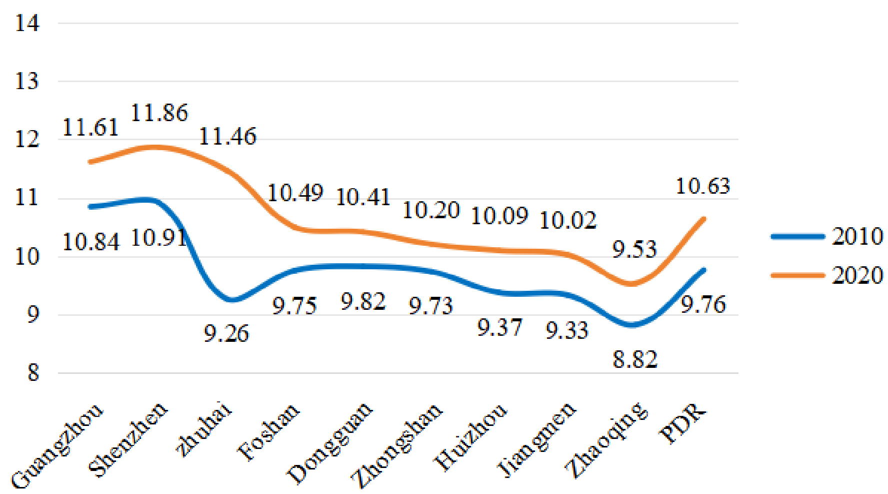

Figure 3. Average years of education in the PRD region in 2010 and 2020

5. EVOLUTIONARY CHARACTERISTICS OF SPATIAL POPULATION STRUCTURE

This section decomposes the spatiotemporal differentiation of population distribution in the Pearl River Delta (PRD) from 2010 to 2020 by integrating spatial autocorrelation analysis with composite population-distribution indices [27].

5.1. Spatial Autocorrelation Analysis

We select 50 districts/counties across the PRD as basic spatial units and compute global spatial autocorrelation of resident population for 2010 and 2020 using Moran's I. The results are shown, the global Moran's I rose from 0.045 in 2010 ($Z = 0.923$, not significant at $P > 0.05$) to 0.152 in 2020 ($Z = 2.183$, $P < 0.05$). This shift from weak, nonsignificant positive autocorrelation to a significant positive spatial correlation indicates an intensification of population clustering and increased similarity in population size among adjacent districts.

Local spatial autocorrelation, visualized via LISA cluster maps (Figure 4), reveals these patterns in finer detail: (1) High–High clusters (HH): In 2010, HH clusters were concentrated in Guangzhou Panyu, Shenzhen Longhua, and Bao'an. By 2020, they had expanded to encompass the entire Dongguan jurisdiction, confirming a core-city polarization effect. (2) Low–High outliers (LH): Persistently located in fringe subareas of core cities—Shenzhen Guangming and Foshan Chancheng—and, by 2020, newly including Huizhou Boluo, indicating these peripheral zones are attracting population despite being adjacent to high-density cores. (3) Low–Low clusters (LL): In 2010, LL clusters appeared in Zhaoqing Gaoyao, Sihui, and Huaiji; by 2020, they had extended to Dinghu, Deqing, and Guangning, forming contiguous low-value belts that expose acute peripheral population loss. (4) High–Low outliers (HL): Not observed in either census, suggesting no significant discontinuities in population gradient within the PRD. This spatial pattern— "core polarization" through industrial upgrading and "peripheral collapse" in outlying districts such as Zhaoqing—highlights deep structural contradictions in population-factor allocation under the Greater Bay Area's coordination framework. Peripheral counties trapped in a "low-level equilibrium" face mounting risks of sustained outmigration and resource underutilization, underscoring the urgent need for balanced regional planning and targeted policy interventions.

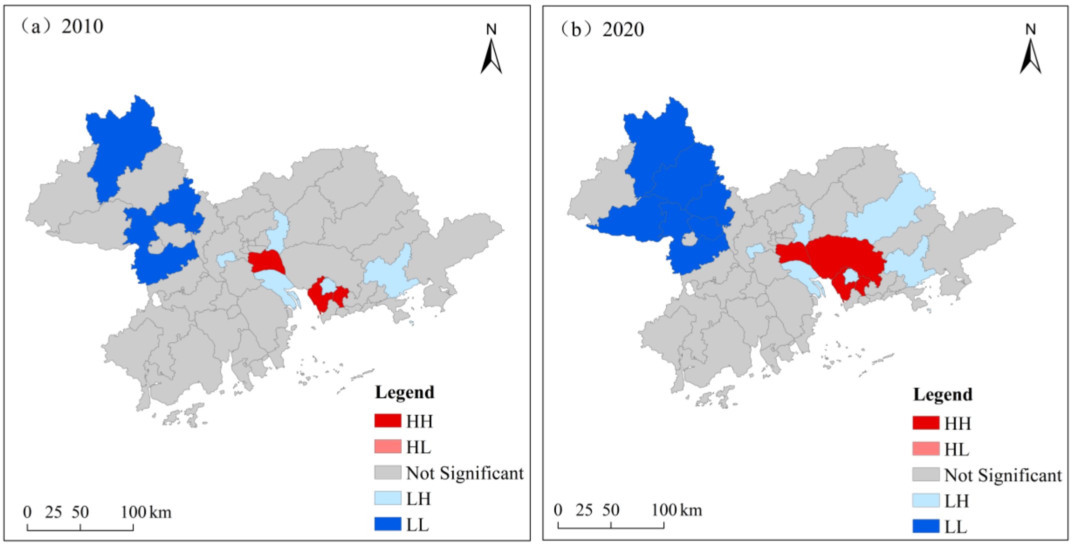

Figure 4. Local spatial autocorrelation clustering analysis of PRD in 2010 and 2020

5.2. Population Distribution Structure Indices

Population spatial distribution exhibits dynamic evolution (Table 6). This study quantifies the PRD's spatial restructuring from 2010 to 2020 using the dual metrics of the population imbalance index and concentration index [28]. Both indices display an upward trend, indicating a transformation from "equilibrium" toward "polarization" and a continuously strengthening agglomeration effect. Firstly, between 2010 and 2020, the range of the imbalance index widened from 0.002–0.142 to 0.001–0.154, and the concentration index extended from 0.001–0.101 to 0.001–0.109, revealing increasing heterogeneity in population distribution. Notably, Zhuhai, Foshan, and Dongguan experienced synchronous declines in both indices, reflecting a trend toward more balanced population distribution. In contrast, Guangzhou, Shenzhen, Zhongshan, Huizhou, Jiangmen, and Zhaoqing all saw varying degrees of increase in both their imbalance and concentration indices, underscoring pronounced agglomeration trends. Moreover, Zhaoqing exhibits a "double-high" profile (imbalance index = 0.154; concentration index = 0.109), closely tied to its extensive spatial morphology, low urbanization level, and monocentric development pattern. Conversely, Zhuhai shows a "double-low" profile (both indices = 0.001), benefiting from its compact municipal footprint, high economic density, and polycentric development. This “spatial scale–development intensity” interaction profoundly shapes the multidimensional differentiation of population distribution across the PRD.

Table 6. Comparison of Unbalanced index and Concentration Index of PRD in 2010 and 2020

	Unbalanced index		Concentration Index	
	2010	2020	2010	2020
Guangzhou	0.066	0.075	0.047	0.053
Shenzhen	0.105	0.134	0.074	0.095
Zhuhai	0.002	0.001	0.001	0.001
Foshan	0.041	0.036	0.029	0.026
Dongguan	0.072	0.063	0.051	0.045
Zhongshan	0.016	0.017	0.011	0.012
Huizhou	0.089	0.093	0.063	0.066
Jiangmen	0.067	0.080	0.048	0.056
Zhaoqing	0.142	0.154	0.101	0.109
PRD	0.078	0.087	0.424	0.462

6. CONCLUSION AND DISCUSSION

Drawing on comprehensive nationwide census data—characterized by full geographic coverage, temporal continuity, and standardized methodology [29]—this study has systematically analyzed the spatiotemporal evolution of population structure in the Pearl River Delta (PRD) for 2010–2020 through an integrated framework of statistical visualization, spatial autocorrelation modeling, and distribution-index measurement. Three principal findings emerge:

The PRD’s age structure exhibits a pronounced trend of low fertility and accelerated aging: the working-age cohort share declined markedly, reflecting both the transformative impact of fertility-policy adjustments on population reproduction patterns and gains in life expectancy driven by improving healthcare. Concurrently, the sex ratio imbalance intensified slightly—male share increased while female share declined—capturing the lagged demographic legacy of the one-child policy, economically driven male-dominated in-migration to the PRD, and persistent traditional gender norms influencing migration choices.

In the industrial domain, the region is transitioning from manufacturing-led to service-dominated economies, evidenced by a clear labor shift toward tertiary sectors. Guangzhou and Shenzhen have surpassed the mature industrialization stage, forming post-industrial service economies, whereas Zhaoqing and Jiangmen remain locked in agricultural and low-end industrial trajectories, revealing institutional barriers in regional factor allocation. In the educational sphere, overall human-capital quality has risen: the higher-education share has grown substantially, and average schooling years have increased. The “economic–education” virtuous cycle in Guangzhou, Shenzhen, and Zhuhai—driven by clusters of high-skilled labor—contrasts with peripheral cities, where industrial structure constraints have led to lagging educational advancement and a “skills–industry” lock.

The PRD’s spatial population configuration has shifted from relative equilibrium toward intensified polarization. Core cities (Guangzhou and Shenzhen) have leveraged industrial upgrading and innovation-factor agglomeration to achieve rapid increases in population density, while peripheral counties (e.g., Zhaoqing) are ensnared in a “low-level equilibrium trap” amid population outflows. This “core-polarization/periphery-collapse” pattern underscores structural tensions in population-factor allocation under the Greater Bay Area coordination strategy.

Based on the above conclusions, the Pearl River Delta (PRD) will face a series of challenges and opportunities in its future population-structure evolution: Firstly, the “low fertility–aging” trend is likely to exacerbate labor shortages and pension pressures. The government should optimize fertility support policies and strengthen eldercare service systems, while also monitoring potential social issues arising from skewed sex ratios—such as marriage squeeze. Improvements in healthcare provide a foundation for addressing aging, but further enhancements to elderly-healthcare services will be necessary. Secondly, the optimization of the social structure supplies essential human capital for industrial upgrading, yet regional disparities risk deepening development imbalances. The shift toward service-sector economies and the elevation of educational and cultural attainment offer critical labor resources for the PRD's industrial transformation. However, differences in industrial and educational structures across cities may aggravate uneven development. Policymakers must increase support for economically underperforming and educationally lagging areas, promote equitable allocation of industrial and educational resources, and advance coordinated regional development. Finally, the polarization of spatial structure demands innovations in regional coordination mechanisms. Overconcentration in the Guangzhou–Shenzhen core brings "big-city ills"—traffic congestion, housing shortages—while outmigration from peripheral counties such as Zhaoqing threatens their long-term vitality. The government should employ policy levers—such as strategic industry relocation and targeted infrastructure investments—to guide a more balanced interregional population distribution and foster coordinated growth. Attention must also be paid to divergent urbanization processes: accelerating urbanization in peripheral counties will enhance their attractiveness to residents.

This study is subject to scope and data constraints. First, population structure is inherently multidimensional; beyond the natural, social, and spatial dimensions, it encompasses ethnicity, marital status, and more. Future work could develop a more comprehensive analytical framework incorporating these finer dimensions. Second, while this research focused on key drivers—economic development, industrial change, and migration—the deeper mechanisms related to environmental change, the urban–rural dichotomy, and shifting marriage and fertility norms remain underexplored. Interdisciplinary theoretical dialogue is needed to illuminate these complex dynamics. Finally, this analysis emphasized macro-scale trends; targeted studies of specific subpopulations—including stratified migrants, differences between registered and resident populations, elderly spatial distributions, cultural adaptation of ethnic minorities, and high-skilled talent flows—using finer-grained data will provide actionable insights for precision policymaking and sustainable regional development.

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