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Assessment of Urban Spatial Integration Using Human Settlement Environmental Geographic Dataset: A Case Study in the Guangzhou–Foshan Metropolitan Area

Rui Chen [1,2,3], Siyu Zhou [1], Shuyuan Liu [1], Zifeng Li [1,*] and Jing Xie [1,*]

[1] School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, China; chenrui23@mails.ucas.ac.cn (R.C.); zhousy25@mail2.sysu.edu.cn (S.Z.); liushy75@mail2.sysu.edu.cn (S.L.)
[2] Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[3] University of Chinese Academy of Sciences, Beijing 101408, China
* Correspondence: lizifeng5@mail.sysu.edu.cn (Z.L.); xiej95@mail.sysu.edu.cn (J.X.)

Abstract: Urbanization is an important process in China's urban development, significantly contributing to resource allocation and the cooperative development of neighboring cities. In recent years, remote-sensing technology has emerged as a powerful tool in urbanization research. However, the disparity in development between urban and rural areas poses challenges in evaluating the degree of urbanization within a region. This paper addresses this issue by using LCZ (Local Climate Zone) data to provide a unified framework for analyzing a human settlement environmental geographic dataset. This study focuses on the spatial development and transformation of the Guangzhou–Foshan urbanization from 2000 to 2020. The LCZ data offer a suitable framework for examining urban–rural gradients, facilitating the analysis of spatial characteristics under varying development conditions. This unified framework enables a comprehensive analysis of the spatiotemporal characteristics of urban spatial integration. The results show that the analysis of the Guangzhou–Foshan metropolitan area reveals that the region has maintained a "core–edge" spatial structure over the past 20 years. The development rate has decelerated following policy changes in 2010, with the adjacent area experiencing significantly slower development compared to the overall study area. LCZ data are effective for comparative analysis of internal spatial development within urban areas, offering a novel approach to studying spatial integration amid urban development.

Keywords: urban integration; human settlement environmental geographic dataset; local climate zone; urban–rural gradients; Guangzhou–Foshan metropolitan area

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1. Introduction

Urbanization has become an important means of promoting high-quality urban development. It not only pertains to the coordinated development of regional economies but also involves comprehensive enhancements in social structures, cultural identity, and residents' quality of life [1–4]. Urbanization refers to the extensive integration of two or more cities in economic, social, cultural, and administrative aspects, forming a trend of unified development [5–10]. This process typically involves the interconnection of infrastructure, optimization and adjustment of industrial layouts, equalization of public services, and collaborative ecological governance [11,12]. Urban spatial integration is a key feature of urbanization, reflecting the harmonization of economic activities between cities, the coordinated development of industrial clusters, and the complementarity of urban functions [13–17]. Consequently, studying the evolutionary characteristics of urban spatial integration is crucial.

Current research on the spatial evolution of urban integration can be classified into two categories. The first type utilizes single data sources to measure the degree of urban spatial integration. For instance, integration between cities is assessed through indicators such as population mobility [18,19], infrastructure construction [20,21], transport network connectivity [22,23], and land use change [24]. This method is straightforward and easily implementable. However, urbanization is a multi-dimensional and multi-level complex phenomenon, and a single index often fails to capture its full scope and nuances. For different cities' developmental stages and characteristics, a single index cannot accurately reflect the subtle changes in the urbanization process.

The second type of research employs multi-source data to evaluate urbanization levels. This approach constructs a comprehensive urban index system by integrating data from multiple dimensions, including economy, society, culture, and environment [25–27]. For example, combining demographic data, traffic flow, industrial distribution, and public service levels provides a more precise measurement of urbanization and better reflects city interactions and integration [28–31]. Although this method considers multi-dimensional factors, it often overlooks intra-city development disparities.

From the above analysis, it is evident that initial studies on urban spatial integration relied on single data sources for evaluation. With advancements in data and methodologies, an increasing number of studies now use multi-source data to develop more comprehensive evaluation indicators, yet they still do not account for internal city differences. The rapid urban expansion of Chinese cities is linked with urbanization, and changes across various dimensions may stem from inherent city growth rather than urbanization impacts. Traditional vector and raster data are limited in capturing the diversity of urban functions and forms, lacking flexibility in analyzing the continuous changes from urban centers to suburbs and failing to reflect the dynamic processes of urban expansion and land use changes.

The Local Climate Zone (LCZ) classification provides a more comprehensive, standardized, and adaptable method for urban spatial analysis, categorizing urban and rural areas based on land cover, structure, material, and human activities [32]. This system simplifies complex urban spatial structures, enhancing the efficiency of spatial analysis. Thus, LCZ serves as the framework for analyzing multi-source data to further investigate urban space integration.

The objective of this paper is to utilize LCZ data to construct a multi-source data analysis framework for a comprehensive assessment of urban spatial integration in the Guangzhou–Foshan urbanization from 2000 to 2020. By analyzing the spatiotemporal changes in land use and land cover, as well as the dynamics of human settlement environmental geographic dataset, this study seeks to uncover the spatial structure characteristics and development trends in the metropolitan area along an urban–rural gradient. This research expects to offer new insights into the impact of urbanization on urban spatial structure, provide precise and dynamic decision support for urban planning and policymaking, and furnish a standardized analytical tool for regional and inter-city comparative analysis.

2. Materials and Methods

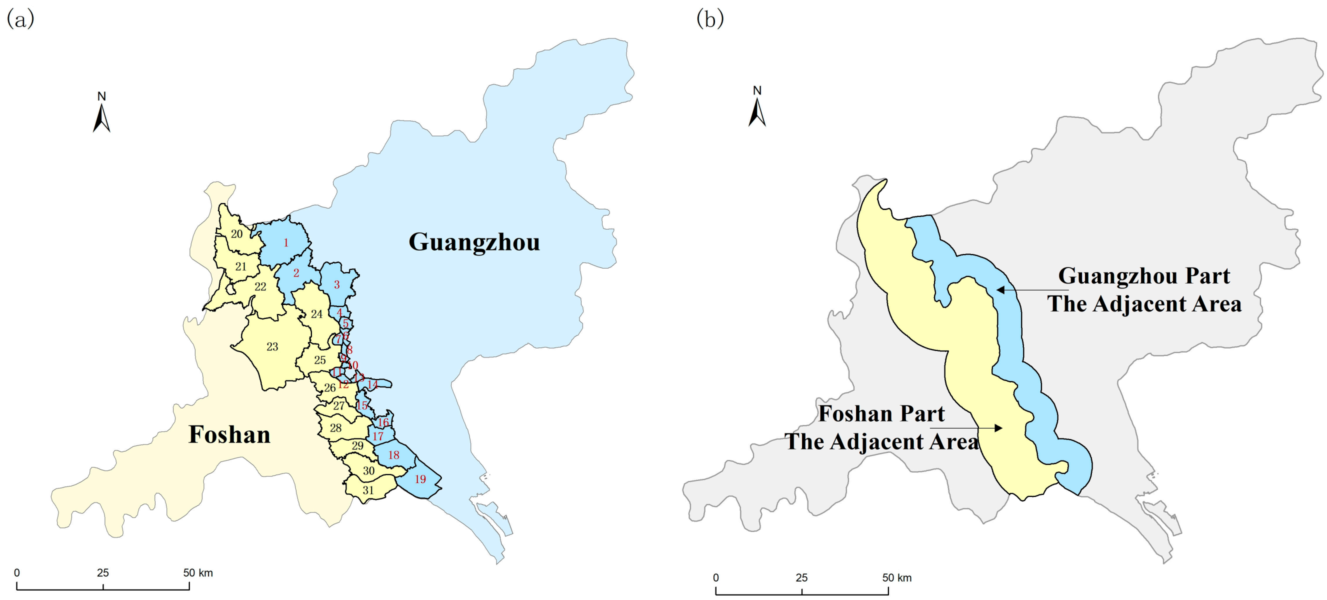
2.1. Study Area

For this study, the Guangzhou–Foshan metropolitan area was selected to be the study area (Figure 1). Guangzhou and Foshan, as the regions with the highest degree of urbanization in China, are geographically adjacent and engage in frequent economic and cultural exchanges. The "Western Union" proposal for Foshan was introduced by the Guangzhou planning in 2000, followed by the explicit endorsement of "Guangzhou–Foshan integration" by the government in 2008. Subsequently, transportation construction rapidly progressed, reducing travel time between the downtown areas to less than one hour by 2020. The government's 2020 proposal for high-quality development and integration pilot areas signifies a transition to a new stage of integration. As the core of the Guangdong–Hong Kong–Macao Greater Bay Area (GBA), the Guangzhou–Foshan metropolitan area spans a total area of 11,309.00 km^2, with a permanent population of 28.29 million in 2022 and a GDP of 4153.73 billion CNY (Data source: the people's government of Guangzhou municipality https://www.gz.gov.cn/ and the people's government of Foshan municipality http://www.foshan.gov.cn/). This metropolitan area plays a crucial strategic role in China's economic and social development. The development characteristics and influencing factors of both cities not only significantly impact the economic development of southern China but also offer important reference points for other metropolitan areas.

Figure 1. Location and boundaries of the Guangzhou–Foshan metropolitan area. The dark gray area represents the Guangdong–Hong Kong–Macao Greater Bay Area (GBA), and the orange area represents the Guangzhou–Foshan area. The boundaries depicted herein adhere to the map of China produced under the supervision of the Ministry of Natural Resources of the People's Republic of China (Approval Number: GS (2016)2923; Source: http://bzdt.ch.mnr.gov.cn/).

2.2. Delineation of Adjacent Areas

As geographically adjacent cities, Guangzhou and Foshan, with their border area serving as the integration core, provide a prime vantage point for observing the integration process [33]. With the development of urbanization, the built-up areas of Guangzhou and Foshan have merged into a contiguous entity, transcending administrative boundaries. In this study, 31 towns and subdistricts (19 in Guangzhou and 12 in Foshan) adjacent to the administrative boundary of Guangzhou–Foshan were selected (Figure 2). The total areas of Guangzhou (855.55 km^2) and Foshan (1684.33 km^2) were calculated, along with the length of the boundary line (133.25 km). The average distance between the boundary of the two cities (Foshan 12,640.00 m, Guangzhou 6420.00 m) was determined, and the buffer zone was delineated accordingly, establishing the research scope of the adjacent area between Guangzhou and Foshan.



Note: Guangzhou area: 1 Chini town, 2 Tanbu town, 3 Jianggao town, 4 Shimen subdistrict, 5 Shijing subdistrict, 6 Songzhou subdistrict, 7 Jinsha subdistrict, 8 Qiaozhong subdistricts, 9 Shi-weitang subdistrict, 10 Chajiao subdistrict, 11 Hailong subdistrict, 12 Zhongnan subdistrict, 13 Dongshad subdistrict, 14 Luopu subdistrict, 15 Shibi subdistrict, 16 Shatou subdistrict, 17 Shawan, 18 Lanhe town 19 Dagang town; Foshan area: 20 Datang Town, 21 Lubao Town, 22 Leping Town, 23 Shishan Town, 24 Lishui Town, 25 Dali Town, 26 Guicheng Subdistrict, 27 Chencun Town, 28 Beijiao Town, 29 Lunjiao Subdistrict, 30 Daliang Subdistrict, 31 Ronggui Subdistrict.

Figure 2. Town/subdistrict nearby administrative junction (**a**) and delineation of the Guangzhou–Foshan adjacent area (**b**).

2.3. Land Use and Land Cover Changes

This study utilized the global 30 m land cover time series dynamic remote-sensing product for 1985–2022 published by Zhang et al. [34]. This product is the first global land cover dataset to offer a fine classification system, comprising 16 global LCCS land cover types and 14 detailed regional land cover types. The overall accuracy of this dataset is 80.88% (±0.27%) under the basic classification system (10 major land cover types) and 73.24% (±0.30%) under the LCCS level one verification system (17 LCCS land cover types). We used seven land use types from this dataset for the period 2000–2020 (settlement, cropland, forest, grassland, wetland, water, and others) to classify and compare land use types in ArcGIS.

A land use transfer matrix encapsulates the area data of various land use types in a specific region during a defined period (Table 1). It reflects the dynamic process of land use conversion within that region.

Table 1. The general form of this matrix.

TL	**TN**				
	A1	**A2**		**An**	
A1	P11	P12	...	P1n	P1*
A2	P21	P22	...	P2n	P2*
	...	...	...	...	...
An	Pn1	Pn2	...	Pnn	Pn*
	P*1	P*2	...	P*n	

TL represents the first temporary phase, TN represents the next temporary phase, A1 to An represents n different land cover types, Aij denotes the area from phase Ai to phase Aj, Pi* signifies the total land coverage area of phase Ai, and P*j represents the sum of the area in the next temporary phase.

This study used ArcGIS (v10.8, ESRI, Redlands, California, USA) to execute land transfer matrix analysis, examining the change data of land use and land cover types in the Guangzhou–Foshan metropolitan and its adjacent areas from 2000 to 2020. It compares the sources and change rates of urban construction land. The investigation aims to explore the integration development status and the role of the integration area over the past two decades.

2.4. Human Settlement Environmental Geographic Dataset

LCZ, Population, building density, and building capacity data were acquired from the Global Human Settlement Layer (GHSL) (https://ghsl.jrc.ec.europa.eu/, accessed April 2024) [35]. Data with a 100 m resolution and a Mollweide coordinate system were downloaded and processed using ArcGIS. The building density data were derived from GHS–BUILT–S data spanning from 2000 to 2020, while the building capacity data were derived from GHS–BUILT–V data of 2000, 2005, 2010, 2015, and 2020. The population density data were obtained from GHS–POP data up to 2020, using CIESIN/SEDAC global population data.

Nighttime light data were obtained from DMSP–OLS data integrated with SNPP–VIIRS data [36]. Invariant pixels were selected to calibrate DMSP–OLS data, and SNPP–VIIRS data were predicted and corrected using an exponential smoothing model. This study utilizes data from 2000, 2005, 2010, 2015, and 2020.

2.5. Urban–Rural Gradients Using Local Climate Zones

LCZ, introduced by Stewart and Oke in 2012, defines uniform regions based on underlying surface, spatial morphology, human activity, and surface material [37]. Within the LCZ classification system, compact high-rise areas (LCZ 1) are characterized by densely distributed buildings of several stories, with minimal vegetation cover [38–40]. These areas exhibit the highest ratio of impervious surfaces among all building types, predominantly comprising materials such as concrete, steel, glass, and similar substances. The urban–rural gradient centered on LCZ 1 (compact high-rise) plays a crucial role in urban expansion and development, making it suitable for identifying urban centers and measuring urbanization gradients in megacity areas. Xie et al. (2022) [32] reported that LCZ 1 is consistently densely distributed in urban centers; the areas and proportion of LCZ 2–10 decreased regularly with their distance to LCZ 1 across the Guangdong–Hong Kong–Macao Greater Bay Area (GBA) [38]. Establishing a 250 m urban–rural gradient centered around LCZ 1 in the GBA, which can be applied in metropolitan studies depending on urban–rural gradients, such as urban heat island effect [39], demography [41], and urban ecology [38].

This study used the 2019 LCZ map of the GBA established by Xie et al. (2022) [32], with an overall accuracy of 93.0% and a Kappa coefficient of 0.864. Employing ArcGIS, multiple buffers with a fixed distance of 250 m were established centered around all LCZ 1 areas (Figure 3). This paper used the 2019 LCZ data to calculate the gradient changes for three time points. Given that the urban center and gradient of the GBA have not undergone significant changes in the past 20 years, it is reasonable to use the latest gradient data to estimate changes over the twenty-year period. The urban–rural gradient covering the Guangzhou–Foshan metropolitan area obtained from this process serves as the foundation for the analysis conducted in this study.

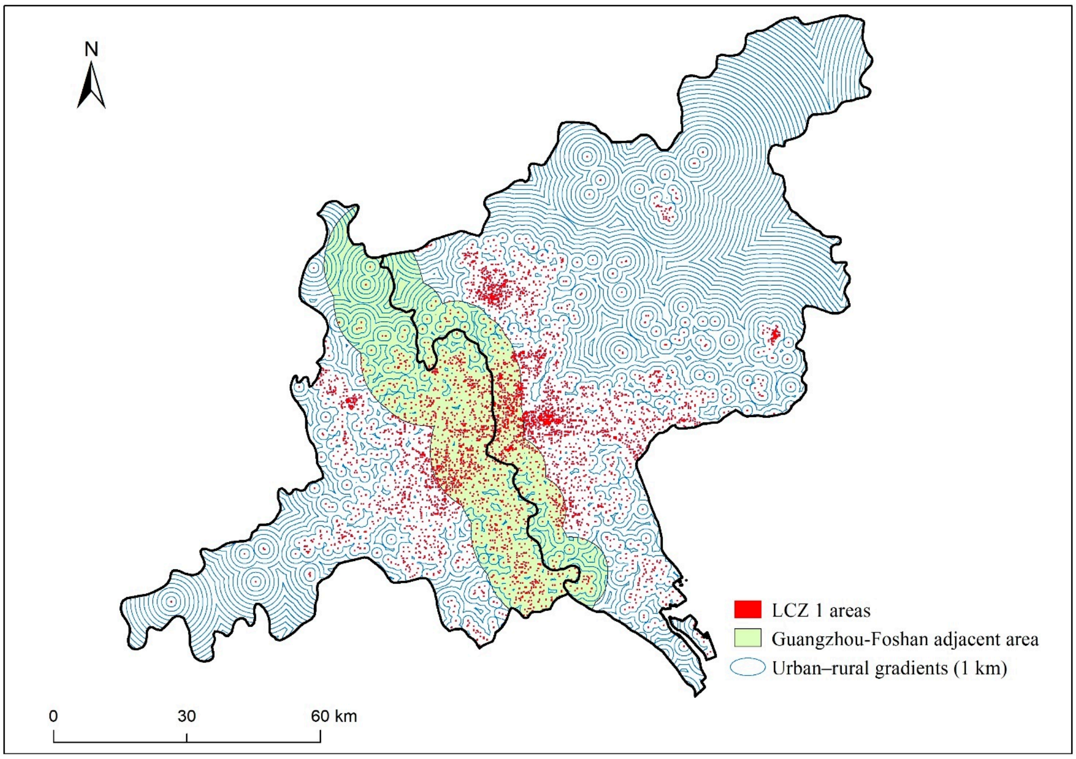


Figure 3. Urban–rural gradients using local climate zones in the Guangzhou–Foshan metropolitan area.

2.6. Statistical Analysis

We calculated averages to compare the changes in various data across different urban–rural gradients. Prior to calculating the averages, we filtered the data to correct any potential inaccuracies or outliers, thereby enhancing the robustness and completeness of the research findings. Calculating averages is a fundamental method used throughout this study. It ensures reliable data analysis and facilitates meaningful comparisons between variables in the context of urban expansion and city integration analysis.

To assess the dynamics of urban development and spatial structure changes over time, a comparative analysis method was adopted. At intervals of five and twenty years, differential analyses were conducted on land use data and human settlement environmental geographic datasets. By comparing the rate of change in land use data within the study area, the rate of change in the boundary integration area was compared with that of the overall Guangzhou–Foshan metropolitan area. A result greater than 1 indicates that the rate of change for that land use type in the boundary integration area is lower than in the metropolitan area, while a result less than 1 indicates a higher rate of change. Comparisons of various human settlement environmental geographic information data along the urban–rural gradient show that positive values indicate overall growth over the time interval, while negative values indicate an overall decline.

3. Results

3.1. Spatiotemporal Changes in Land Use and Land Cover

In the urban development of the Guangzhou–Foshan metropolitan area and its adjacent zone, urban construction land primarily originates from converted cultivated land, water bodies, and forest land. Notably, arable land serves as the primary source, constituting 39.9% and 35.0% of urban construction land, respectively, in 2020 (Table 2a,b). The period from 2000 to 2005 marked the peak phase of cultivated land conversion to urban construction land, with subsequent proportions diminishing to 4.8% and 3.6% from 2015 to 2020.

Table 2. Changes in urban construction land in the Guangzhou–Foshan metropolitan area and integration area.

(a) Sources of urban construction land inthe Guangzhou–Foshan metropolitan area					
	2000–2005	**2005–2010**	**2010–2015**	**2015–2020**	**2000–2020**
Settlement	76.2%	81.6%	89.4%	93.8%	52.2%
Cropland	20.3%	15.7%	9.0%	4.8%	39.9%
Forest	2.4%	1.7%	1.1%	0.9%	5.1%
Grassland	0.2%	0.1%	0.1%	0.1%	0.5%
Wetland	0	0	0	0	0
Water	0.9%	0.9%	0.4%	0.4%	2.2%
Other	0	0	0	0	0
Overall	100%	100%	100%	100%	100%
(b) Sources of urban construction land inthe Guangzhou–Foshan adjacent area					
	2000–2005	**2005–2010**	**2010–2015**	**2015–2020**	**2000–2020**
Settlement	80.2%	83.3%	90.8%	95.4%	57.9%
Cropland	16.5%	14.2%	7.9%	3.6%	35.0%
Forest	2.1%	1.5%	0.8%	0.5%	4.2%
Grassland	0.2%	0.1%	0.1%	0.1%	0.4%
Wetland	0	0	0	0	0
Water	1.0%	0.9%	0.4%	0.4%	2.5%
Other	0	0	0	0	0
Overall	100%	100%	100%	100%	100%
(c) Change rate of urban construction land in the adjacent area compared with that in the Guangzhou–Foshan metropolitan area (dimensionless unit: 1)					
	2000–2005	**2005–2010**	**2010–2015**	**2015–2020**	**2000–2020**
Settlement	1.052	1.021	1.015	1.017	1.110
Cropland	0.813	0.903	0.880	0.756	0.876
Forest	0.882	0.894	0.789	0.561	0.822
Grassland	0.861	0.904	0.811	0.639	0.770
Wetland	1.000	1.000	1.000	1.000	1.000
Water	1.128	1.021	0.911	0.934	1.106
Other	1.000	1.000	1.000	1.000	1.000

A comparison of the overall urban construction land changes between the border integration area and the Guangzhou–Foshan metropolitan area reveals a slightly slower integration pace in the border zone (Table 2c). Except for water bodies and wetlands, the conversion rates of cropland, forest, and grassland are lower than those of the entire metropolitan area. Notably, for cultivated land—the primary conversion type—the contrast rate of the border-adjacent area initially increased before decreasing, reaching 0.876 of the metropolitan area's overall conversion rate. This suggests a slower urban construction development rate in the Guangzhou–Foshan adjacent area compared to the Guangzhou–Foshan metropolitan area, where Guangzhou and Foshan's collective development outpaces that of their border regions. Strengthening integration efforts in the border zone is essential to foster a new development center and advance integration in subsequent stages.

3.2. Spatiotemporal Changes in the Human Settlement Environmental Geographic Dataset across Urban–Rural Gradients

In the Guangzhou–Foshan metropolitan area, the distribution of population density exhibits a distinct "core–edge" pattern (Figure 4a), with the central area being the most densely populated within a 3000 m radius. Although there was an overall upward trend in population from 2000 to 2020, growth slowed in the core region after 2010, while fluctuations were more pronounced in the periphery (Figure 4b).

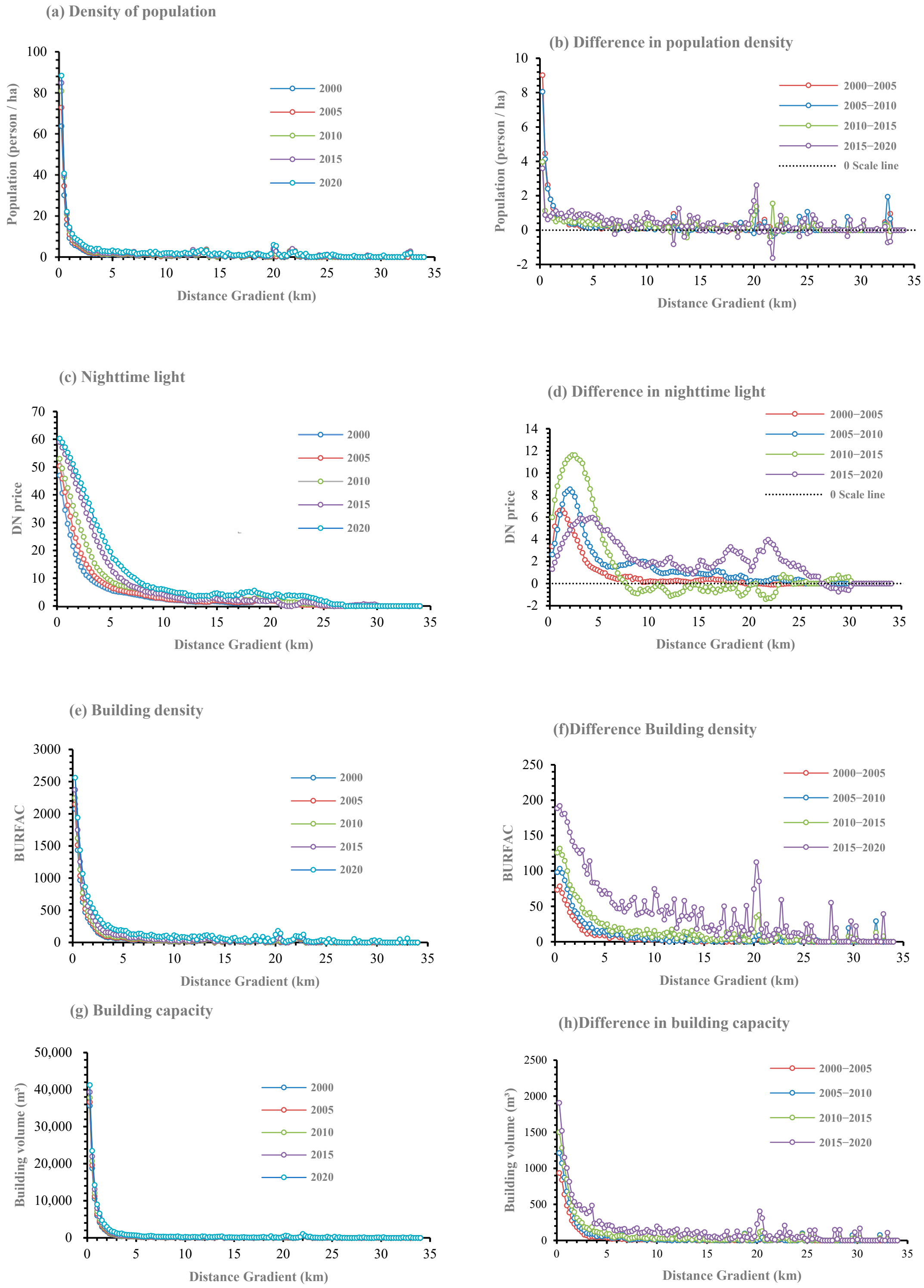


Figure 4. The urban–rural changes and their temporal variations in the human settlement environmental geographic dataset of the Guangzhou–Foshan metropolitan area.

The distribution of nighttime light similarly reflects this structure (Figure 4c), with the expansion of the core area being particularly pronounced over the past two decades (Figure 4d), especially within the 5000 m range. Growth within this range displays an inverted U-shape, while regions beyond 5000 m experienced rapid growth between 2015 and 2020 after a brief decline from 2010 to 2015. This indicates that the center of urban development is shifting from the core to the fringe areas.

Building density and construction volume also follow a "core–edge" distribution pattern (Figure 4e,g). The core area mainly refers to the region within 3000 m of the city center. From 2015 to 2020, the growth rate of construction density nearly doubled compared to previous years, with significant fluctuations in the fringe area within approximately 20,000 m. Construction density in the suburbs also showed an upward trend, with building capacity growth peaking in 2015–2020, especially at 20,000 m, indicating strong growth momentum in the core area (Figure 4f,h).

In Guangzhou and Foshan, the spatial distributions of population density both present a typical "core–edge" pattern (Figure 5a,b). The peak population density in Guangzhou's core area is twice that of Foshan, indicating a more pronounced centralization trend.

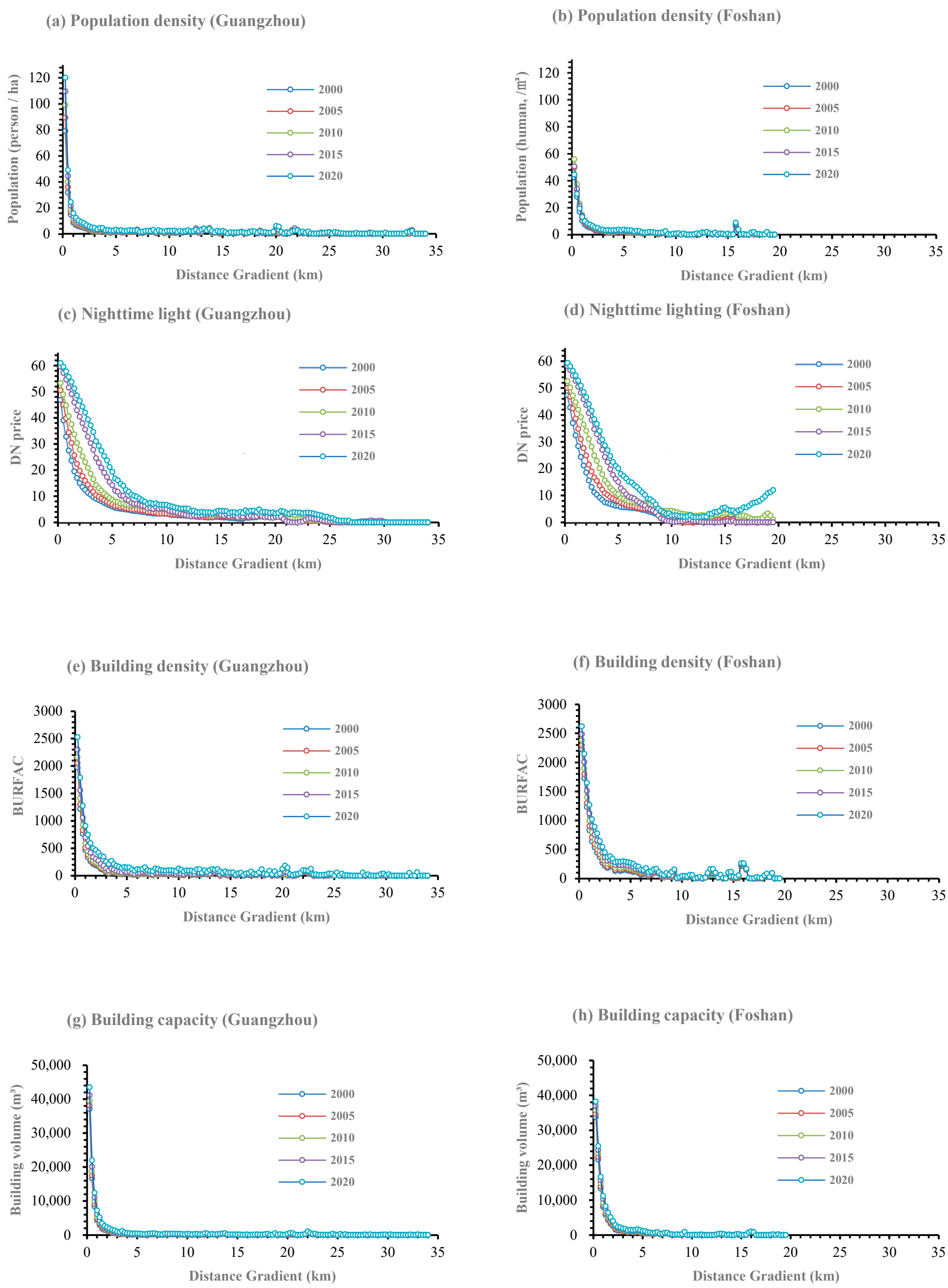


Figure 5. The urban–rural changes in the human settlement environmental geographic dataset of Guangzhou and Foshan, respectively.

In terms of the nighttime light distribution, Guangzhou's pattern is similar to the overall Guangzhou–Foshan metropolitan area (Figure 5c), while Foshan's peripheral areas exhibit different changes beyond 15,000 m. The nighttime light on Foshan's edge fluctuated in 2015 but gradually increased by 2020, forming a U-shaped distribution from 5000 to 20,000 m (Figure 5d).

The distribution map of building density and capacity reveals Guangzhou's spatial pattern with a 3000 m boundary (Figure 5e,g). From 2000 to 2020, the building density and capacity in the core and boundary areas gradually increased, while the marginal areas saw little change. Foshan also displays a high-center and low-edge building distribution (Figure 5f,h), with the building density slowly declining at the 3000 to 6000 m boundary of the core area.

When comparing the human settlement environmental geographic datasets of the two cities, the most significant disparity was observed in population density (Figure 6a,b). Foshan's "core" area experienced sustained negative growth from 2010 to 2020, whereas growth in the "edge" area was sluggish. Conversely, Guangzhou witnessed positive growth in its "core" area, with the disparity widening over the years, while the "edge" area exhibited relatively steady yet fluctuating growth.

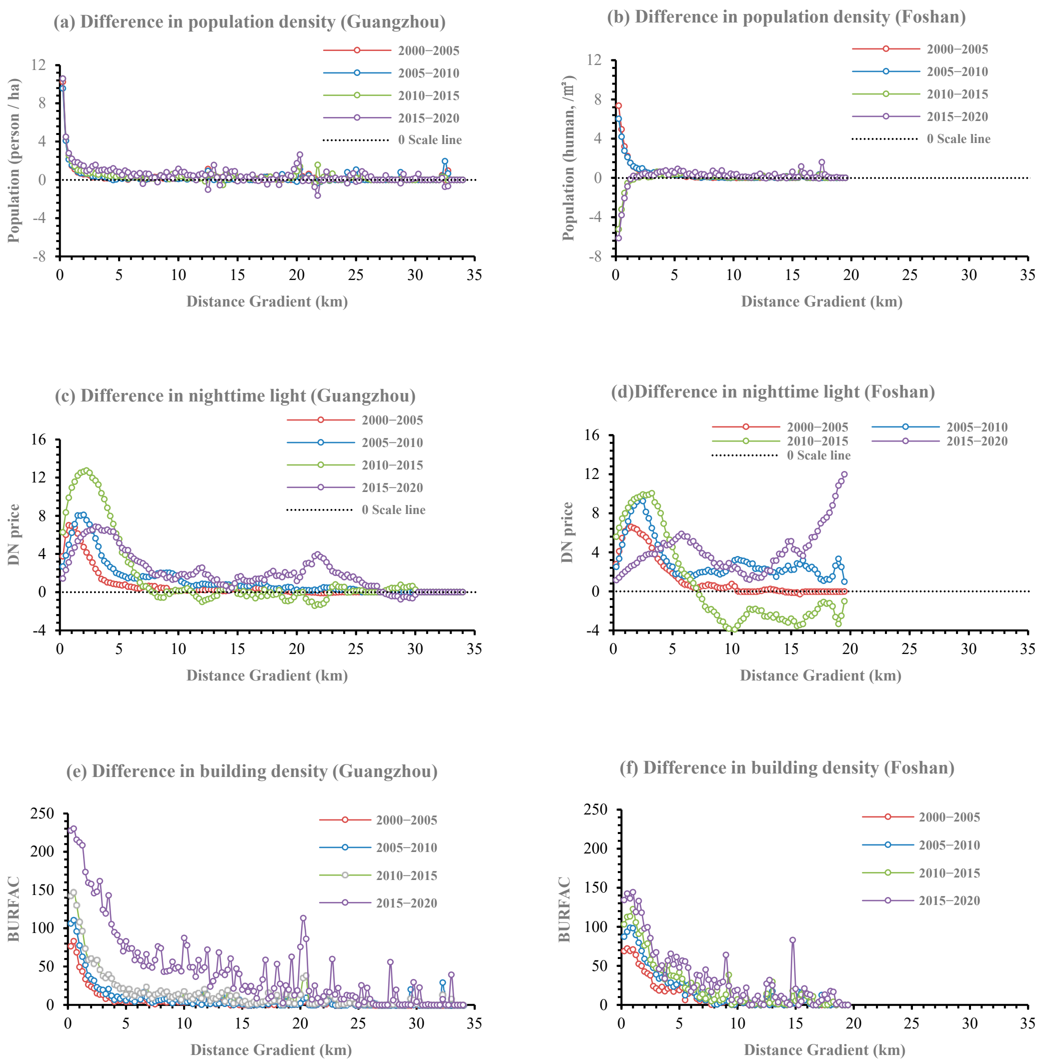


Figure 6. *Cont.*

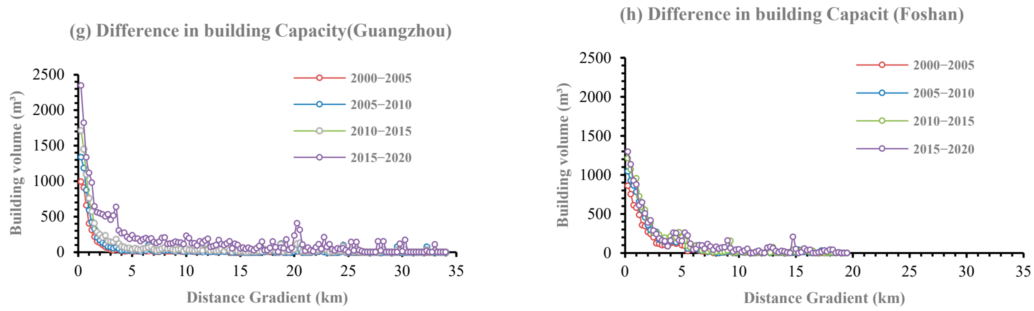


Figure 6. The urban–rural changes and their temporal variations in the human settlement environmental geographic dataset of Guangzhou and Foshan, respectively.

A significant variation in the nighttime light is evident in the "edge" area (Figure 6c,d). Between 2010 and 2015, a period characterized by substantial changes, Guangzhou experienced rapid growth in the "core" areas and expansion into more "edge" areas. Conversely, Foshan witnessed rapid growth in the "core" areas but an overall sharp decline in the "edge" areas.

Regarding building distribution (Figure 6e,h), the most significant changes occurred between 2015 and 2020, marked by a substantial increase in building density in Guangzhou and rapid growth in numerous "edge" zone areas, while Foshan's building capacity exhibited consistent growth across all regions annually. In terms of the spatial growth of building density and capacity, the difference peak value and the change frequency of different zones in Guangzhou are higher than that in Foshan.

3.3. Evaluating Spatiotemporal Integration of Adjacent Areas in the Guangzhou–Foshan Metropolitan Area across Urban–Rural Gradients

In the vicinity of the Guangzhou–Foshan metropolitan area junction, with the exception of nocturnal illumination, the spatial arrangement of population density, building density, and building capacity distinctly exhibits a "high center–low periphery" pattern (Figure 7a,c,e,g). Notably, population density registered negative values within the 1000–2000 m radius from the epicenter between 2010 and 2020 (Figure 7b). Additionally, nocturnal luminosity in the "edge" zone experienced a pronounced surge, surpassing that of the "core" area from 2010 to 2020, thereby narrowing the disparity (Figure 7d). However, the escalation of building density and capacity is discernible across all gradients, with building density showing a more pronounced increase compared to building capacity, particularly notable during the 2015–2020 period (Figure 7f,h). Noteworthy is the notably rapid growth observed around the 4800 m mark.

Comprehensive analysis reveals that human settlement environmental geographic dataset in the adjacent region continue to exhibit a declining trend along the urban–rural gradient in spatial allocation. However, in terms of growth differences over the years, distinct characteristics emerge compared to the broader Guangzhou–Foshan metropolitan area. The growth pattern within the adjacent area does not primarily center on the central region but rather manifests as a fluctuating terrain across the entire integration domain.

In the adjacent area of Guangzhou–Foshan, certain segments of both cities exhibit analogous characteristics in the spatial distribution of human settlement environmental geographic dataset (Figure 8). Both population density and building capacity demonstrate an L-shaped pattern, with the highest concentration in the central area exhibiting variability. The inflection point is 2000 m, and the growth rate of each segment remains modest from 2000 to 2020 (Figure 8a,b,g,h). Regarding the spatial distribution of nocturnal illumination, both Guangzhou and Foshan depict notable growth trends over the years, with the Digital Number (DN) value in Guangzhou surpassing 6000 m from the center, exceeding the lowest value by approximately 5000 m (Figure 8c,d). Concurrently, building density exhibits a fluctuating decline beyond the central zone. While both Guangzhou and Foshan experience rapid decreases within 6000 m from the center, the fluctuations in Guangzhou are minimal beyond this radius, whereas Foshan's reduction rate is comparatively slower (Figure 8e,f).

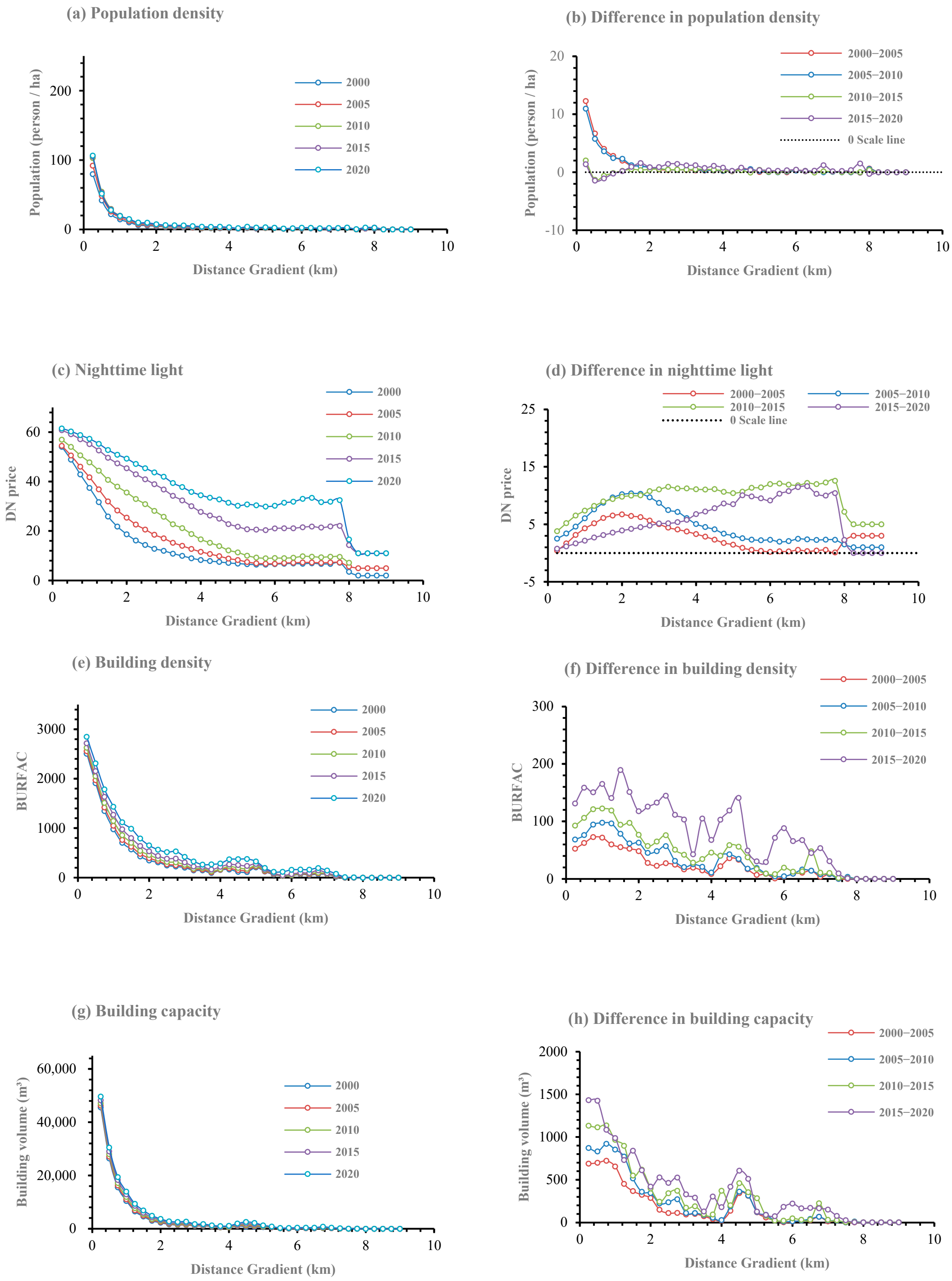


Figure 7. The urban–rural changes and their temporal variations in the human settlement environmental geographic dataset of the Guangzhou–Foshan adjacent area.

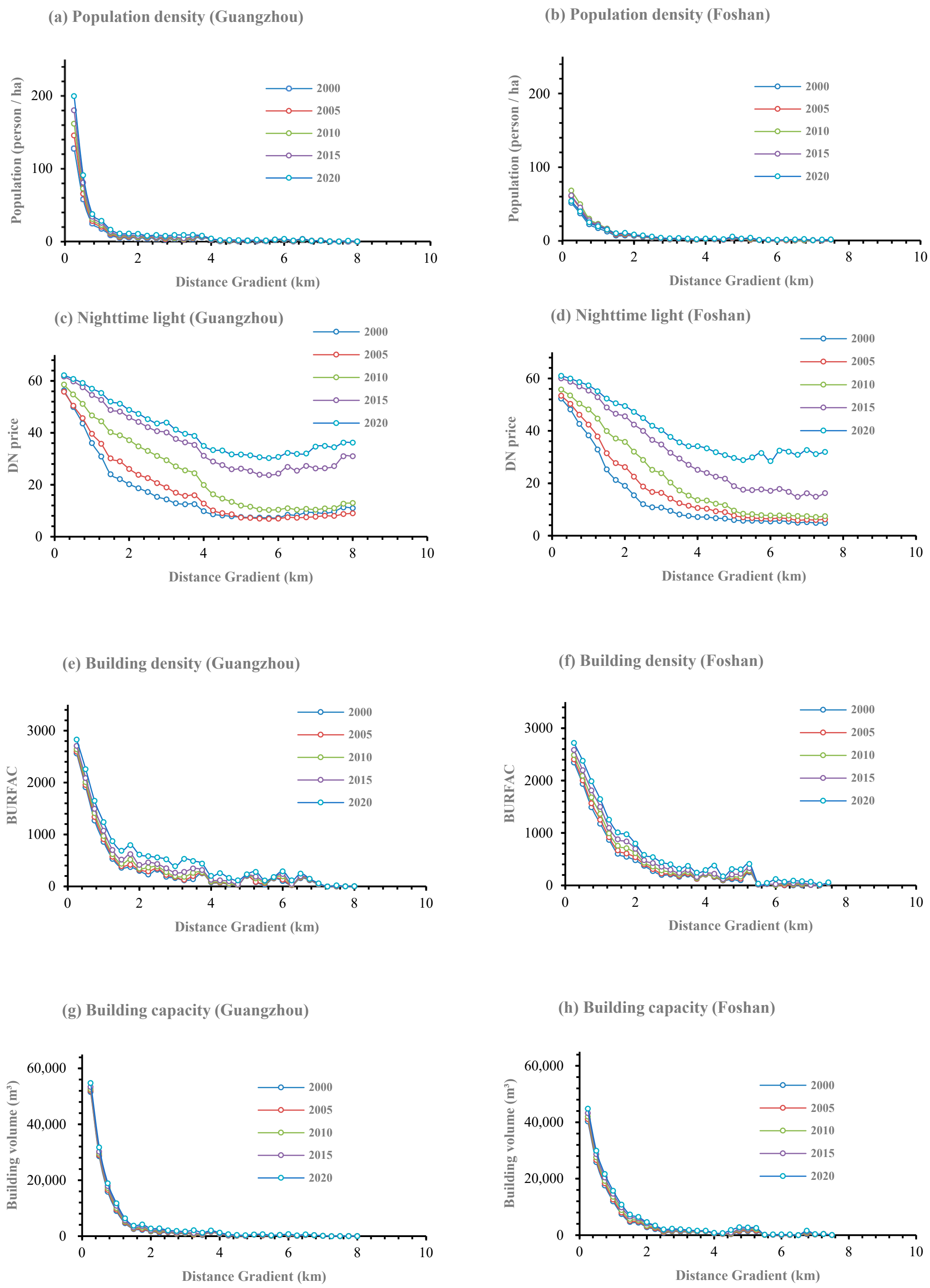


Figure 8. The urban–rural changes in the human settlement environmental geographic dataset of Guangzhou and Foshan parts in the adjacent area.

On the spatial distribution of population density difference (Figure 9a,b), Guangzhou and Foshan exhibit distinct distribution characteristics. Over the past two decades, the Guangzhou region has primarily displayed an L-shaped growth pattern, wherein the growth rate diminishes with increasing distance. Conversely, in Foshan, population density has predominantly experienced negative growth since 2010, particularly in the central area, which contrasts sharply with the situation before 2010.

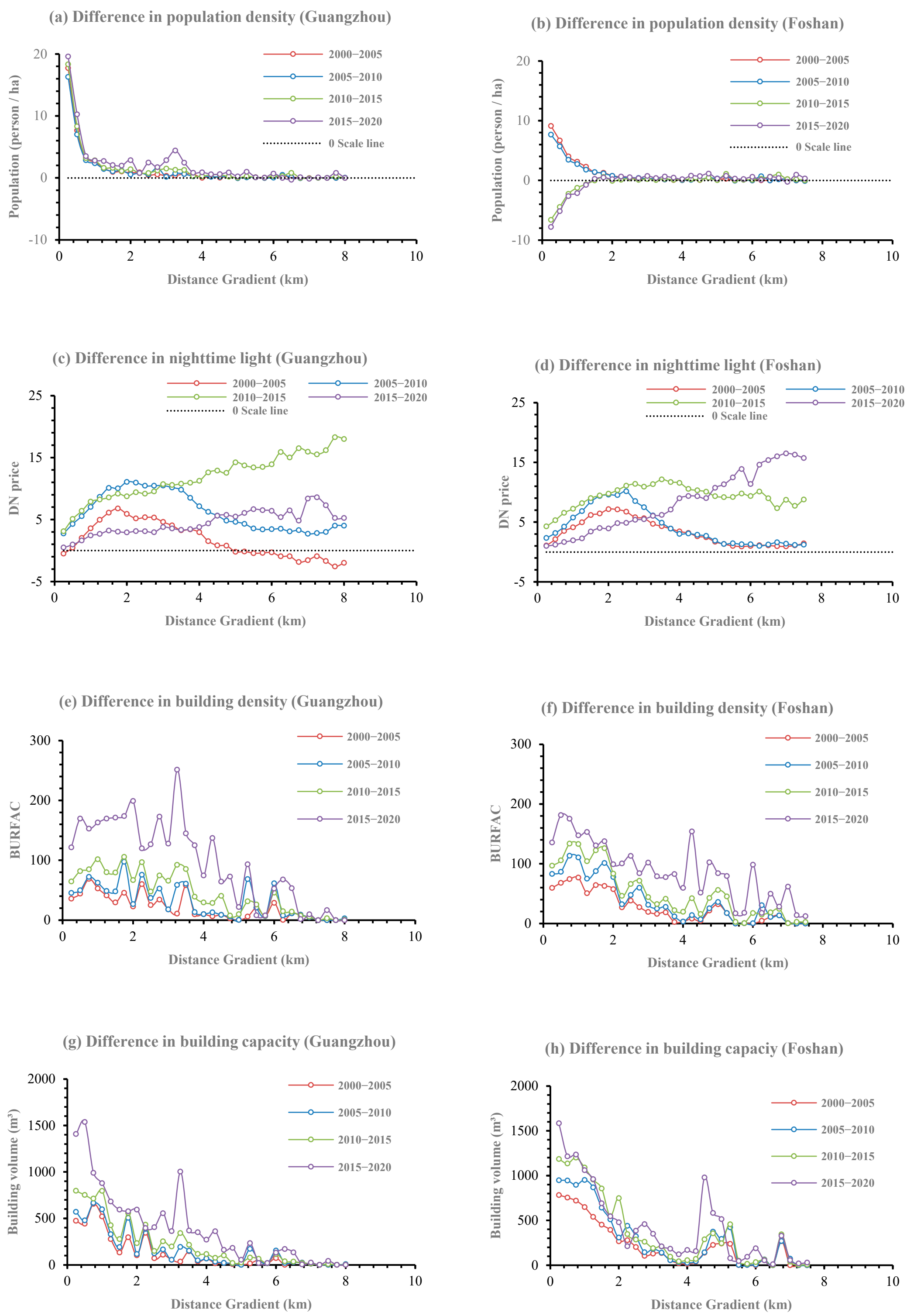


Figure 9. The urban–rural changes and their temporal variations in the human settlement environmental geographic dataset of Guangzhou and Foshan parts in the adjacent area.

Regarding the distribution of nighttime light difference (Figure 9c,d), the Guangzhou area witnessed negative growth in the "edge" area from 2000 to 2005, thereafter transitioning to sustained positive growth, surpassing the "core" area incrementally post-2010. Similarly, Foshan's growth curve exhibited an inverted U-shaped pattern until 2010, followed by an inverse relationship with distance from the center during 2015–2020.

The disparity curve of building density and capacity between Guangzhou and Foshan follows a similar distribution pattern (Figure 9e,h). Overall, it demonstrates a fluctuating-downward trend along the urban–rural gradient, with the range of fluctuation in the difference expanding over time, peaking in 2015–2020.

To summarize, the spatial evolution characteristics of the Guangzhou–Foshan metropolitan area are reflected in the distribution and changing trends in population density, nighttime light, and building features. The boundary of the "center–edge" structure of the Guangzhou–Foshan metropolitan area is 5000 m, while the adjacent area is 2000 m. Guangzhou and Foshan show different growth patterns in population density, with Guangzhou exhibiting L-shaped growth, while Foshan experienced negative population growth in its central region after 2010. The growth of nighttime light was significant in both cities, but Guangzhou's fringe area growth rate exceeded that of the core area after 2010, while Foshan showed an inverse growth trend from 2015 to 2020. The building density and capacity fluctuated along the urban–rural gradient in both regions, with increments peaking during 2015–2020.

This spatial evolution is closely linked to broader trends and patterns observed in urban integration. The distinct "core–edge" model emerging in the Guangzhou–Foshan metropolitan area, characterized by rapid development at the junction of the two cities, underscores the significance of regional economic coordination and policy-driven development. The decelerating growth in the central region contrasted with active growth in peripheral areas reflects the natural expansion of urban centers and the influence of urbanization policies. The fluctuating growth along the urban–rural gradient and the shift in the center of regional development highlight the dynamic nature of urban spatial integration, necessitating ongoing analysis and adaptation in urban-planning strategies.

4. Discussion

4.1. Spatiotemporal Structure Characteristics of Urban Integration

Significant differences have been observed between the urban expansion characteristics during the process of urban integration and those of individual cities [24]. Since China's reform and opening up, the construction land in the Guangzhou–Foshan metropolitan area has undergone continuous expansion. A distinct "core–edge" model has emerged in its spatial structure, with the junction of the two cities rapidly evolving into the "core" [42]. Huang et al. discovered that from 1985 to 2020, the spatial pattern of the Guangzhou–Foshan region exhibited an expansive trend, with Liwan District as the central core, connecting multiple sub-centers. This study delves into land expansion and spatial interaction by using human settlement environmental geographic data spanning from 2000 to 2020. It reveals that since the inception of the "Guangzhou–Foshan metropolitan circle" concept, amidst the overarching urban construction and expansion, the "core–edge" spatial configuration has remained constant (Figure 4). Additionally, the presence of dual urban centers within the "core" area is further elucidated. The evolution of planning policies and shifts in development focus have imbued the research area with distinct spatial expansion characteristics around 2010. These include significant southward expansion of the "core" area prior to 2010 and overall land optimization thereafter, alongside the phenomenon of rapid construction and sluggish development in border areas.

By employing various indexes to study land use expansion methods [27,29], this research introduces urban and rural gradient data to analyze the spatial and temporal dynamics from the core to the periphery of the Guangzhou–Foshan metropolitan area. It scrutinizes the spatial development and interaction of the two cities individually and conducts an in-depth examination of the "core–edge" spatial structure gradient. The findings reveal that while both the Guangzhou–Foshan metropolitan area and the two cities individually exhibit similar spatial characteristics in terms of building distribution and nighttime light, manifesting an evident "core–edge" structure, population dynamics diverge. Foshan displayed outward population loss tendencies before 2010, whereas Guangzhou maintained consistent growth (Figures 5 and 6). The analysis of the regional impact disparity of the Guangzhou–Foshan metropolitan area based on city size reveals that Guangzhou plays a pivotal role in driving rapid growth in the "core" areas, while Foshan focuses more on developing the "edge" areas.

In contrast to the continuously increasing population density in Guangzhou's city center, the population density in Foshan's central area experienced a shift around 2010, primarily influenced by administrative boundary adjustments and industrial economic patterns. Prior to 2000, due to the relative independence of municipal and county administrative divisions, inter-regional connections were weak. The major administrative reorganization in 2002, which transformed cities into subdistricts, promoted the spatial integration of Foshan, gradually forming a concentrated core area in Chancheng and Nanhai subdistricts [43]. By 2010, Foshan encouraged the relocation of primary industries and supported the development of capital-intensive and technology-intensive industries, driving urban spatial optimization and population migration [44].

In the process of urban development in China, the government plays a crucial role, particularly in infrastructure, transportation construction, ecological management, and industrial collaboration, offering significant advantages. In the urbanization of the Guangzhou–Foshan area, these advantages provide a solid material foundation for inter-city collaborative development. The official urbanization process in the Guangzhou–Foshan metropolitan area began in 2009, with the "Guangzhou–Foshan Urban Integration Development Plan (2009–2020)", primarily focusing on infrastructure construction and transportation network connectivity. The building density growth in the adjacent area from 2010 to 2020 exceeded that from 2000 to 2010, especially between 2015 and 2020 (Figure 7f), with more pronounced growth in the Guangzhou and Foshan sections of the integration area (Figure 9e,f). Meanwhile, population density and nighttime light data did not show a corresponding growth trend (Figures 7 and 9). It is evident that significant advancements in infrastructure and transportation construction occurred from 2010 to 2020, but the adjacent area has yet to develop sufficient growth momentum. Future efforts need to strengthen cultural and ecological construction and promote organic industrial linkages to deepen the Guangzhou–Foshan urbanization.

Utilizing quantitative data to examine the stage and extent of urban development [45], this study broadens empirical research on integration development stages and enriches the repertoire of multi-source geographic information data and methodologies for integration process analysis. By leveraging population density, building capacity, building density, and nighttime light data—representative of regional integration spatial characteristics—the study further investigates the core–edge structure of the Guangzhou–Foshan urban area pre-2015. It discerns that this spatial pattern endures and is projected to persist post-2020. Moreover, by dissecting land use type transformations and policy introductions, this study elucidates the attributes and rationales underlying integration construction across administrative boundaries.

4.2. Comparative Analysis of Urban Spatial Structure in China

The phenomenon of city integration in China exhibits unique spatial structural characteristics in different regions, especially in terms of urban expansion and coordinated regional development. The Guangzhou–Foshan urbanization is renowned for its high degree of spatial integration [46]. Guangzhou and Foshan are geographically closely connected, with highly complementary urban functions and spatial structures [47], leading to increasingly blurred city boundaries (Figure 7). The "core–edge" structural characteristic is significant and continually strengthening (Figure 4).

The Chengdu–Chongqing city integration displays different spatial characteristics. As two important cities in the western region, Chengdu and Chongqing have strengthened their regional connectivity through shared transportation infrastructure, such as the Chengdu–Chongqing high-speed railway, which promotes spatial expansion and development along the route [48,49]. However, the distance between the two cities far exceeds that of Guangzhou and Foshan, with the administrative centers of Chengdu and Chongqing being 266 km apart, making it difficult for the city integration to form a single "core" area.

In contrast to the urbanization seen in Guangzhou–Foshan and Chengdu–Chongqing, the urbanizations of Beijing–Tianjin and Shanghai–Suzhou are more characterized by the radiation effect of a major city on a secondary city. The Beijing–Tianjin urbanization focuses on administrative division adjustments and the relocation of non-capital functions, with its spatial structure reflecting policy-driven industrial transfers and functional reorganization rather than natural expansion [10,50]. The development of Shanghai–Suzhou city urbanization is dominated by Shanghai's radiative driving effect, where Suzhou achieves rapid urban space expansion by accepting Shanghai's industrial transfers and functional spillovers. Centered on Shanghai's financial services, Suzhou's manufacturing industry forms a tight industrial chain with Shanghai, promoting regional economic integration [51,52].

By comparing the spatial structures and urban expansions of different city integration regions, it can be seen that various factors, including geography, economy, and policy, influence the development of city integration, resulting in diverse spatial structures and urban expansion models. Compared to other regions, the Guangzhou–Foshan urbanization features natural geographical advantages, market-driven forces, and coordinated government planning. The central areas of Guangzhou and Foshan are only 20 km apart, with a contiguous boundary of 197 km. This geographical advantage has facilitated the construction of inter-city railways, highways, and other infrastructure, driving the rapid flow of population, capital, and goods. The two cities have formed a complementary industrial chain of "Guangzhou services + Foshan manufacturing". Guangzhou boasts a robust service industry base, including finance, education, healthcare, and research, while Foshan is manufacturing-oriented, excelling in home appliances, machinery, ceramics, and metal processing. This mutual complementarity provides ample space for industrial cooperation between the two cities.

Urban planning has provided spatial development guidance for Guangzhou–Foshan city integration. Guangzhou began a "westward connection" with Foshan in 2000, and Foshan actively engaged in infrastructural cooperation. In 2010, the city integration entered a new phase, with Guangzhou's urban planning shifting from "southward expansion, northward optimization, eastward progression, and westward connection" (The Overall Urban Planning of Guangzhou 2001–2010) to a "quality enhancement" strategy (The Overall Urban Planning of Guangzhou 2011–2020), directly influencing the development of the boundary integration area. Additionally, the signing of new agreements institutionalized and standardized the urbanization process (On 19 March 2009, Guangzhou and Foshan governments signed the "Cooperation Agreement on Urban Construction of Foshan City, Guangzhou" and four docking agreements), focusing on interconnected infrastructure, industrial layout, and public services. Policy played a crucial role in regulating and guiding this process, promoting rational development through planning controls and resource allocation.

4.3. LCZ Provides a Tool for Regional and Inter-City Comparisons

In urbanization research, the LCZ framework is used to analyze multi-source geographic information data, offering a comprehensive evaluation of urban spatial structure and environmental characteristics. The primary advantage of LCZ data is to integrate multi-dimensional data, including population distribution (Figures 4b and 7b), night lighting (Figures 4d and 7d), building density (Figures 4f and 7f), and building capacity (Figures 4h and 7h), to assess the spatial effects of urbanization at both macro and micro levels. This integration enhances the understanding of spatial heterogeneity within the city and helps identify and quantify boundary evolution during urbanization, offering precise and dynamic decision support for urban planning and policymaking.

LCZ data not only excel in multi-source data fusion but are also applicable across various scales, from small regions to entire cities and even larger regional studies. This paper uses the rural–urban gradient centered on LCZ 1 to study the spatial expansion and development of megacities and the differentiation of urban forms. While this study focuses on the internal spatial pattern of the Guangzhou–Foshan metropolitan area, future research could compare and analyze urbanization across different regions using the standardized classification method provided by LCZ.

5. Conclusions

This study innovatively constructs a multi-source data analysis framework to evaluate spatial integration in the context of urbanization. By utilizing LCZ data, the study simplifies complex urban spatial structures and enhances the efficiency of spatial analysis. Through the examination of spatial development and transformation in the Guangzhou–Foshan metropolitan area from 2000 to 2020, this research reveals the persistence of a "core–edge" spatial structure (the boundary of the "core–edge" structure of the Guangzhou–Foshan metropolitan area is 5000 m, while the adjacent area is 2000 m) over the past two decades and analyzes the impact of policy changes on development. Furthermore, this study employs LCZ data to analyze the urban–rural gradient, providing a new analytical tool for understanding urban integration and spatial expansion. These methodologies and findings offer new perspectives on the spatiotemporal dynamics of urban spatial structures and provide significant empirical support for urban planning and policymaking.

Additionally, this research compares the spatial structure and urban expansion patterns of the Guangzhou–Foshan metropolitan area with other urban integration regions, showcasing the unique spatial characteristics of different areas. The application of LCZ data excels in multi-source data integration and is suitable for studies of various scales, from small regions to entire cities and even larger regional analyses. This provides a standardized classification method for comparative analyses between regions and cities. Through this approach, the study can assess urban spatial structures and environmental characteristics, thereby offering precise and dynamic decision support for urban planning and policymaking. This standardized analytical framework offers a new approach to studying multi-scale urbanization and helps further identify and quantify regional growth differences in the urbanization process.

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