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# Metropolitan Expansion and Migrant Population: Correlation Patterns and Influencing Factors in Chengdu, China

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**Abstract:** The ongoing urban spatial transformation contributes to a more intricate and varied spatiotemporal correlation pattern between metropolitan expansion and the migrant population. In this study, the coupled coordination model (CCD) is applied to enable the quantification of the spatiotemporal correlation index of metropolitan expansion and migrant population from 2010 to 2020. Moreover, various correlation patterns are identified in this research, and the multiscale geographical weighted regression model (MGWR) is employed to examine the spatiotemporal heterogeneity of the influencing factors that contribute to this correlation. The research findings reveal the following insights: (1) The built-up areas increased twofold between 2010 and 2020, with an evident tendency toward southward expansion. In addition, population migration indicates slow migration in the inner metropolitan area and accelerated migration in the outer metropolitan area. The correlation between metropolitan expansion and migrant population follows a central–peripheral layer pattern that is characterized by a low-high-low progression. (2) While the balanced development of public services has somewhat decreased the differentiation patterns observed, the adjustments made to economic growth, employment, and residential markets have intensified the differentiation of spatiotemporal correlation characteristics between the metropolitan expansion and migrant population. (3) This study demonstrates that the Chengdu metropolitan area is transitioning from a rapid development stage driven by structuralism to a human-oriented new urbanization stage. This shift is evident through the clear stage pattern and central–peripheral layer features observed. Through the scientific planning of industry and public service layouts, the promotion of integration employment, residential markets, and the facilitation of urban–rural transformation can be achieved. Implementing these strategies can elevate the standard of human-oriented urban spatial governance, achieve coordinated and balanced development between built-up and residential spaces, and advance the high-quality, sustainable, and inclusive development of metropolitan areas.

**Keywords:** migrant population; metropolitan expansion; spatiotemporal correlation; MGWR; Chengdu



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## 1. Introduction

Since 2010, due to the high-quality evolution of urbanization in China, there has been a notable surge in the urban–rural migrant population. Concurrently, the populations in metropolitan areas have swiftly congregated, and the urban built-up areas have expanded rapidly [1]. The trajectory of urban–rural transformation has become progressively pronounced [2]. This transformative period has continued to drive the evolution of the urban social spatial structure, facilitating the gathering of the migrant population in metropolitan areas. Chengdu's urbanization rate increased by 13.26% from 2010 to 2020, and the migrant population in the metropolitan area increased by 120.27%. With the swift influx of migrant populations into the city, the built-up area of the Chengdu metropolitan region has more than doubled over the past decade.

The influence of metropolitan expansion on the migrant population constituted a pivotal focus in the early stages of urban research. Examining factors at the city level [1,3], such as residential costs [4] and public service levels [5,6] within the metropolitan area, facilitates an analysis of the impact and transmission paths affecting the migrant population. Research has revealed a notable trend where migrant populations gravitate toward settling in higher-level cities [5] boasting developed economies and superior public services [7]. This preference can be attributed to the enhanced employment opportunities and economic income in urbanized cities, which attracts a significant influx of a young labor force and fosters family migration [8]. The spatial variations in the impact of housing costs on the migrant population are evident and influenced by factors such as city level and migration distance [9,10]. Additional studies have corroborated the fact that cities with higher levels of public services, including basic education, medical facilities, and transportation, draw permanent migration from the migrant population [10]. The swift development of intercity and intracity rail transit has played a pivotal role in diminishing spatial distances and costs for the migrant population [9,10]. Amidst urban transformation and development, the enhancement of public services has significantly bolstered the willingness of the migrant population to remain in a particular locale [11,12]. Consequently, scholars have delved into discussions surrounding the social integration and citizenship of the migrant population within the context of urban–rural transformation, adopting a humanistic perspective [13,14]. For instance, some scholars have explored the influencing factors contributing to residential space differentiation, encompassing elements such as housing prices, market dynamics, and policy systems. Such scholars have analyzed the repercussions of social residential space differentiation on landless farmers and migrant populations [15].

Simultaneously, the agglomeration process of migrant populations in metropolitan areas plays a pivotal role in catalyzing the substantial expansion and transformation of these built-up areas. Drawing on the empirical research focused on urban population-influx centers such as Guangdong, Shenzhen, and Shanghai, it becomes evident that the influx of a substantial migrant population has propelled regional expansion and spurred industrial development and upgrading to a significant extent, consequently fostering the transformation and development of urbanization in those regions. Subsequently, with the gradual increase in the proportion of migrant populations in the central and western provinces, coupled with the wave of population return and the eastward industrial transfer, key cities in the central and western regions have experienced rapid development [16]. Consequently, the residential choices of the migrant population are intricately intertwined with the transformation and development of urban built space and social space.

Furthermore, in numerous studies, distinct spatial variations in the correlation between the expansion of metropolitan areas and the migrant population have been established [17–19]. However, the majority of these studies adopt a static single perspective and focus on the meso–macro scale, overlooking the microscale dynamics of metropolitan expansion and the migrant population process [20]. Consequently, there is a gap in the understanding of the spatiotemporal correlation, differentiation, and influence between these two factors during the era of incremental change, which leads to the potential emergence of an isolation paradox. Some studies utilize population and land urbanization rates as quantitative measures to depict the development of population and land [21]. The existing studies have encountered challenges in capturing the dynamic developmental processes and spatiotemporal differentiation patterns within the land and population systems. Therefore, it is crucial to further explore the spatiotemporal correlation between metropolitan expansion and the migrant population, along with the influencing factors, in order to promote the inclusiveness and sustainable development of metropolitan areas.

In the context of the metropolitan networking trend, the expansion of metropolitan areas reflects the growth model of geographical field space, while the migrant population serves as a representation of flow space [22]. The distinction in the correlation pattern between

these two elements signifies the transformation and development of the urban flow field space within the city, as discussed in the characterization of spatiotemporal composites [23]. The existing research has predominantly adopted a one-way perspective and focused on isolated elements [24]. However, recent studies have progressively recognized the bidirectional nature of the influence path between the expansion of metropolitan areas and the migrant population in anticipating potential imbalances or mismatches in the urban transformation and development process [25]. In particular, from the perspective of the coupling of humanism and structuralism, the spatiotemporal correlation and interaction between the expansion of urban areas and the migrant population exhibit a multiscale, multidimensional, and significantly differentiated nature [26].

The urban landscape of Chengdu is gradually transitioning from the traditional center-circle balanced expansion to a more focused expansion toward the south, resulting in a significant transformation of the urban spatial structure [27]. This shift, which has been accompanied by rapid metropolitan expansion and an influx of migrant population, has given rise to challenges such as job–housing problems, spatial separation, and traffic congestion [28]. Consequently, in transformative development, is there a correlation between the metropolitan expansion and the increase in the migrant population in Chengdu? Furthermore, (1) what is the pattern of the correlation? (2) What distinctions exist in the correlation patterns? Ultimately, (3) what mechanisms underlie the differentiation of these correlation patterns? This study aims to address the above-mentioned questions to foster harmonious and sustainable development that integrates both human and environmental aspects, thus providing valuable scientific references and theoretical insights for urban planning and governance. Furthermore, it is anticipated to enhance the efficiency of urban spatial governance, foster the urbanization and residential integration of the migrant population, and offer policy insights for the coordinated development of urban flow field spatial integration, thereby driving the sustainable and inclusive development of metropolitan areas.

## 2. Research Methods and Data Sources

### *2.1. Research Design*

In this research, we initially apply street-scale urban built-up area data and migrant population data covering the period of 2010 to 2020, which enables the characterization of the spatiotemporal pattern of Chengdu's metropolitan area expansion and migrant population. The subsequent analysis delves into the spatiotemporal correlation patterns and differentiation patterns of these two aspects. Factors such as economic development, urban planning, education, and transportation are then selected for further investigation. The MGWR model is employed to analyze the primary influencing factors and the scale of spatiotemporal differentiation in the correlation patterns. In this analysis, the migrant population is calculated as the difference between the permanent population and the registered population, which essentially captures the migrant population within the municipal area [29]. The expansion of the built-up area is represented by the new construction land area during the periods ranging from 2000 to 2010 and from 2010 to 2020. Using the coupling coordination degree (CCD) model, the correlation between metropolitan area expansion and the migrant population is measured, and its spatiotemporal correlation pattern is identified. Furthermore, using the MGWR model facilitates a multiscale attribution analysis of spatiotemporal differentiation and enables an in-depth examination of the processes exerting influence at the street scale. The research framework diagram for this article is illustrated in Figure 1.

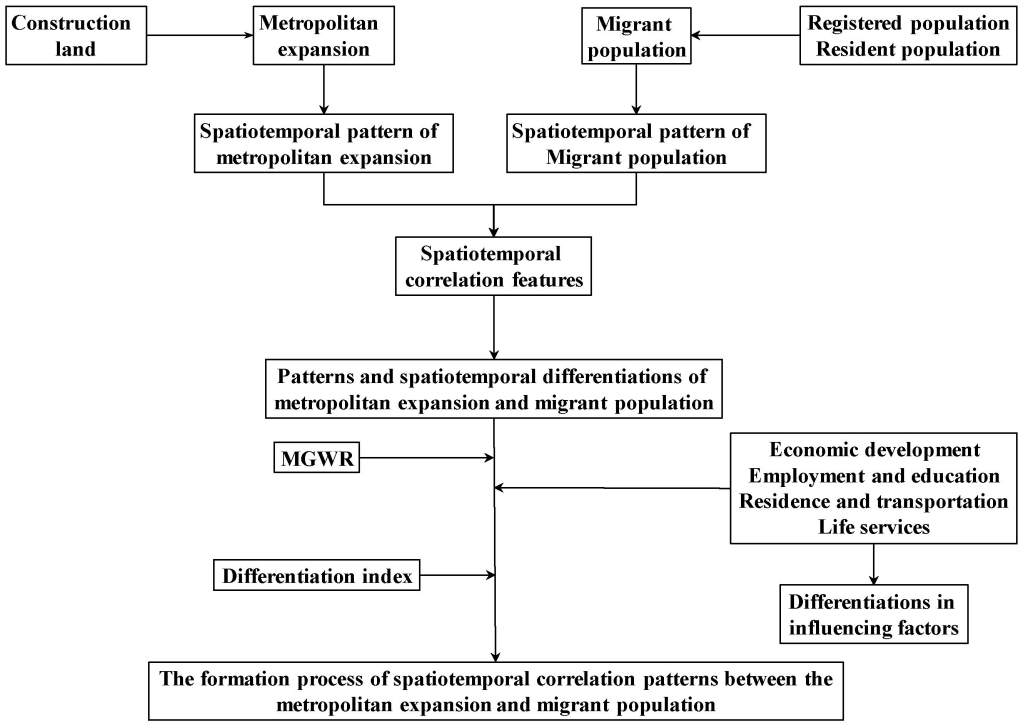


**Figure 1.** Research framework for the spatiotemporal correlation patterns between metropolitan expansion and the migrant population.

### *2.2. Overview of the Study Area*

As the national central city in the western region and the core city of the Chengdu–Chongqing economic circle, Chengdu holds significant importance in the western region. By focusing on the Chengdu metropolitan area as our research domain, we aim to contribute insights into the development and urban space governance of the central and western regions of China, as well as its emerging first-tier cities. Notably, Chengdu has experienced a rapid increase in its migrant population in recent years, propelling the urbanization rate from 65.51% in 2010 to 78.77% in 2020. Specifically, the migrant population in the Chengdu metropolitan area surged from 3.09 million in 2010 to 6.80 million in 2020, representing a substantial increase of 120.27%. Simultaneously, the city's construction land area expanded from 441.82 $km^2$ in 2010 to 909.65 $km^2$ in 2020, doubling in size over the course of a decade. Chengdu's unique natural conditions, historical urban construction, and modern development have collectively shaped a circular urban spatial pattern at the city's center. This distinctive spatial structure provides an opportune context for analyzing the relationship between metropolitan expansion and the migrant population, particularly under the backdrop of differentiated urban development, spatiotemporal differentiation, and various influencing factors. It is noteworthy that the metropolitan area planned by the Chengdu government encompasses the construction scope of the Chengdu urban contiguous area and the Chengdu economic circle, spanning 36 districts and counties, including numerous rural areas. Consequently, this article strategically narrows its focus to the Chengdu metropolitan core area, specifically the central urban area and Tianfu New District, comprising a total of 128 street (township) units. This refined approach is more closely aligned with the essence of a metropolitan area (Figure 2).

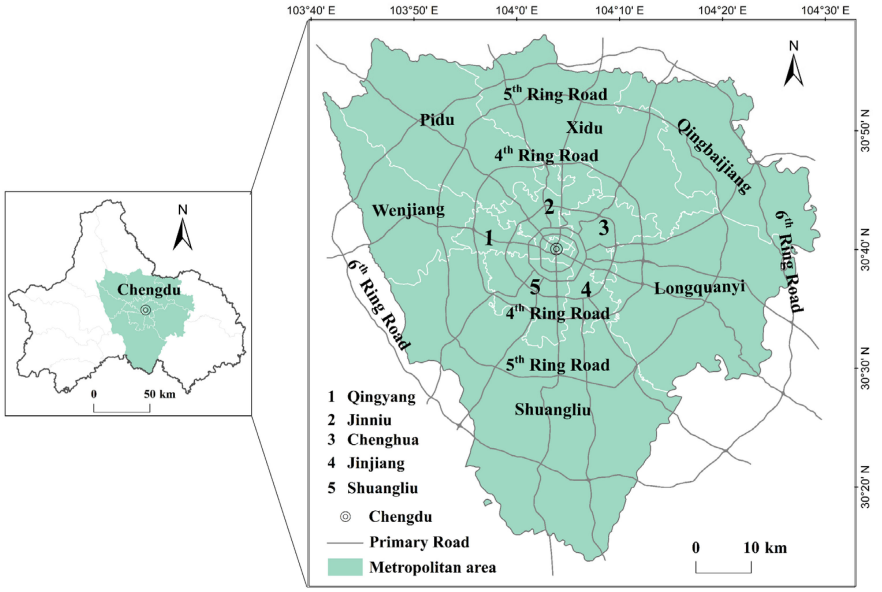


**Figure 2.** Chengdu metropolitan area overview.

### *2.3. Data Source and Processing*

We utilize data representing the expansion of the built-up area during the two distinct periods of 2000–2010 and 2010–2020. These data serve to visually depict the changes and developmental trends of the Chengdu metropolitan area expansion. In this study, a specific emphasis is placed on understanding the dynamics of metropolitan area expansion and population flow during the years of 2010 and 2020. The purpose is to unravel the influencing mechanisms behind the spatiotemporal correlation patterns of populations. Aligned with the relevant studies [30] and considering the regional characteristics of the Chengdu metropolitan area, 8 influencing factors are selected with which to construct a comprehensive index system [9,31]. The temporal aspect and source of various data utilized in this article are detailed in Table 1.

**Table 1.** Research institute data overview.

| Category | Major Categories | Minor Categories | Year | Data Source |
|---|---|---|---|---|
| 1 | Migrant population | - | 2010, 2020 | The Sixth and Seventh Population Censuses and Statistical Yearbooks |
| 2 | Land use data | - | 2000, 2010, 2020 | China 30 m Resolution Land Cover Dataset |
| 3 | Economic growth | GDP | 2010, 2020 (the data for the year 2020 is replaced by the data from 2019) | Resource and Environmental Science and Data Center (https://www.resdc.cn/ (accessed on 3 July 2022)) |
| | | Night lighting | 2010, 2020 | Institute of Tibetan Plateau Research Chinese Academy of Sciences (http://data.tpdc.ac.cn/zh-hans/ (accessed on 3 July 2022)) |
| 4 | Employment and educational situation | Employment opportunities | 2010, 2020 | Gaode map (https://ditu.amap.com/ (accessed on 19 July 2022)) |
| | | Educational resources | 2010, 2020 | |
| 5 | Quality of life services | Life service facilities | 2010, 2020 | |
| 6 | Residential and transportation conditions | Residential quantity | 2010, 2020 | |
| | | Transportation stations | 2010, 2020 | |
| | | Road network density | 2010, 2020 | Resource and Environment Science and Data Center (https://www.resdc.cn/ (accessed on 16 July 2022)) |

The built-up region expansion area is determined by aggregating the new construction land area of each street (township) unit. GDP and nighttime lighting data are derived from zoning statistics at the street (township) unit level. The road network density is represented by the ratio of the total road length in each street unit to the respective street area. The quantities of vector data points, including enterprises, schools, residential areas, bus stops, museums, shopping malls, etc., are individually extracted. Following this, the sum of these quantities is computed for each street (township) unit.

### *2.4. Research Methods*

#### 2.4.1. Coupling Coordination Degree (CCD)

The CCD model serves as a valuable tool for gauging the intensity of interaction and the extent of mutual influence between systems [32]. It is an effective method for analyzing the degree of mutual influence and relationships among different systems. In light of this, the CCD model is used in this study to construct the correlation index between the expansion of built-up areas and the migrant population, thereby scrutinizing their correlation and spatiotemporal heterogeneity. First, the coupling degree between the expansion of built-up areas and the migrant population is computed to determine the degree of correlation between these two systems. Subsequently, the comprehensive coordination index is used to measure the overall coordination between the two factors throughout the evolution process of the system. Finally, the correlation degree index aids in identifying the pattern of correlation that exists between metropolitan area expansion and migrant populations.

$$C = 2 \times \left[ \frac{U \times L}{(U + L)^2} \right]^{\frac{1}{2}} \tag{1}$$

$$T = aU + bL \tag{2}$$

$$D = \sqrt{C \times T} \tag{3}$$

where $C$ is the coupling degree; $T$ is the comprehensive coordination index; $D$ is the correlation index; $U$ and $L$ represent the standardized value of the absolute value of the migrant population and the standardized value of the built-up area expansion index; $a$ and $b$ represent the migrant population. Finally, the weight of each indicator within the metropolitan area expansion system is $a + b = 1$. With reference to the literature and the actual analysis of this article, the expansion of metropolitan areas has equal importance to the migrant population, so the undetermined coefficient is determined as $a = b = 0.5$ [33].

#### 2.4.2. Multiscale Geographically Weighted Regression (MGWR)

Geographically weighted regression (GWR) was introduced by Fotheringham et al., and it utilizes local regression analysis and variable parameter theory [34]. This approach is highly intuitive in detecting the nonstationarity of spatial data. Multiscale Geographically weighted regression (MGWR) is an optimization of the GWR model. By employing a multi-bandwidth method, the use of the MGWR model facilitates the detection of spatiotemporal heterogeneity in correlations, along with the scope and scale of influence [35]. The calculation formula for the MGWR model is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{n} \beta_{bw_j}(u_i, v_i) x_{ij} + \varepsilon_i \tag{4}$$

where $y_i$ is the correlation index for the $i$-th street (township), $(u_i, v_i)$ is the spatial location of the $i$-th street (township) units, $\beta_0(u_i, v_i)$ is the intercept term for the $i$-th street (township), $\beta_{bw_j}(u_i, v_i)$ is the $j$-th regression coefficient for the $i$-th street (township); $bw_j$ is the bandwidth for the $j$-th variable, $x_{ij}$ is the $j$-th independent variable for the $i$-th street (township), and $\varepsilon_i$ is the random error.

2.4.3. Differentiation Index

Given that the regression coefficient may have negative values, it is necessary to transform the data to ensure that all values are positive. Consequently, the maximum–minimum standardization method is applied to achieve linear transformation of the original data, thus creating a new data series [36]. Building upon the calculation of the regression coefficient, a differentiation index is formulated to assess the spatiotemporal differentiation of factors influencing correlation. The formula is as follows:

$$R_j' = \left(R_j - minR_j\right) / \left(maxR_j - minR_j\right) \quad (5)$$

$$C = \sqrt{\sum_{j=1}^{n} \left[\left(R_j / \overline{R_j}\right) - 1\right]^2 / n} \quad (6)$$

where $R_j^{'}$ is the normalized regression coefficients, $maxR_j$ and $minR_j$ are maximum and minimum values of the raw regression coefficients. $C$ is the differentiation index for influencing factors, $\overline{R_j}$ is the mean of standardized regression coefficients, and $n$ is the number of street (township) units.

## 3. Results

### *3.1. Spatiotemporal Patterns of Metropolitan Expansion and Migrant Population in the Chengdu Metropolitan Area*

3.1.1. Spatiotemporal Patterns of Metropolitan Expansion

Figure 3 illustrates the spatiotemporal pattern of built-up area expansion in the Chengdu metropolitan area during the periods of 2000–2010 and 2010–2020. The incremental changes occurring during these two time periods (Figure 3a,b) and the variation range of the increments (Figure 3c) reveal that the growth rates in the traditional central urban areas and outer suburbs are relatively modest. The primary areas undergoing growth are concentrated in the new urban regions between the third and fifth rings, presenting an overall central circle-type spatial structure. In a regional context, the Shuangliu District, which is situated between the Third Ring Road and the Fifth Ring Road in the southern part of the urban area, emerged as a key expansion zone during the period of 2010 to 2020. Over the past decade, the proportion of new construction land in this area relative to the entire urban area increased by 10.23%. While the growth rate in the northern part of the metropolitan area has been slower than that in the south, new areas continue to expand. Notably, the key expansion areas during 2000 to 2020 were concentrated in the northwest of Shuangliu District, the south of Wuhou District, and the west of Longquanyi District in the southern metropolitan area. The pace of built-up area expansion in the central city and outer suburbs of the Chengdu metropolitan area has been slower, creating a discernible slow-fast-slow center-circle structure from the center to the edge. The southern Shuangliu District has experienced particularly rapid metropolitan expansion over the past decade, indicating a clear southward trend. This trend is closely linked to urban spatial development and planning policies. The Tianfu New District, which is located in the southern Shuangliu District, was established in 2014, and it has become the 11th national-level new district in China, and covers an area of 1578 km$^2$. It has significantly contributed to industrial transfer, infrastructure investment, and public service development, thereby driving the substantial southward expansion of the Chengdu metropolitan area. In summary, the expansion of the Chengdu metropolitan area is currently undergoing a phase of rapid growth. The slow expansion area in the central city has expanded notably, the peripheral slow expansion area has contracted, and the expansion frontier of the metropolitan area has gradually extended. Within the spatiotemporal pattern of metropolitan area expansion, the slow-fast-slow center-circle structure from the center to the edge has become more pronounced.

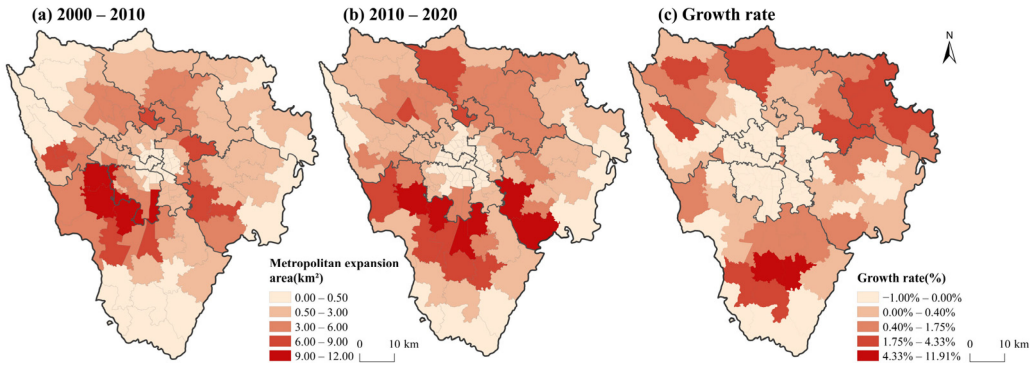


**Figure 3.** The spatiotemporal patterns of metropolitan expansion and growth rate in Chengdu from 2000 to 2020.

### 3.1.2. Spatiotemporal Patterns of Migrant Population

In 2010, a total of 102 streets (townships) in the Chengdu metropolitan area served as net population inflow areas, constituting 79.68% of the total number (Figure 4a). The primary inflow areas were concentrated in southeast Shuangliu District, north Jinniu District, and southeast Pidu District, along with other peripheral urban areas. Conversely, Qingbaijiang District and the agricultural-related streets (townships) in the southern part of Shuangliu District have emerged as the main net population outflow areas. By 2020, the proportion of net population inflow into street (township) units increased by 7.03%, as depicted in Figure 4b. Moreover, the net population outflow area significantly decreased compared to that in 2010, with only 17 peripheral towns exhibiting this characteristic.

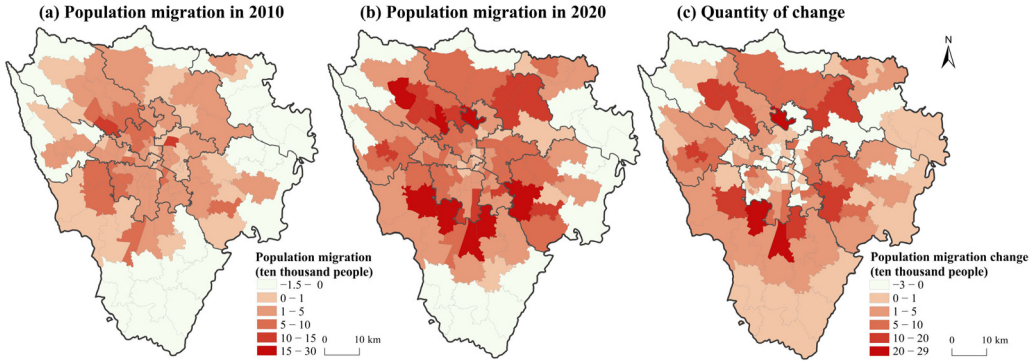


**Figure 4.** The spatiotemporal patterns of migrant population and its changes from 2010 to 2020.

Over the past decade, the migrant population in Chengdu has notably expanded (Figure 4c), with the peripheral streets (townships) transforming from net outflow areas to net inflow areas. This shift indicates that the new migrant population is predominantly concentrated in the new urban areas between the third and fifth ring roads, signifying a continual expansion of the population's living space. From a differentiation pattern perspective, the migrant population exhibited a spatial pattern of decline from the center to the periphery in 2010. By 2020, this pattern had gradually transformed into one characterized by small-scale population agglomeration in the central city, large-scale population agglomerations in the middle ring, and dispersed population areas in the periphery. Additionally, the spatial pattern of the new migrant population during the period of 2010 to 2020 indicates a slowdown in population agglomeration in the central city, with a noticeable trend of population return in the peripheral new cities, particularly in the southern new cities where the population agglomeration trend is most prominent.

### *3.2. Correlation Patterns and Metropolitan Expansion and Migrant Population Models of the Chengdu Metropolitan Area*

#### 3.2.1. Correlation Index between Metropolitan Expansion and Migrant Population

Figure 5 presents the correlation levels between Chengdu's metropolitan area expansion and the migrant population from 2010 to 2020. The average correlation between Chengdu's metropolitan area expansion and the migrant population in 2010 and 2020 was 0.35 and 0.37, respectively. In terms of spatial patterns, the correlation between the two continues to exhibit a central circle spatial pattern. The correlation between the central city and the suburbs beyond the fifth ring remains low, with areas of high correlation primarily distributed in the annular area between the third and fifth rings. Notably, the high-value correlation areas in 2010 were concentrated mainly in the northwestern area of Shuangliu District and the western area of Longquanyi District. By 2020, the scope of such high-value areas had expanded, and the spatial balance had improved, with high-value areas emerging in both the south and north of the ring area between the third and fifth rings. In recent years, the central urban area of Chengdu has continued to experience a population inflow, but the growth of the built-up area has been slow or stagnant, leading to the decoupling of their development. The expansion of the built-up area has lagged behind the development speed of the migrant population, resulting in a relatively low correlation between the two. The agriculture-related streets (townships) in the outer suburbs have undergone a transformation from population-dispersed areas to agglomeration areas, indicating a clear urban–rural transformation trend. However, the increase in the built-up area remains modest, thus contributing to the low correlation between the two. From 2010 to 2020, the overall spatiotemporal correlation between the expansion of the Chengdu metropolitan area and the migrant population has significantly improved. The scope of the central low-value area expanded, the peripheral low-value area contracted, and the middle-ring high correlation area rapidly expanded. The spatial differentiation pattern of the high–low center circles from the center to the edge is gradually apparent, although its spatial anisotropy remains evident.

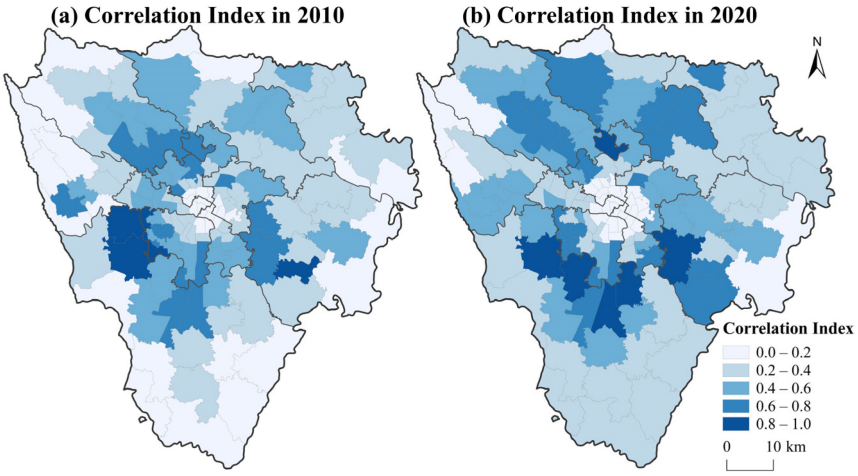


**Figure 5.** The correlation index between metropolitan expansion and migrant population from 2010 to 2020.

#### 3.2.2. Correlation Patterns between the Metropolitan Expansion and Migrant Population

Based on the spatiotemporal patterns of Chengdu's metropolitan area expansion, the migrant population, and the differentiation patterns of their spatiotemporal correlation levels, the Chengdu metropolitan area is categorized into four patterns: the mature development pattern, rapid expansion pattern, urban–rural transformation development pattern, and built-up area expansion advanced pattern (Figure 6). The mature development pattern is primarily situated in the central urban area of Chengdu and characterized by low metropolitan expansion and high population inflow. Over the past decade, this area

has undergone a significant 187.69% increase, following a noticeable expansion trend. The advanced urbanization development of the central city, enriched by high-quality public services and well-developed business and service industries, has rendered it highly attractive to the migrant population. However, due to the relative maturity and stability of its urban planning and the slowed pace of urban construction, this pattern exhibits a lower spatiotemporal correlation between the expansion of the built-up area and the migrant population. The rapid expansion pattern, however, encompasses the areas characterized by both high population inflow and high metropolitan expansion, and undergoing simultaneous rapid development. Predominantly located between the third and fifth rings, there has been a considerable increase in the area for this pattern by 286.98 $km^2$ from 2010 to 2020. The spatial scope of this pattern contracts and then gradually expands. The built-up area in this pattern expands rapidly, primarily driven by a swift population influx of the population. This pattern represents the frontier area of metropolitan expansion, and it exhibits a high level of correlation between the expansion of the built-up area and the migrant population.

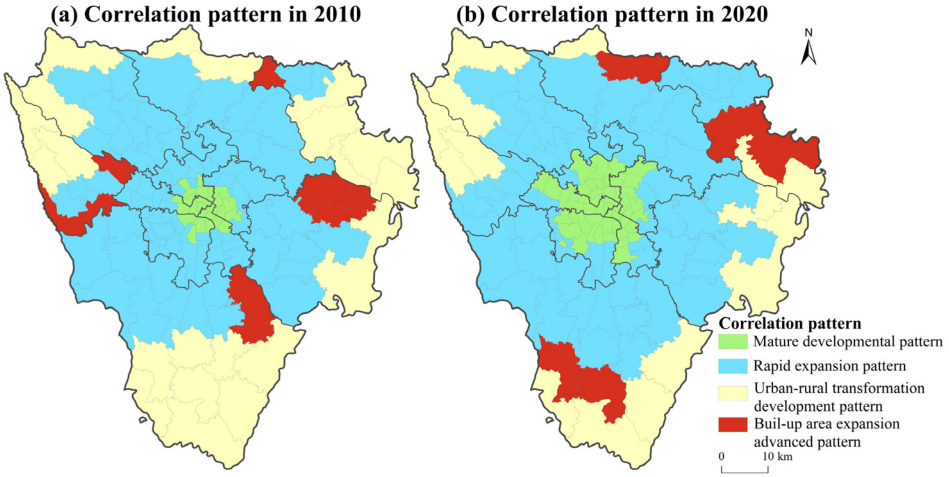


**Figure 6.** The spatiotemporal correlation pattern between metropolitan expansion and the migration population in the Chengdu metropolitan area.

In the outermost area, the dominant pattern is the urban–rural transformation development pattern. This category represents a transitional phase in urban–rural transformation and development. The migrant population gradually shifts toward a net inflow, and there is an emerging trend of population agglomeration. The land use structure is transitioning from predominantly agricultural land to construction land, marking a noticeable transformation in the urban and rural areas. Compared to 2010, the distribution range of this pattern significantly decreased by 32.36%. Most of the associated patterns have transformed into fast-growing types, indicating coordinated development between the expansion of built-up areas in the peripheral regions and the migrant population. This suggests that the urban–rural transformation is gradually reaching completion. The built-up area expansion advanced pattern is sporadically scattered on the urban area's edge. This correlation pattern indicates that urban area expansion is outpacing the population inflow. Over the past decade, the number of street (township) units in this category has decreased from 7 to 5, while the spatial distribution has continued to expand. The rapid expansion of built-up areas is attributed to increased government investment in urban construction. However, due to a lack of urban population agglomeration power in these areas, phenomena such as "ghost cities" and "empty cities" can occur. Notably, from 2010 to 2020, the number of urban–rural transformation and development patterns decreased from 21 to 14. However, five street (township) units transitioned into the built-up area expansion advanced pattern, and only two units transformed into the rapid expansion pattern. This highlights that urban–rural transformation in the Chengdu metropolitan area is primarily driven by land

urbanization, such as urban planning and construction. There is an insufficient migrant population to support transformation, and population urbanization lags behind, which can lead to advanced spatial planning with low urbanization quality.

### *3.3. Influencing Factors of the Correlation Patterns of Metropolitan Expansion and Migrant Population*

All the selected variables in the MGWR model successfully pass the significance test. The adjusted $R^2$ for the correlation between metropolitan area expansion and the migrant population in 2010 and 2020 is 0.62 and 0.69, respectively (Table 2). The sum of the squares of the residuals progressively decreased, indicating an increasing level of fit for the selected model. This suggests that the impact of influencing factors on the spatiotemporal correlation pattern of metropolitan area expansion and the migrant population has significantly improved. However, it is important to note that both the scope and intensity of this influence exhibit both commonalities and spatiotemporal differences.

**Table 2.** MGWR model parameter results.

| Index | | Correlation between Metropolitan Expansion and Migrant Population | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2010 | | | 2020 | | |
| | | Band Width | Mean Coefficient | Correlation Coefficient | Band Width | Mean Coefficient | Correlation Coefficient |
| Economic growth | GDP | 120 | −0.36 (0.44) | −0.067 ** | 75 | −1.59 (0.23) | −0.002 ** |
| | Night lighting | 125 | 0.55 (0.61) | 0.274 ** | 127 | 0.93 (0.69) | 0.360 ** |
| Employment and education | Employment opportunities | 9 | −0.38 (0.62) | 0.230 * | 64 | −0.59 (0.57) | 0.409 ** |
| | Education resources | 18 | 0.48 (0.41) | 0.590 ** | 27 | 0.29 (0.48) | 0.661 ** |
| Residence and transportation | Quantity of residential properties | 81 | 0.01 (0.68) | 0.316 * | 86 | −0.39 (1.08) | 0.532 ** |
| | Transportation stations | 112 | 0.26 (0.85) | 0.222 ** | 117 | 0.78 (1.28) | 0.662 ** |
| | Road network density | 127 | 0.18 (1.13) | −0.394 * | 127 | −0.47 (0.57) | 0.360 ** |
| Lifestyle services | Life service facilities | 121 | −0.14 (0.46) | 0.178 ** | 124 | −0.31 (0.20) | 0.029 * |
| AICc | - | | −109.77 | | | −135.75 | |
| Adjusted R-squared | - | | 0.62 | | | 0.69 | |
| Residual sum of squares | - | | 2.33 | | | 1.71 | |

Note: Numbers in parentheses represent standard errors; * indicates correlation significant at the 0.05 level (two-tailed); ** indicates correlation significant at the 0.01 level (two-tailed).

#### 3.3.1. Influencing Factors on the Spatiotemporal Correlation Patterns of Metropolitan Expansion and Migrant Population

There is a negative correlation between GDP and that between metropolitan area expansion and the migrant population. The impact of GDP on this correlation during the period of 2010 to 2020 gradually diminishes from the center to the periphery (Figures 7a and 8a), exhibiting a more pronounced impact on the mature development pattern (Table 3). On the other hand, the influence of nighttime lights in 2010 and 2020 exhibits a spatial pattern that intensifies from the center to the edge. Nightlights provide the most significant explanatory power for the transformation and development zones on the outer edge of the metropolitan areas (Figures 7b and 8b). The bandwidth of these nightlights consistently exceeds 125, indicating a broad scope of influence and a robust driving effect on the changes in correlation. Consequently, the outer peripheral areas

should prioritize the attraction of population inflow via urban construction, ultimately achieving coordinated development.

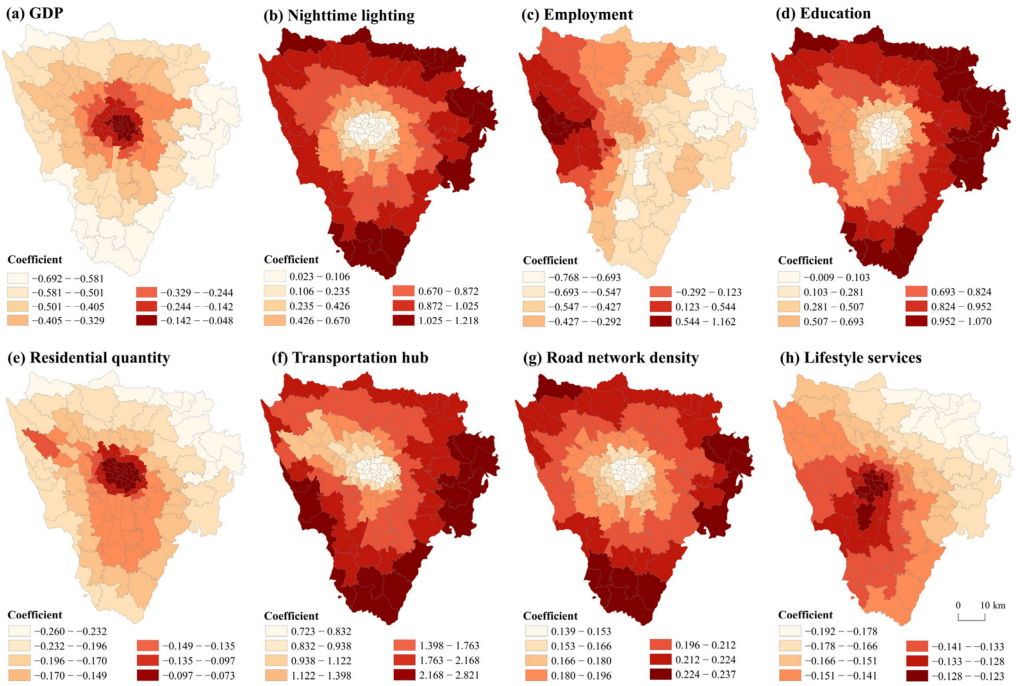


**Figure 7.** The regression coefficients of the influencing variables on the degree of correlation in 2010.

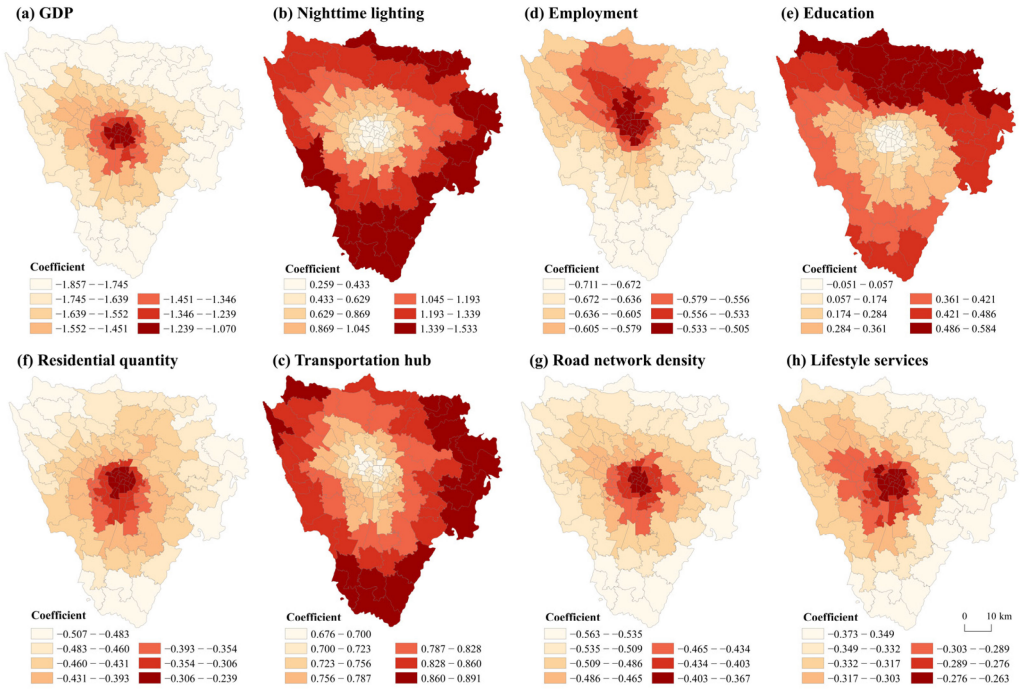


**Figure 8.** The regression coefficients of the influencing variables on the degree of correlation in 2020.

**Table 3.** The main influencing factors of the different correlation patterns.

| Correlation Pattern | Main Influencing Factors | |
|---|---|---|
| | 2010 | 2020 |
| Mature developmental pattern | Night lighting, education resources, transportation stations, road network density | Night lighting, transportation stations |
| Rapid expansion pattern | Transportation stations, road network density, life service facilities | Education resources, transportation stations |
| Urban–rural transformation development pattern | GDP, residential quantity, life service facilities | GDP, employment opportunities, residential quantity, road network density, life service facilities |
| Built-up area expansion advanced pattern | Employment opportunities, transportation stations | Night lighting, education resources, transportation stations |

The bandwidth value indicates that employment opportunities and educational resources have a relatively smaller impact on correlation levels. In 2010, the explanatory power of employment opportunities on the correlation between metropolitan area expansion and the migrant population gradually weakened from west to east. In 2020, the areas with strong explanatory power for employment opportunities were primarily concentrated in the mature development areas (Table 3), with a noticeable northward development trend (Figures 7c and 8c). This trend is influenced by Chengdu's "Northern Reform" policy, which, through the revitalization of cities in the northern part of the metropolitan area, improvements in human settlements and adjustments to industrial structure, has led to the formation of urban renewal demonstration areas and industrial development transformation areas. As a result, the expansion and migrant population development of metropolitan areas tend to progress in a coordinated and orderly manner. The regression coefficients of educational resources in both 2010 and 2020 show a trend of gradually decreasing from the center to the periphery (Figures 7d and 8d). Those areas most strongly influenced by educational resources are primarily concentrated in the urban–rural transformation development areas and coordinated development areas in the east and north. In 2020, there was a stronger influence of educational resources on the expansion of urban–rural transformation development zones and built-up areas in the south. This suggests that educational resources are trending southward, and residential choices are closely linked to the distribution of educational resources, resulting in the formation of new advantageous residential locations.

The influence of the number of residences on the correlation between metropolitan area expansion and the migrant population consistently exhibits a distribution pattern that is high in the center and low in the surrounding areas. The mature development area in the center is significantly impacted by the number of residences (Table 3), and the center of gravity shows a tendency to shift southward (Figures 7e and 8e). The influence of transportation stations on the correlation degree consistently demonstrates a pattern of low in the middle and high on all sides (Figures 7f and 8f), with the most significant impact on the urban–rural transition development areas in the east and south (Table 3). The areas beyond the Fourth Ring Road of the Chengdu metropolitan area have a greater sensitivity to transportation stations. The residential choices of the migrant population are more responsive to transportation stations because of the limited and uneven distribution of transportation stations in peripheral areas. The regression coefficient of road network density in 2010 displayed a differentiation pattern of high, medium, and low, and it was the most influential in explaining the urban–rural transformation development areas in the east and south, as well as some of the advanced metropolitan expansion areas (Table 3). The correlation with road network density in 2020 exhibits a decreasing trend from the center to the surroundings, with a southward development trend (Figures 7g and 8g). In 2010, the influence of living service facilities on the correlation displayed a spatial pattern that decreased from southwest to northeast, with the most prominent impact on the mature development pattern and the rapid expansion pattern in the southwest. In 2020, it presented

a pattern of high correlation in the center and low correlation on the four sides, with a focus on the central mature development area (Figures 7h and 8h).

#### 3.3.2. Differentiations of the Influencing Factors on Correlation Patterns

Table 4 presents the differentiation index of the regression coefficients for each influencing factor on the correlation between metropolitan area expansion and the migrant population. A higher differentiation index indicates stronger differentiation and a weaker balance. The differentiation index of GDP, the number of residences, and the number of employment opportunities have all increased, signifying an augmented uneven impact on the level of correlation. In the central mature development area, which has been significantly influenced by these factors, the correlation index increased by 0.02. This suggests that the unbalanced development of these three factors can potentially enhance the level of correlation. Therefore, policy planning should adhere to the "mid-quality" and "southern expansion" guidelines, decentralize urban functions from the central city, adjust the industrial layouts, and shape a new form of metropolitan development. The impact of nighttime lights and traffic stations on urban–rural transition development areas primarily occurs at the periphery. The correlation degree of this pattern of area has slightly increased. Over the past decade, the differentiation of the impact of nighttime lighting on correlation has increased, while the differentiation of traffic stations has weakened. This indicates that a southward development orientation is conducive to enhancing connectivity and promoting the balance of transportation and other public service facilities, which contributes to the coordinated and balanced development of metropolitan area expansion and the migrant population. The differentiation index of the impact of educational resources on relevance is significantly reduced, indicating an improvement in the balance of educational resources. The rapid development pattern is mainly affected by educational resources, and the average value of the relevance index for this pattern increased by 0.07 in 2020. Hence, enhancing the balance of educational resources increases the level of relevance. In 2020, the road network density and living service facilities primarily affected the correlation of the mature development areas, and the differentiation index of both decreased. Therefore, improving the balance of the road network density and the layout of the living service facilities will help enhance the correlation degree in this area pattern.

**Table 4.** Differentiation index of the regression coefficients for each influencing factors.

| Index | | DI Value | | |
|---|---|---|---|---|
| | | 2010 | 2020 | Change Value |
| Economic growth | GDP | 0.28 | 0.40 | 0.12 |
| | Night lighting | 0.30 | 0.54 | 0.24 |
| Employment and education | Employment opportunities | 0.32 | 0.52 | 0.20 |
| | Education resources | 0.38 | 0.25 | −0.13 |
| Housing and transportation | Quantity of residential properties | 0.26 | 0.47 | 0.21 |
| | Transportation stations | 0.31 | 0.26 | −0.05 |
| | Road network density | 0.47 | 0.37 | −0.10 |
| Daily life services | Life service facilities | 0.22 | 0.14 | −0.08 |

In summary, the differentiation of influencing factors both increased and decreased from 2010 to 2020, with an overall trend toward greater prominence. Notably, factors such as economic development, employment, and housing exhibited significant increases in differentiation, highlighting the fact that spatial differences in economic growth, employment opportunities, and residential locations have intensified, contributing to a growing imbalance in internal development among cities. Conversely, the differentiation of factors such as educational resources, transportation stations, and road network density has weakened. Despite the relatively small change values, this reflects a trend toward balanced development led by government-initiated public services in the expansion of metropolitan

areas, mitigating, to some extent, the regional expansion and spatial differentiation of the migrant population.

## 4. Discussion and Conclusions

### *4.1. Discussion*

#### 4.1.1. The Process of Forming the Mechanism of Differential Correlation Features

In the context of rapid urbanization in the major cities in China, given the dual influence of the government and the market, a complex spatiotemporal correlation pattern has significantly impacted the metropolitan expansion and migrant population. If the development of residential and entertainment facilities, and other market-led aspects does not align soon with government-led urban planning, it may result in an imbalance between metropolitan expansion and migrant population, hindering the coordinated and sustainable development of the city [37,38]. The findings from the Chengdu case analysis, using the multiscale geographically weighted regression model, validate the claim that the growing differentiation in economic growth, employment opportunities, and residential markets has heightened the complexity of the spatiotemporal correlation pattern between metropolitan area expansion and the migrant population. Simultaneously, the development of public services enhanced the correlation between these two aspects to some extent.

Under the socialist market economic system, the expansion of metropolitan areas is primarily a planning and construction endeavor that is led by the government. In contrast, the population migration is considered a market-driven phenomenon that reflects individual decisions under the freedom of migration [38]. The spatiotemporal correlation between these two aspects can be viewed as a multiagent trade-off game between government and market forces in the city's transformation and development [39,40]. This has resulted in an imbalance in the spatial distribution of educational resources, employment opportunities, public transportation, and other resources. Therefore, promoting the coordinated and balanced development of the correlation between the metropolitan expansion and migrant population is conducive to promoting the spatial equity of public resources, thereby enhancing spatial justice. In the era of networked urban agglomerations, the correlation between the expansion of built-up areas and the migrant population serves as an indicator of the spatial and temporal composition of urban flow field space during urban transformation and development [40]. Therefore, alleviating spatial differentiation between the expansion of metropolitan areas and the influx of migrant population, promoting the coordinated and sustainable development of both, can not only enhance the synergy between government and market behavior, but also improve urban spatial efficiency and equity [41]. In metropolitan development, coordinated progress often emerges from the competition and collaboration among various entities. The advanced expansion of built-up areas is a key indicator that a city is entering the structuralist development stage. At this stage, the development of cities is dominated by the government. The metropolitan area is rapidly expanding outward in a "pancake" manner. However, the market-oriented migrant population struggle to align themselves with government policies and planning in a timely manner, leading to a disconnect between government and market behaviors and resulting in inefficient urban development space [37]. Over the past decade, 70% of Chengdu's forward areas in built-up area expansion have transitioned into fast-growing areas. This shift signifies that, as the metropolitan development stage evolves, the market-oriented migrant population will gradually adapt to government-led metropolitan expansion in the future, which effectively enhances the spatial efficiency in urban development. In the future, with the balanced development of educational resources and living service facilities, the coupling coordination between the expansion of metropolitan areas and migrant population will increase.

#### 4.1.2. Policy Inspiration for Empirical Research in the Chengdu Metropolitan Area

The development process of Chinese cities is very different from that of Western cities, so it is difficult to fully explain the urbanization issues in China using existing Western

urban theories and models. Therefore, through exploring the spatiotemporal correlation pattern and influencing factors of metropolitan expansion and mobile population, and proposing optimization suggestions tailored to local conditions, we can provide a scientific reference with Chinese characteristics to enhance the refined governance of urban space in metropolitan areas and offer new ideas for the high-quality and inclusive development of urbanization in other cities [40]. Viewed through the lenses of humanism and structuralism [26], the urban development stages can be categorized into a period of rapid expansion driven by structuralism, followed by a transitional phase of adjustment and enhancement, ultimately culminating in a phase characterized by new people-oriented urbanization development [42,43] (Figure 9). The current metropolitan area of Chengdu is in the urbanization stage, and in the future, it may go through the process of urbanization, suburbanization, and re-urbanization [44,45]. Presently, the majority of areas within the Chengdu metropolitan region are in the transitional stage of adjustment and enhancement. Only the central mature development area has progressively shifted toward the phase of new people-oriented urbanization. As a whole, the Chengdu metropolitan area is still navigating through the transitional phase, reflecting the process and stages of the transformation of the urban development model from structuralism to humanism.

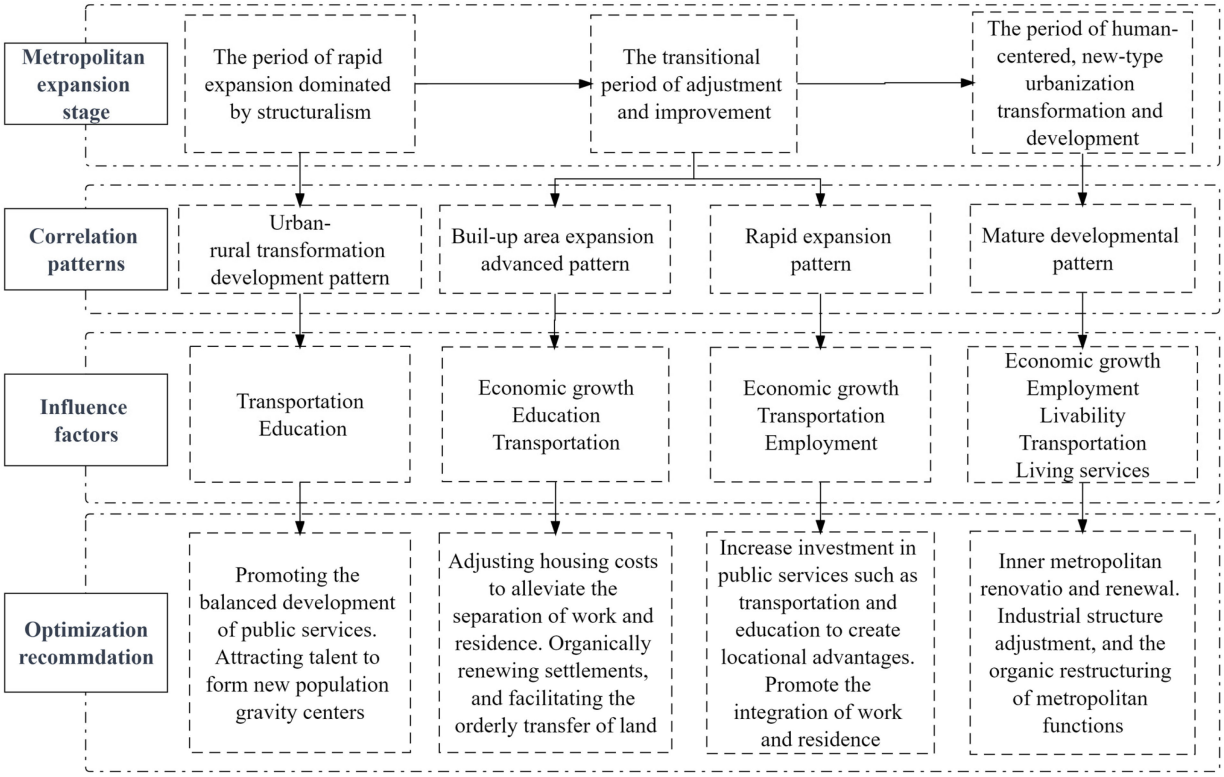


**Figure 9.** The correlation among the expansion of metropolitan areas, the migrant population patterns and optimization paths.

Tailoring refined urban governance according to the distinctive stages of urban growth is essential (Figure 9). Mature cities undergoing development require the advancement represented by old city transformations, comprehensive urban renewal, and the facilitation of a harmonious urban functional order. Those areas experiencing rapid growth should shift toward a humanistic urban development stage, emphasize people-centric strategies, elevate public services such as education, transportation, and living environments, fostering the integration of work and residence, and establish conditions for the organic connection of these spaces. Uncontrolled metropolitan expansion reflects an imbalance between urban growth and the evolution of the migrant population. Hence, not only vigorously developing physical urban space and driving economic growth but also augmenting investments

in public infrastructure and services, regulating housing costs, and mitigating the separation between work and residence is imperative. Simultaneously promoting the organic revitalization of settlements and the systematic transfer of land assures a swift adjustment of the migrant population to the urban spatial structure's transformation and development being driven by spatial expansion, thus expediting the transition toward a novel people-oriented urbanization model. The urban–rural transformation and development model pertains to the transition period between structuralism and humanistic development models. Facilitating the balanced development of public services, implementing measures to attract talent, strategically deploying emerging industries, and establishing new population gravity centers are essential components for fortifying the foundation of the urban–rural transformation and development model, thereby creating favorable conditions for the rapid transformation of growth patterns.

### *4.2. Conclusions and Insights*

Through analyzing the construction land area and migrant population data for each street (township) in the Chengdu metropolitan area, we delve into the spatiotemporal patterns and correlation patterns of metropolitan area expansion and migrant population in this study. Relevant variables such as the economy, residence, employment, and transportation were selected to elucidate the influencing factors on the spatiotemporal correlation pattern of metropolitan area expansion and migrant population in 2010 and 2020. The application of MGWR provides insights into the dynamic process behind the formation of this pattern. The key findings and insights are outlined below:

(1) From 2010 to 2020, the built-up space of the Chengdu metropolitan area doubled, and the southward expansion trend was prominent; during the same period, the migrant population showed a slowing trend regarding the agglomeration of old cities and an accelerating trend regarding the agglomeration of new cities, and the circle-type balanced expansion transitioned to southward focused expansion. The spatiotemporal correlation between the expansion of metropolitan areas and the migrant population in the past 10 years has exhibited a low-high-low center–periphery circle pattern, and can be divided into a mature development pattern, rapid expansion pattern, urban–rural transformation development pattern, and built-up area expansion ahead of schedule pattern.

(2) From 2010 to 2020, the influencing factors of the spatial and temporal correlation between metropolitan area expansion and the migrant population showed a center-circle pattern. Among them, the influence of GDP, housing quantity, employment, road network and life services decreased from the inside to the outside, while the influence of educational resources and transportation stations increased from the inside to the outside, and they all exhibit a southward trend.

(3) The increasing differentiation of economic growth, employment opportunities, and residential markets has intensified the differentiation of the spatiotemporal correlation pattern between metropolitan area expansion and migrant population, while the balanced development of public services, such as education and transportation, has alleviated this spatiotemporal differentiation to some extent. The mature development pattern is mainly affected by the increased differentiation of economic development and residential space, while the increased balance of educational resources weakens the differentiation of the fast-growing spatiotemporal correlation pattern. The enhanced differentiation of economic growth and the balance of public transportation exert negative impacts on the spatiotemporal relationship of this pattern of area. The complex differentiation of the correlation pattern exerts a strong shaping effect. The correlation pattern of the advanced expansion of built-up areas is increasingly affected by education and transportation.

(4) The ongoing urban spatial transformation contributes to a more intricate and varied spatiotemporal correlation pattern between metropolitan area expansion and the migrant population. Chengdu is in a transitional phase, progressing from the rapid

expansion characteristic of structuralism to the emerging era of people-centric urbanization and displaying a discernible staged and center–periphery circle pattern. In essence, the evolution of the spatiotemporal correlation pattern reflects the intricate interplay and negotiations between governmental and market forces. Consequently, the judicious planning of industrial and public service layouts can implement these strategies can elevate the standard of human-oriented urban spatial governance, achieve coordinated and balanced development between built-up and residential spaces, and advance the high-quality, sustainable, and inclusive development of metropolitan areas.

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