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Has Rural Public Services Weakened Population Migration in the Sichuan–Chongqing Region? Spatiotemporal Association Patterns and Their Influencing Factors

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Abstract: The association between rural public services (RPSs) and population migration (PM) has become a key aspect of rapid urbanization in developing countries and an important breakthrough for improving rural–urban relations. An in-depth analysis of the heterogeneity of the weakening effect of RPSs on PM at different transformation phases and the internal mechanism of the evolution of association patterns driven by RPSs and PM helps to ensure better co-ordinated urban and rural development. This paper establishes an interactive analysis framework for measuring the spatiotemporal association and regional differences between RPSs and PM in the Sichuan–Chongqing region (SCR), and reveals the influence mechanism by employing multiscale geographically weighted regression (MGWR). The results indicate that the association rapidly increased with clear spatial heterogeneity across topographic units and the weakening effect of RPSs on PM begin to diverge during the urban–rural transition. The natural, economic, social, and urban–rural disparity factors in terms of the association exhibit significant spatial variability. In mountainous areas, where topography dominates, RPSs fail to effectively weaken rural migration. However, in the plain areas, urbanization is the main driver of urban–rural transition, and the adaptive upgrading and transformation of RPSs has made their weakening effect stronger, thus alleviating rural exodus and increasing population concentration. All these findings show that differentiated optimization strategies adhering to the association trends should be proposed for a deeper integration of rural revitalization and new urbanization in the SCR.

Keywords: rural public services; population migration; spatiotemporal association patterns; multiscale geographically weighted regression; Sichuan–Chongqing region

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1. Introduction

Since 2010, China's migrant population has increased rapidly, with an average annual growth rate of 6.97%. The proportion of rural–urban migration has further climbed, with rapid urbanization continuously attracting rural, and small- and medium-sized town populations to cluster in the central (core) cities, and the trend toward the urban–rural transition of the population has become prominent. From 2010 to 2020, the urban population increased by 236.42 million, while the rural population decreased by 164.36 million, and the urban population grew by 14.21% [1]. Population migration is the result of the combined effects of natural, human, and economic factors in different spatial and temporal dimensions [2]. In essence, as a manifestation of resource flows and factor reorganization in the process of urban–rural transformation, it reflects the regional differences in the evolution of urban–rural relations. One important reason for rural–urban migration can be attributed to the uneven development of public services in urban and rural areas. Most of the population flows into cities and towns in one direction, while the trend of

rural population return is weak. As the main element of rural revitalization, the quantity, structure, and flow direction of the population are all related to the realization of rural revitalization goals, so rural public services are closely interrelated with rural development. Undoubtedly, the upgrading of rural public services has become an important driving force for retaining the rural population and realizing rural revitalization, as well as an important link in the co-ordination of urban and rural development. At present, the strategies of new-type urbanization and rural revitalization run in parallel [3], and the deep integration of the two has become the key to promoting the formation of new urban–rural relations and realizing the high-quality development of urban and rural areas in the new era.

Given the structural transformation of migration and the increase in individual demand for quality public services, the migration decision-making process is characterized by a new trend; that is, the driving effect of traditional economic factors is weakened [4], while the effect of noneconomic factors (public services, urban and rural environment, social network, etc.) is enhanced. In particular, the importance of the public service level of inflow areas in attracting people is becoming increasingly evident, and the spatial difference in public services between areas forms a "potential energy" that further drives migration [5], especially between urban and rural areas. Population migration is a key element in reshaping urban–rural relations, leading to the effective integration and optimal allocation of labor resources between urban and rural areas [6]. Public services play an important regulatory role in influencing population migration, and the spatial equilibrium and level rationality of their distribution are related to whether they can effectively promote urban and rural areas to enter a new stage of functional complementarity, social integration, and co-ordinated development [7]. However, the rapid urbanization that China has undergone since the reform and opening-up of the country has highlighted the special characteristics of rural areas [8]. The current trend of rural–urban migration presents a growing concern, as the depletion of the rural population poses a pressing challenge to achieving sustainable development in the middle and later stages of urbanization. The spatial feedback between the mismatch or lack of public services caused by rural decline and rural migration profoundly affects the quality of regional development. China's urban–rural transformation presents a complex overlap of obvious geographical differences and multistage development logic [9]. The traditional view that rural public services are effective in weakening rural migration and promoting population clustering is moot and has become a proposition to be further freshly examined [10]. In this context, rural public services and population migration have emerged as key variables in this dynamic framework of rural reconstruction and rural–urban transitions. Based on the adaptation linkages of rural revitalization and urbanization, chain-type changes and adaptation processes between rural public services and population migration were demonstrated [11,12]. The question that must therefore be answered is whether the development of rural public services has weakened population migration and, if so, whether the relationship is global in effect. Accordingly, exploring spatiotemporal association patterns between rural public services (RPSs) and population migration (PM) and analyzing the variation characteristics, consistency, and co-ordination of the interaction between the two has become an important research topic to promote sustainable population migration and urban–rural transformation.

2. Literature Review

Domestic and international studies on public services focus on the comprehensive evaluation or single measurement of public services, analyzing the difference or efficiency of regional public service supply from diverse dimensions and perspectives, designing single or comprehensive social public service measurement indicators, examining the accessibility of a single category of public services and the equalization of public services in large-scale areas [13,14], and mostly concentrating on urban public services. Some studies focusing on rural public services believe that the pursuit of basic public service conditions in rural areas that are homogeneous with those in cities can provide an external impetus for rural development and attract the inflow of rural elements to achieve integrated urban–

rural development by narrowing the gap between urban and rural public services [15,16]. With the deepening of public service theory, the exploration of public services has gradually shifted to the study of multisystem associations and the in-depth analysis of the spatial and temporal spreading of synergistic relationships with other subsystems, such as the regional economy, urbanization, and poverty [17–19]. Some scholars have measured the degree of association between population urbanization and basic public services at the national or provincial scale, but the indicators and evaluation models constructed are still centered on urban or integrated urban–rural development, and thus it is insufficient to reflect the various aspects of rural public services due to the disparity between urban and rural areas [20]. The research on rural public services is limited to a preliminary evaluation of their spatial distribution patterns, quality characteristics, and accessibility [21,22].

The population migration of China is undergoing a profound transformation in line with the rapid development of the economy, and domestic scholars have conducted extensive discussions on the evolution of the spatial pattern, driving mechanism, and economic effects of population migration on the basis of Western population migration theories [23,24]. Some studies regard the evolution of migrant population patterns as a manifestation of China's urbanization and urban–rural transition, arguing that the objective development differences between urban and rural areas are the main reason for the formation of the spatially uneven process of population migration and that there are marked discrepancies in the mechanisms affecting the distribution of the migrant population at different stages of urban and rural development [25]. Since the beginning of the 21st century, the impact of economic growth and industrialization on population migration has faded, and the role of public services, environmental resources, and other factors has begun to emerge [26]. The motivation for population migration has gradually changed to a decision to balance the pursuit of high-quality public services with diversified needs [27]. The provision of regional public services, with health care and education as the core, has become an important incentive for people to move [28]. Most of the abovementioned studies have discussed the issue of public services as one of the factors influencing population migration and concluded that public services are an essential local factor influencing the self-selection and decision making of the migrant population, indicating that the gap between urban and rural public services influences rural–urban migration. However, the current implementation of the rural revitalization strategy has put RPSs into a dynamic process of continuous development, so it is more reasonable to place the two on an equal status, examine the level of association and degree of co-ordination between them in a dynamic context, and verify whether RPSs still act as a unidirectional driver in the spatial process of population migration.

In summary, although public service and rural–urban migration have been of great concern to the academic community, most studies have focused on only one aspect, with a relatively single-entry point (Table 1). Few studies have concentrated on the two-way influence between RPSs and PM, and there is a dearth of analysis of the dynamic association with spatial processes of population migration. Most studies only analyze the spatial matching between regional public services and population scale based on life-circle theory from a static perspective [29] or measure the coupling degree of public services in conjunction with micro features, such as population structure [30], and pay less attention to intraregional differentiations; that is, there is little research on the specific spatial association paths and heterogeneity characteristics of public services and population migration, and even less attention is given to the southwest region, which has a diverse topography, significant urban–rural differences, typical population migration, and an urgent need for urban–rural integration.

Table 1. Representative views on rural public services and population migration.

	Research Content	Principal Author	Main Conclusions
The impact of rural public services on population migration	Public services accessibility and population migration options	Zhang et al. (2020) and Firmino Costa da Silva et al. (2017) [5,31]	The importance of the public service level of inflow areas in attracting people is becoming increasingly evident, and spatial differences in public services between areas form a "potential energy" that further drives migration, especially between urban and rural areas.
	Spatial–temporal evolution of rural migration and its mechanism	Guo et al. (2020) and Alamá-Sabater et al. (2019) [32,33]	Rural migration is the result of a combination of the natural environment, the humanities, and the economy, which is a social phenomenon triggered by the imbalance of regional factors and resources. Currently, personal and family factors have become the direct drivers of rural exodus, and rural public services have an important influence on migration trade-offs and decisions.
	Rural public service provision and urban–rural integration	Zhang and Wu (2017) and Li (2018) [34,35]	Rural public services are effective in weakening rural migration and promoting population clustering for rural–urban integration. Innovative rural public service provision can be a positive, transformative force in rural reconstruction.
	Rural public service configuration from a dynamic development perspective	Gao et al. (2023) and Li (2023) [36,37]	The construction of rural public services in China has experienced a transformation from "increasing quantity" to "improving quality" under combined forces. In addition, the relevant research has also gradually shifted to a people-oriented focus, and population structure and migration are incorporated into the model to complete the pattern study.
The impact of population migration on rural public services	Heterogeneity of rural public services in mountainous areas	Wan and Yang (2020) [38]	Compared with urban areas or rural areas in the urban periphery, most rural areas in mountains are featured with a decreasing population and scattered settlements. The heterogeneity of rural spaces in mountainous areas leads to a heterogeneous population and social structures, and poses many challenges to the equalization of public services.
	Rural vulnerability, migration, and relocation in mountain areas	Chen et al. (2021) [39]	Rural migration has a mixed impact on mountain societies. The information and skills brought back by migrants will make rural society progress; however, the mass exodus of people will lead to a shortage of labor resources in rural areas, the development of public services will be hindered, and the aging of rural subjects accumulated by various factors will have a great negative impact on rural development.

Table 1. *Cont.*

	Research Content	Principal Author	Main Conclusions
The association between rural public services and population migration	Population urbanization dilemma and public service supply	Wu (2017) and Zhao et al. (2022) [40,41]	In China, the new urbanization corresponds to population urbanization, which is based on urban–rural integration, and there is a strong coupling association between population urbanization and the equalization of public services. The root cause of the relative lag in population urbanization was the inadequacy or lack of public services, and rural public services were one of the important aspects.

To that end, (1) this study intends to develop an improved research framework for characterizing spatiotemporal association patterns and differentiation in diversified terrain areas; (2) the spatial variability of factors influencing spatiotemporal association patterns is then detected and identified based on multiscale geographically weighted regression; and (3) differentiated optimization strategies are proposed under the influence mechanism of spatiotemporal association patterns for the scientific planning of urban and rural development systems.

3. Methods and Data

3.1. Study Area

The Sichuan–Chongqing region (SCR) is in the transition zone from the Tibetan Plateau to the middle and lower reaches of the Yangtze River plain, with significant differences in regional topography (Figure 1), and is one of the typical population outflow areas in China. The total population outflow scale of this region reached 12 million in 2010, accounting for approximately 11.2% of the household registered population, and the diverse topographic environment has led to significant differentiation in the spatial structure and urban–rural transition stages of population migration within it. In recent years, the total GDP of SCR has steadily increased as a national share. As an important growth pole, SCR has emerged as a driving force for the high-quality development of the country, and it is in a new stage of socioeconomic development. SCR is also a national pilot area for urban–rural integration, while the twin cities economic circle of the Chengdu–Chongqing region and the rural revitalization strategy have further promoted urban–rural transformation, with the urban–rural dual structure characteristics gradually weakening, the construction of public services making great progress, and the characteristics of population migration obviously changing. The strategic position of SCR is prominent, and its urban and rural elemental characteristics and transformational development stage are typical in Southwest China. Therefore, choosing SCR as the study area, this paper adopts townships and streets to distinguish between urban and rural areas and takes districts and counties as the main research units to quantitatively analyze spatiotemporal association patterns between RPSs and PM and the variation in their influencing factors. The findings may provide some policy implications for rural revitalization and integrated urban–rural development in SCR.

3.2. Study Design

In this study (Figure 2), POI data reflecting reality, complete types of business, and high location accuracy are selected for kernel density analysis and combined with corresponding weights to construct a comprehensive development index to measure the level of RPSs [42]. Taking the population outflow as a reference, the difference between registered and resident populations to characterize the scale of migration is used, with positive values being outflow areas and negative values being inflow areas, thus distinguishing different types of migration areas. Using the coupling co-ordination degree model, the association between RPSs and PM is calculated with the absolute value of the population migration scale and

the comprehensive development index of rural public services. The differentiation index is calculated to compare the spatial variability in the degree of association of districts and counties in different years and different terrain types, i.e., to analyze their spatial variation trends in relation to the transitional characteristics of SCR. Finally, based on multiscale geographically weighted regression analysis, the influencing factors and scale differences of the spatiotemporal association between RPSs and PM are analyzed, obtaining the influence mechanism.

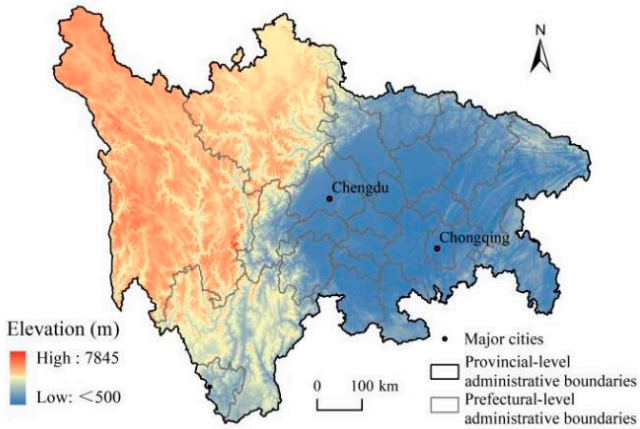


Figure 1. Topography and the main cities in SCR.

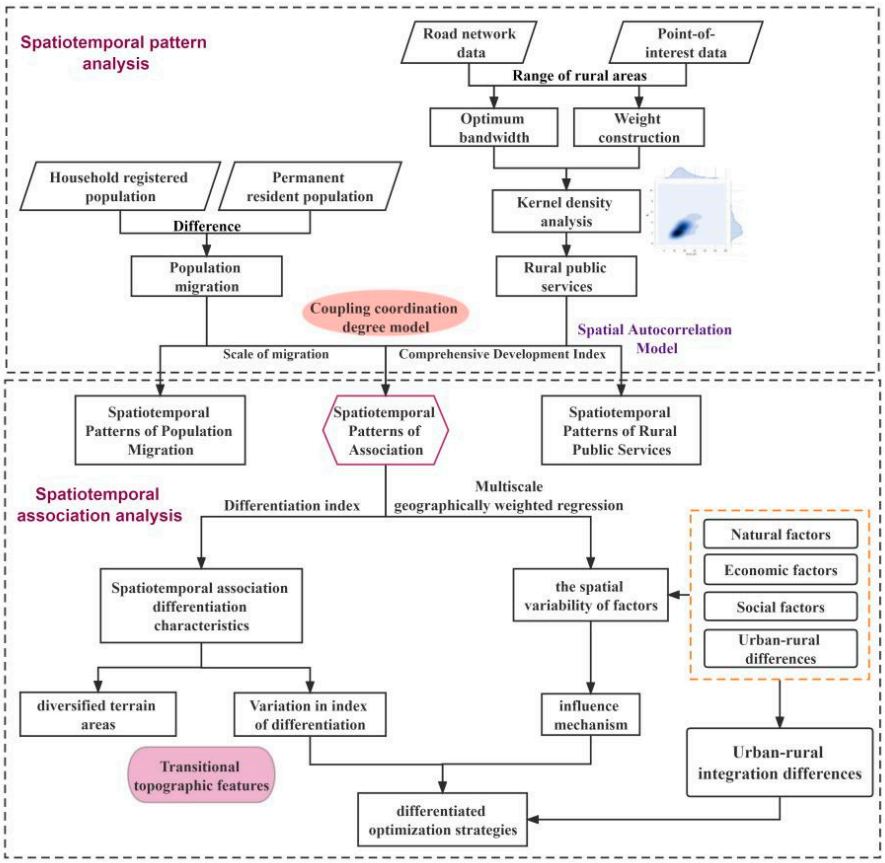


Figure 2. Technology roadmap.

3.3. Data Source and Processing

The terrain data (digital elevation model, DEM), administrative division data, and road network data are from the Resource and Environment Data Cloud Platform (http://www.resdc.cn/ (18 June 2022)). The POI data come from Gaudet Map. Based on the classification

standards and guidelines of public infrastructure, considering the characteristics of RPSs, and taking into account relevant studies [43,44], the data are re-merged into two hierarchies and ten categories after cleaning (Table 2). In addition, the calculated road network density is used to represent the basic traffic service, and thus is divided into highway, national road, provincial road, county road, township road, and substandard road according to road grade, with weights of 0.3, 0.2, 0.16, 0.14, 0.15, and 0.05, respectively [45]. The household registered and permanent resident population data are derived from China's sixth and seventh censuses, while other indicator data employed in this research are collected from statistical yearbooks and bulletins in Sichuan and Chongqing from 2010 to 2020 and included statistics on population income, GDP per capita, and rural electricity consumption. In determining the spatial scope of the evaluation subject, the rural area boundaries of the other two years are obtained by referring to the 2020 administrative boundaries at the township level and making backward comparisons based on the Compendium of Administrative Divisions of the Townships of the People's Republic of China.

Table 2. The evaluation indicator system for RPSs in SCR.

Hierarchy System	Major Categories	Minor Categories	Weight
Basic public services	Basic transportation services	Calculated using road network density	0.147
	Basic medical services	Health center, clinic, and pharmacy	0.262
	Basic education services	Secondary school, primary school, and kindergarten	0.114
	Life services	Post office, bank, laundry, funeral facility, etc.	0.062
	Catering services	Restaurant, teahouse, dessert shop, cold drink shop, etc.	0.082
	Shopping services	Shopping mall, supermarket, specialty shop, etc.	0.069
Advanced public services	Cultural and sports services	Library, cinema, sports hall, training institute, etc.	0.093
	Tourism and leisure services	Travel agency, hotel, scenic spot, holiday resort, etc.	0.081
	Transport and travel services	Service area, car repair, petrol station, coach station, etc.	0.090
	Health care services	General hospital, specialist hospital, emergency center, etc.	

3.4. Research Methods

3.4.1. The Improved CRITIC Entropy Method

The CRITIC entropy method constructs relatively objective indicator weights by determining the strength of comparison and the magnitude of correlation between evaluation indicators. This study is based on the improved CRITIC method for calculating the weights of different types of public services; the mean and correlation coefficients are used to calculate the weight values, with the normalized mean indicating the intensity of the spatial distribution of public services and the correlation coefficient indicating the association of their spatial distribution [46,47]. We multiply the weight value with the kernel density value to obtain the comprehensive development index of RPSs, and the specific formula is as follows:

$$S_i = \sum_{n=1}^{m} (V_{ni} \times w_n), w_n = \frac{V_n \sum_{m=1}^{m} \beta_{mn}}{\sum_{m=1}^{m} \left(V_n \sum_{m=1}^{m} \beta_{mn} \right)} \quad (1)$$

In Equation (1), S_i is the value of the comprehensive development index of the i-th pixel. V_n is the mean value of the pixels in the n-th layer, β_{mn} is the correlation coefficient

between m and n layers, V_{ni} is the value of the i-th pixel in the n-th layer, and w_n is the weight value of the n-th layer.

3.4.2. Coupling Co-Ordination Degree Model

The coupling co-ordination degree model can provide a thorough measurement of the level of co-ordination and development between systems, which is conducive to the overall evaluation of the study area and the balanced perception of the study object. This study uses an improved coupling co-ordination degree model to measure the spatiotemporal association patterns and differentiation characteristics of RPSs and PM in SCR. The model increases the degree of distinction of the coupling degree C because of the original one [48], and the resulting association degree D can more reasonably characterize the co-ordination relationship and development level between regional systems. The calculation formula is as follows:

$$C = \sqrt{[1 - (U_2 - U_1)] \times \frac{U_1}{U_2}}, D = \sqrt{C \times T}, T = \alpha_1 U_1 + \alpha_2 U_2 \quad (2)$$

In Equation (2), U_1 and U_2 are the normalized comprehensive index values of the two systems in each district and county, respectively, where U_{max} is U_2. D is the association degree of the two systems, taking values in the range of [0, 1], and the higher the value, the better the overall effectiveness and synergistic effect of the system. C is the coupling degree, and T is the comprehensive co-ordination index, reflecting the overall co-ordination effect of the system. α_1 and α_2 are the coefficients to be determined. This study considers the two systems to be of equal importance, so that $\alpha_1 = \alpha_2 = 0.5$.

3.4.3. Differentiation Index

The degree of association is used to characterize the state of co-ordination between RPSs and PM. On the basis of calculating the association degree, the differentiation index is constructed to measure the difference in the co-ordinated development of the two systems in each district and county of SCRs, and it is possible to obtain the changes in the differences in the association degree of each district and county in different years [49]. The calculation formula is as follows:

$$ID = \sqrt{\sum_{m=1}^{n} \left[\left(RI_m / \overline{RI_m} \right) - 1 \right]^2 / n} \quad (3)$$

In Equation (3), ID is the differentiation index, RI_m is the degree of association, $\overline{RI}_m$ is the average of the association degree, and n is the number of districts and counties. The larger the ID is, the greater the difference in the association degree between counties and districts, and the spatial distribution presents an uneven trend.

3.4.4. Multiscale Geographically Weighted Regression

Multiscale geographically weighted regression (MGWR) is further extended based on geographically weighted regression, as it can generate different bandwidths for each variable to evaluate their spatial influence range, overcoming the defect where traditional GWR cannot explain the spatial scale difference of the influencing factors [50]. This study analyzes the spatial heterogeneity and scale differences of the factors influencing spatiotemporal association patterns between RPSs and PM in SCR based on the local regression and multiple bandwidth attributes of the multiscale geographically weighted regression model. The specific formula is as follows:

$$y_i = \beta_{bw0}(\mu_i, \nu_i) + \sum_{j=1}^{n} x_{ij} \beta_{bwj}(\mu_i, \nu_i) + \varepsilon (i = 1, 2, \ldots, m; j = 1, 2, \ldots, k) \quad (4)$$

In Equation (4), y_i is the dependent variable for the i-th element, x_{ij} is the attribute value of the independent variable j at position i, and bwj denotes the bandwidth used to calibrate the j-th conditional relationship; i.e., MGWR is calibrated using the backfitting

algorithm model, setting the GWR parameter estimates as the initial state to evaluate the best bandwidth and local estimation coefficients in an iterative manner. Thus, β_{bwj} is the bandwidth value used in the calculation of the regression coefficient for the j-th variable, and (μ_i, ν_i) denotes the spatial position of the county center of the i-th element.

4. Results

4.1. The Evolution of the Spatiotemporal Patterns in SCR

4.1.1. Spatiotemporal Patterns of RPSs

From 2010 to 2020, the overall level of RPSs in the SCR improved, and the comprehensive development index increased from 14.45 to 19.06, with an upsurge of 31.93%. In 2010, approximately 53.70% of the districts and counties had a low level of public services, with very few of them having a high or extremely high level, and approximately half or more of the districts and counties in SCR had a below-average level of public services. In 2020, the level of RPSs in the SCR significantly improved, the number of districts and counties at low and extremely low levels decreased sharply, and the number of those at moderate and above levels increased rapidly. Most districts and counties have above-average levels of public services. In terms of regional distribution, the level of RPSs decreases gradually from the core urban centers to the periphery, and most districts and counties with high or extremely high levels are located near transportation arteries in a spatially networked pattern. Overall, the level of RPSs in the SCR is higher in the east than in the west (Figure 3). The global spatial autocorrelation analysis shows that Moran's I value was 0.481 in 2010 and 0.503 in 2020 ($p < 0.01$), showing remarkable positive spatial agglomeration with an increasing trend. The local autocorrelation analysis shows that the high-value areas of RPSs are clustered around the urban areas of Chengdu and Chongqing, while the low-value areas are mainly located in the mountainous areas of western Sichuan, with a clear low–low clustering pattern.

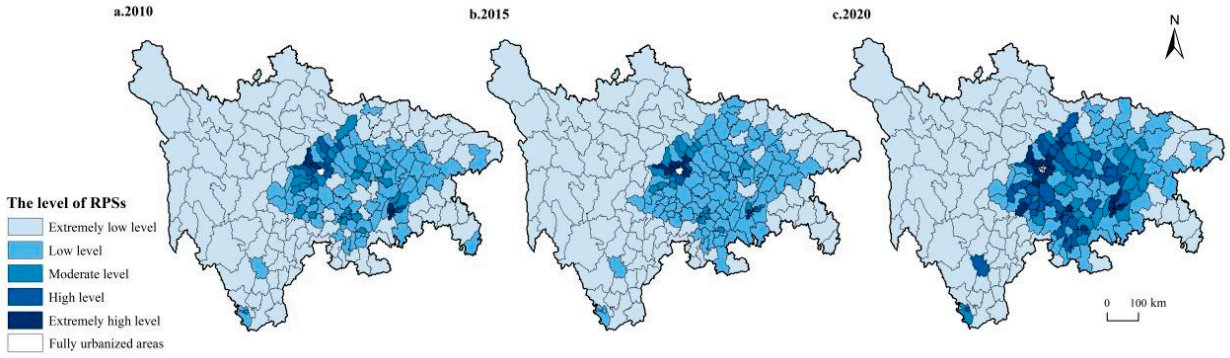


Figure 3. Spatiotemporal patterns of RPSs in SCR.

4.1.2. Spatiotemporal Patterns of PM

The scale of population migration in the SCR increased by approximately 45.14% in 2020 compared to 2010. Most districts and counties in the SCR have different degrees of population outflow (Figure 4), with serious population loss in northeast Sichuan and northeast Chongqing, which are mainly traditional agricultural areas with a large rural population base and poor economic conditions [51]. These areas are less attractive to the population, with out-migration as the main source of employment, and are experiencing a diversification of population migration. Chengdu and Chongqing continue to produce a siphon effect, with urban areas and surrounding districts and counties becoming concentrated areas of population inflow. The middle counties of the SCR suffer from general population outflow, forming a central low-value collapse zone in space [52]. In western Sichuan, the population is sparse, the base is small, and most areas are at low levels of migration, with little change in population inflow and outflow.

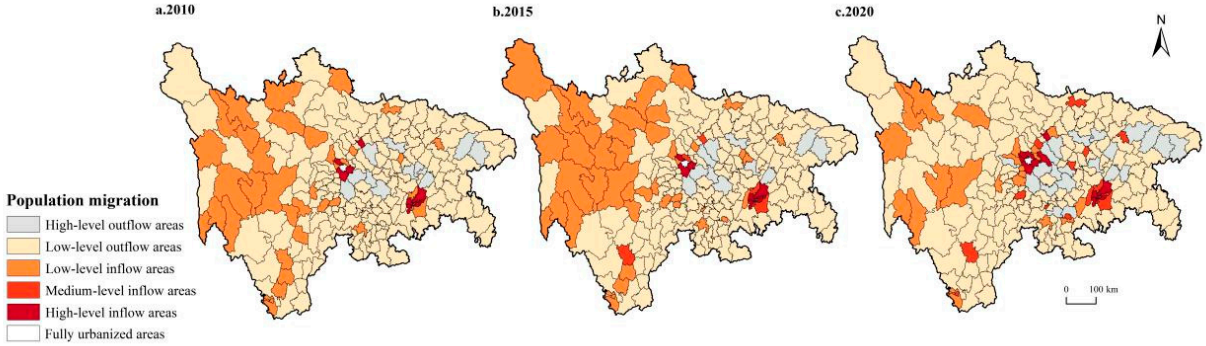


Figure 4. Spatiotemporal patterns of rural PM in SCR.

4.2. Spatiotemporal Associations between RPSs and PM in SCR

4.2.1. The Spatiotemporal Patterns of Association

From 2010 to 2020, the association between RPSs and PM in the SCR increased steadily, and the increase rate accelerated from 2015 to 2020. The spatial differentiation of association is obvious (Figure 5). The districts and counties with high and extremely high association levels are concentrated in the Chengdu Plain, eastern Sichuan, and southern Sichuan. Most of them have been expanding their spatial scope since 2010. The spatial distribution of districts and counties at moderate levels of association is gradually dispersed, with a shrinking trend. The number of districts and counties with low or extremely low levels of association does not show a marked decrease, with small changes in the spatial scope and strong spatial adjacency. The spatial pattern of association is stable overall. That is, the areas with high levels of association are mostly counties around the metropolitan core region and counties under the jurisdiction of some prefecture-level cities. These areas have a level of RPSs that matches the PM scale and are therefore in a highly associated state. Some areas of western SCR are lagging in RPSs, making their realistic levels and supply strength far from those of others, and the scale of PM is small, so the two have long presented a low association state.

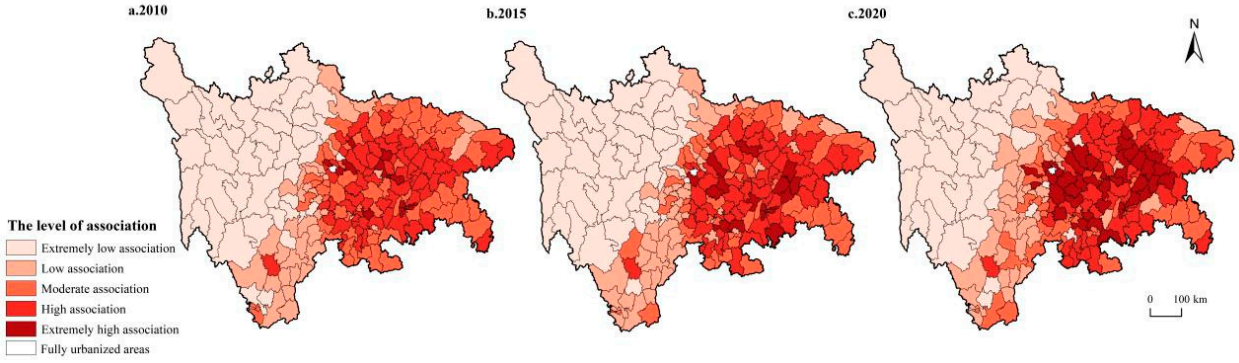
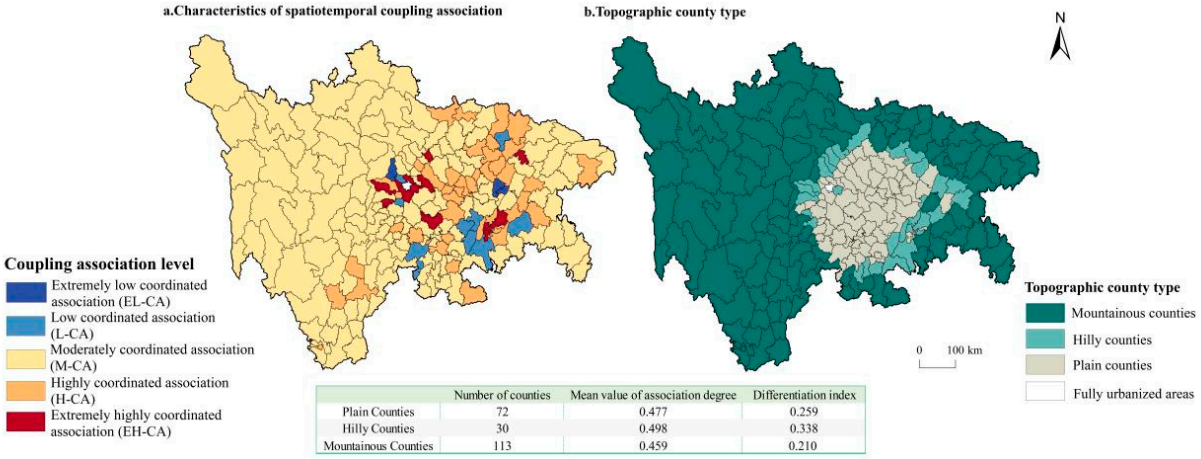


Figure 5. The spatiotemporal patterns of association between RPSs and PM in SCR (2010–2020).

4.2.2. Types and Divisions of Spatiotemporal Association Patterns

Based on the above three-period cross-sectional association data, it can be concluded that there is a significant spatial association between RPSs and PM in the SCR. Therefore, the 215 districts and counties in the SCR are divided into four types: net population inflow, net population outflow, outflow to inflow, and inflow to outflow. Their spatiotemporal associations are calculated using absolute values of changes in RPSs and PM in 2010 and 2020 to further explore the dynamic association patterns. From the calculation results, the co-ordinated development of RPSs and PM in the SCR was optimized. The level of RPSs increased from 2010 to 2020, and the improvement of their supply and quality led to the spatiotemporal association with PM from synchronous lag to local lag and disorder to order [53]. The spatial consistency was enhanced.

According to the association degree of the amount of change, the 215 districts and counties in the SCR are classified into five types (Figure 6): extremely highly co-ordinated association (EH-CA), highly co-ordinated association (H-CA), moderately co-ordinated association (M-CA), low co-ordinated association (L-CA), and extremely low co-ordinated association (EL-CA). EH-CA means that the two systems of RPSs and PM develop in parallel and are highly co-ordinated. The districts and counties of this type are mostly located around the core urban areas of the Chengdu–Chongqing twin cities. They are mainly population inflow areas, with flat terrain and obvious location advantages. To take on the overloaded urban functions of the core metropolitan area, the level of RPSs has been continuously improved, thus narrowing the gap between urban public services and increasing co-ordination with population migration. With the two systems in a state of highly co-ordinated and synchronized development, a new stage in the urban–rural transition has been brought about by the acceleration of urban–rural factor flows. The districts and counties with the H-CA type are mostly located in the suburbs of Chengdu and Chongqing, as well as some areas in eastern Sichuan, southern Sichuan, and north-eastern Chongqing. In these areas, RPSs have clearly improved, population outflows have decreased, or population inflows have increased, so the two systems are well-co-ordinated, and the level of association is relatively high. Further clarification of their urban–rural transformation path is required to achieve comprehensive integrated development.



	Number of counties	Mean value of association degree	Differentiation index
Plain Counties	72	0.477	0.259
Hilly Counties	30	0.498	0.338
Mountainous Counties	113	0.459	0.210

Figure 6. Characteristics of spatiotemporal coupling association between RPSs and PM.

Nearly 27% of the districts and counties are the M-CA type, concentrated in areas such as western Sichuan and southeast Chongqing. Less enhancement of RPSs, little change in the scale of PM, and slow urban–rural transformation place them at a moderate level of co-ordination. Influenced by SCR topography, most of them are mountainous counties with small-scale PM. The unique natural environment makes its migration characteristics distinctive, so it is necessary to fine-tune the configuration structure and spatial layout of RPSs, enhance the spatial association between the two, and improve the level of co-ordination in accordance with the basic trend of urban–rural transformation in the region. L-CA refers to a situation where the degree of variation of the two systems differs significantly, with one system developing ahead of the other and with the possibility of a subsequent lower level of co-ordinated association and a shift toward dysfunction. This type of area has increased population inflow and population density, but RPS development lags PM, and the two are poorly co-ordinated, making it a key area for rural revitalization. With extremely poor co-ordination and intensified conflict between them, EL-CA implies that the two systems are dysfunctional and that their relationships deteriorate over time, eventually manifesting as developmental decline. For example, Dujiangyan, a mountainous county in the remote suburbs of Chengdu, has a large population inflow, and most rural areas have already transformed their agricultural production. With the general concentration of the population in tertiary industries, urban characteristics are beginning to emerge. In the absence of an

efficient RPS supply, RPSs and PM have poor spatial coherence. In the future, the focus should be on optimizing the spatial allocation of RPSs, conducting cost control, improving the quality of development, and enhancing service capacity.

4.2.3. The Differentiation of Spatiotemporal Association Characteristics

The differentiation index is constructed to measure the internal differences in the spatiotemporal association of different districts and counties and to clarify the yearly variations in their spatial differentiation. The differentiation indices for 2010, 2015, and 2020 are calculated to be 0.538, 0.552, and 0.547, respectively, showing an inverted "U" change. Overall fluctuating growth has been achieved. This indicates that the differences in the association of RPSs and PM between districts and counties in the SCR have increased, and the complexity of the interaction of the two systems has deepened, with spatiotemporal associations continuing to diverge.

The topography of the SCR is complex and varied, with vast differences in elevation, and it spans four major geomorphic units. Topography dominates regional spatial differentiation, and the interaction of various natural and human elements within the formed geographical units leads to spatiotemporal association differentiation. The processes, patterns, differences, and effects of the evolution of the two systems are directly subject to the transitional characteristics expressed by topographic undulations and geomorphological changes [54], thus generating different spatiotemporal association patterns in this region.

The 215 districts and counties in the SCR are divided into mountainous, hilly, and plain counties according to their topography, and the spatiotemporal association characteristics of each type of topography are further analyzed. In terms of the level of association variation, the highest differentiation index is found in hilly counties. This topographic region has an uneven level of RPSs, a complex PM situation, and significant internal differences. Hilly counties are distributed at all levels of co-ordinated association. In addition, from 2010 to 2020, the level of co-ordinated association was better in hilly counties than in plain counties and better in plain counties than in mountainous counties. The highest association is in Yubei among the hilly counties, Shuangliu among the plain counties, and Tongchuan among the mountainous counties. Yubei is close to the core urban area and is influenced by Chongqing's northward development. Shuangliu is the area with the largest net population inflow in Chengdu. In response to the structural changes in PM, this region has actively optimized the allocation of RPSs to promote its cluster development for the coverage of the resident population. The population is generally moving toward high-quality public services, so the association is well-co-ordinated. Tongchuan experienced a slowdown in population loss from 2010 to 2020. The quality of public services, such as education and medical care, in the district has improved significantly, and its attractiveness to the population has been enhanced, contributing to the retention of the local population and the absorption of external populations. In summary, the spatiotemporal associations between RPSs and PM in the SCR are clearly transitional across different topographic units, with prominent spatial heterogeneity.

4.3. Factors Influencing the Spatiotemporal Associations

4.3.1. Influence Factor Selection and Model Establishment

Based on the analysis of spatiotemporal association and differentiation characteristics, the degrees of association in 2010 and 2020 are taken as dependent variables to explore the heterogeneity of influencing factors on spatiotemporal association. Referring to relevant studies and taking into account the characteristics of the SCR, the analysis framework is constructed from four dimensions [55,56]: natural, economic, social, and urban–rural disparity. Weakly correlated variables are excluded by correlation analysis, and variables with VIF values greater than 7.5 are excluded by the variance inflation factor test. The analysis of the spatiotemporal association patterns confirmed the existence of significant spatial correlation and spatial heterogeneity. In addition, the scatter plot of each influence factor showed a remarkable quadrant distribution anisotropy when exploratory data

analysis was performed. In addition, R^2, adjusted R^2, AICc, and residual sum of squares are selected as the performance evaluation metrics of the model to compare the OLS (ordinary least squares), GWR (geographically weighted regression), and MGWR (multi-scale geographically weighted regression) methods. Comparing the results (Table 3), it can be seen that the choice of multi-scale bandwidth makes the fitting effect significantly better, so MGWR is chosen for this study to demonstrate the influencing factors.

Table 3. Model evaluation metrics and comparisons.

Model Parameters	2010			2020		
	OLS	**GWR**	**MGWR**	**OLS**	**GWR**	**MGWR**
R^2	0.655	0.707	0.792	0.710	0.730	0.787
Adjusted R^2	0.637	0.676	0.751	0.692	0.702	0.753
AICc	−390.900	−385.053	−428.480	−340.502	−339.904	−360.001
Residual Sum of Squares	1.988	1.692	1.198	2.246	2.088	1.649

The topographic position index (TPI) is selected to characterize regional topographic variations; the GDP per capita (GDPPC) and rural electricity consumption (REC) are selected to characterize regional economic differences; the urbanization rate (UR), the number of hospital and health center beds (NHB), and the number of social welfare adoptive units (NSWAU) are selected to characterize social development; and the number of regional street offices (NSO), the number of towns and villages (NTV), the number of village employees (NEV), the number of urban unit employees (NEU), and the ratio of urban to total social fixed asset investment (RUSI) are selected to characterize the urban–rural disparities. In the above, a total of 11 explanatory variables are selected to establish MGWR models, and all variables are standardized before regression analysis.

4.3.2. Factor Analysis Based on the MGWR Model

In 2010, TPI, UR, and REC had a significant impact on the association. The absolute value of the regression coefficient of TPI is the largest, acting as the dominant factor negatively affecting the association and showing a gradient decreasing pattern in the northwest–southeast direction (Figure 7). This means that the level of co-ordinated association between RPSs and PM is poor in areas with a complex topography. Among them, the association of western Sichuan is the most sensitive to the topography. The PM characteristics of the region are significantly territorial, and its urban–rural transition process is developing slowly, suggesting that the improvement of RPSs in these areas has not significantly enhanced population retention and that the macrogeographical context dominated by topography has created its urban–rural relationship. Therefore, excessive investment in RPSs should be avoided in this case. In the process of rural revitalization, basic public services should be guaranteed as much as possible to enhance the supply capacity and raise the level of co-ordinated association.

The heterogeneity of UR's effect on association is prominent, with a spatially dispersed pattern. UR acts positively on mountainous counties such as northwest Sichuan and southeast Chongqing and negatively on hilly counties such as northeast Sichuan and southeast Sichuan. The former is constrained by natural economic factors, with insufficient endogenous development momentum and weak population attraction, so there is a need to accelerate the construction of basic public services, such as transport. In this way, the level of urbanization is effectively raised, and the co-ordination of RPSs and PM is improved, leading to an increase in association. For the latter counties, the higher the level of urbanization, the lower the association, indicating that the spatial matching between PM and RPSs in these areas is poor. In these areas, the urban–rural transition should focus on the changing stages of their population flows and enhance spatial synchronization, thus increasing the level of association.

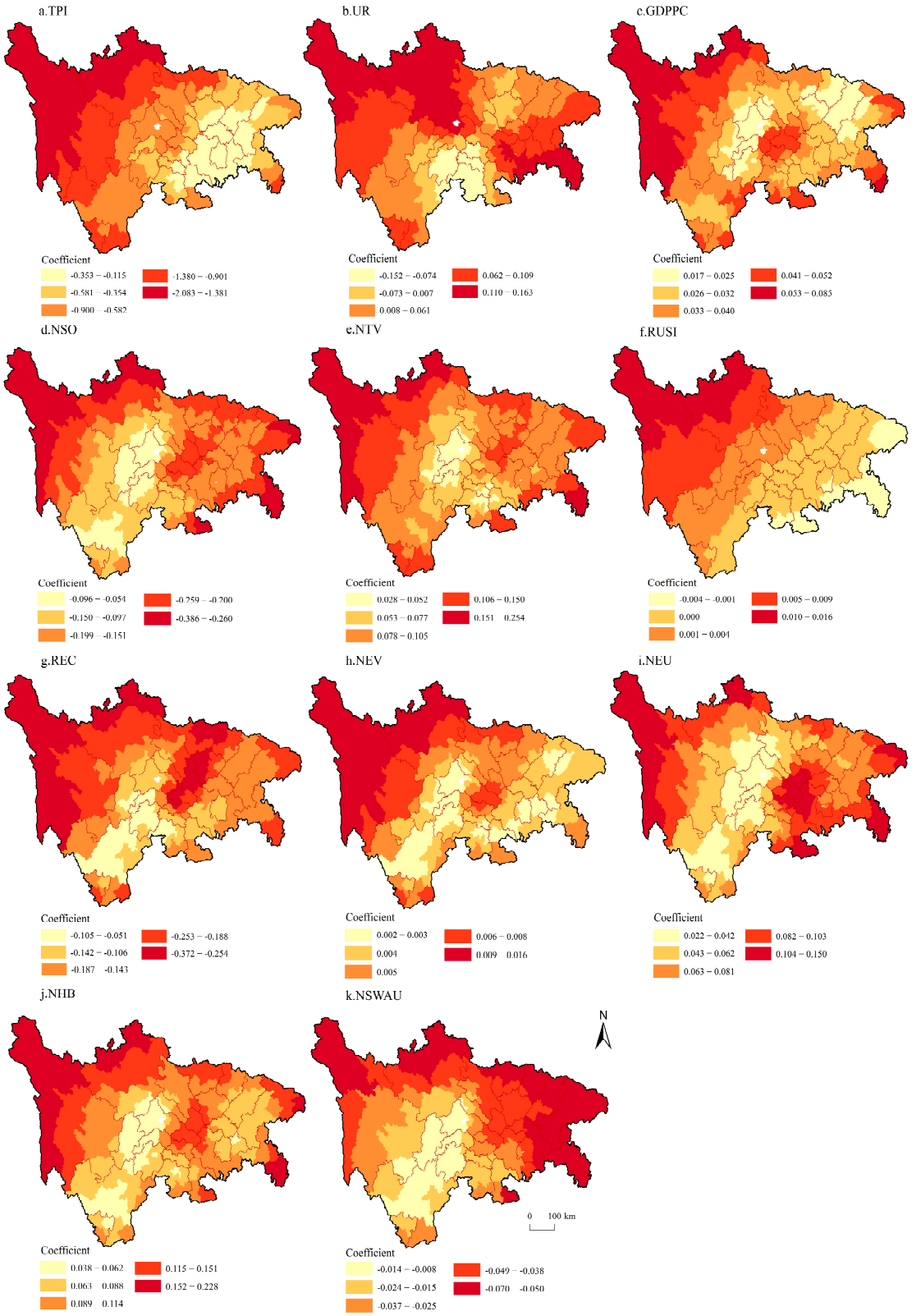


Figure 7. Spatial distribution of variable regression coefficients for the association degree in 2010.

The negative effect of REC on association increases spatially along the core of the Chengdu and Chongqing twin cities in an outward circular pattern, concentrating on peripheral regions, such as northwest Sichuan and southeast Chongqing. Therefore, its effect on association has a significant negative response in areas with lagging economic

development. Poor population retention and inadequate rural development make these areas less well-co-ordinated. However, the urban–rural transformation of the core area of the Chengdu–Chongqing twin cities continues to take place, and the rapid reconfiguration of the rural territorial system has led to the manifestation of rural values. As urban–rural integration further enhances its regional function as a mega-center city, the development of various types of RPSs at all hierarchies is in harmony with the phased shift in PM, so these areas will be at a high level of association.

In 2020, TPI remains the key factor dominating the spatial differentiation of association, with UR continuing to play a prominent role. Moreover, RUSI and the difference in employment between urban and rural residents show significant effects. Among them, the negative impact of the RUSI on the association shows a spatially dispersed pattern (Figure 8). There are notable regional differences in the positive returns on inputs. The negative response is stronger in remote areas of northwest Sichuan, southeast Sichuan, and southeast Chongqing, where fixed asset investment has not enhanced the association co-ordination, so attention should be given to the RPS input threshold in the future to reduce its negative impact. The number of employed persons shows a center-periphery circular differentiation pattern in both rural and urban areas, with both positively affecting the association, but the employment situation in urban areas has a greater impact. The population always flows to areas with more job opportunities. With the frequent introduction of "talent policies" in urban areas and the improvement of related public services, the advantages of core cities in the SCR are beginning to emerge, and some districts and counties are gradually growing into new highlands for population growth, where co-ordinated association is increasing. That is, the urban–rural employment gap, as one aspect of the urban–rural disparity, has a complex effect on PM, exacerbating the divergence of flows and, ultimately, affecting the level of association.

The variation in the influence scale of different factors between 2010 and 2020 is analyzed to explore its driving effect on the degree of association (Table 4). TPI has a scale of action of 213 and played a global role in the association in 2010; in 2020, its scale of action contracts, and spatial heterogeneity increases. The spatial pattern shifts from decreasing from west to the east to presenting an outwardly increasing circular structure from the centers of the two core metropolitan areas of the SCR, indicating an increase in the sensitivity of the central urban areas to topography.

Table 4. Statistical description of MGWR in 2010 and 2020.

Variable	2010					2020				
	Min	**Median**	**Max**	**Adaptive**	**VIF**	**Min**	**Median**	**Max**	**Adaptive**	**VIF**
Intercept	0.232	0.296	0.341	17		0.344	0.346	0.346	210	
TPI	−0.300	−0.299	−0.298	213	2.62	−0.535	−0.357	−0.241	27	2.75
UR	−0.271	−0.086	−0.555	12	4.84	0.341	0.343	0.349	213	4.85
GDPPC	0.032	0.033	0.036	213	2.97	−0.123	−0.116	−0.096	173	1.94
NSO	−0.196	−0.193	−0.189	210	3.65	−0.152	−0.136	−0.111	137	4.06
NTV	0.085	0.088	0.092	213	2.46	0.130	0.134	0.136	213	3.11
RUSI	−0.003	0.000	0.008	213	1.16	−0.775	−0.514	−0.263	16	1.15
REC	−0.200	−0.129	−0.062	38	1.66	−0.011	−0.008	−0.003	203	1.73
NEV	0.002	0.005	0.008	213	4.02	0.067	0.070	0.080	203	4.16
NEU	0.122	0.126	0.130	213	3.65	0.585	0.609	0.641	138	3.41
NHB	0.142	0.145	0.150	213	4.77	−0.076	−0.070	−0.053	183	3.85
NSWAU	−0.045	−0.043	−0.041	213	2.24	−0.042	0.026	0.059	138	1.89

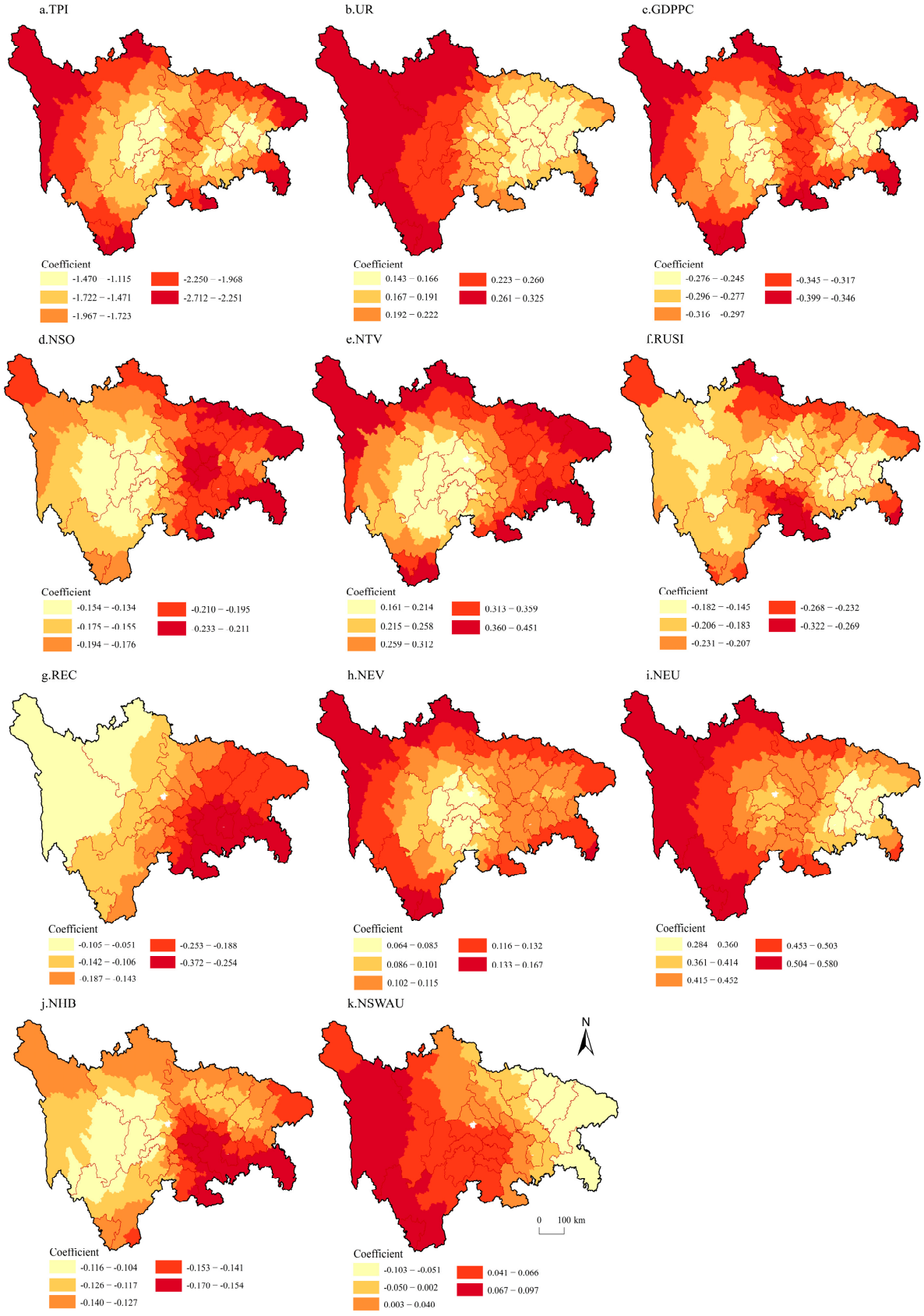


Figure 8. Spatial distribution of variable regression coefficients for the association degree in 2020.

The regression coefficient of UR grows, indicating the increasing intensity of its spatial influence, while its scale expansion shows a smooth trend, indicating that the improvement

of the quality of urbanization has led to an increase in the co-ordination of RPSs and PM. Regions with slower urbanization are more responsive, and sensitivity shows a decreasing characteristic in the form of banded patches from west to east. The bandwidth of NHB falls from 213 to 183, with a contraction in the spatial scope of influence accompanied by a weakening of the effect, indicating that the increased spatial equilibrium of medical resources reduces the constraint on the co-ordinated association between RPSs and PM in remote areas. The impact of GDPPC increases, contributing to a greater drive for association and a lower spatial scope of influence. In terms of the absolute value of the regression coefficients, GDPPC is the most influential of the regional economic factors on association, and its regression coefficient attributes change from positive to negative from 2010 to 2020, indicating that its influence on association has different spatial responses over time. As a global variable, the center of gravity of its spatial influence extends from northwest Sichuan and southeast Chongqing to peripheral areas of south Sichuan and west Chongqing, mainly exerting an important influence on some districts and counties that are lagging in economic development. REC is closely related to rural agricultural development and focuses on describing the rural economy. The increase in the spatial impact of REC from 2010 to 2020 indicates that, as the rural revitalization strategy advances, the economic situation in rural areas has improved sufficiently, and rural public services are making great progress, especially in the construction of basic services, such as transport and medical care, and in the provision of a more diversified supply of life services. A favorable economic situation in rural areas supports the long-term development of RPSs, continuously attracts the inflow of factors, and promotes urban–rural transformation.

The negative impact of RUSI on the association is deepening, suggesting that relying solely on one-way urban investment construction is not always beneficial to co-ordinated development, but its scale of impact decreases and the pattern of regression coefficients shifts from spatially decreasing to spatially symmetrical. The urban–rural employment gap is an important manifestation of the imbalance between urban and rural and the key to reshaping urban–rural relations. Moreover, the quality of urban and rural employment, which is interrelated with the content and capacity of the public service itself, is an embodiment of the level of public service. It is also an important aspect affecting population migration and exerts an essential impact on the degree of association. The impact of NEV increased, and the scale of its action decreased slightly. The impact of NEU also increased significantly, but the scope of action narrowed, showing a clear circular spatial structure and a high degree of heterogeneity. The county is an important intersection between urban and rural areas in China. The availability of employment opportunities in counties has a bearing on the ability to provide nearby employment for the rural labor force, thereby achieving nearby urbanization. Further enriching the supply of public services to enhance the attractiveness to the population, directing more development factors to rural areas, adding more rural jobs, and balancing the employment difference between urban and rural areas can drive rural development and achieve urban–rural integration within the county.

5. Discussion

5.1. New Perceptions of Spatiotemporal Association Regionality in an Improved Framework

Earlier studies have confirmed the importance of public services in inflow areas as an incentive for people to immigrate [57], and the analysis has mostly focused on the one-way impact of public services on population migration. In the past, cities have long held a biased position in socioeconomic development and dominated urban–rural relations, resulting in a widening gap between urban and rural areas, the separation of urban–rural relations, and the annihilation of the intrinsic value advantages of rural areas [58]. The development of urban and rural areas is heading toward an imbalance. In the urbanization-oriented regional process, public services are often reflected as one of the factors acting on the rural–urban migration. As China's social economy enters a new normal, the two-way flow of urban and rural factors accelerates, the trend of urban–rural transformation becomes obvious, and a synergistic development pattern between new-

type urbanization and rural revitalization gradually forms. Rural areas can benefit from urban–rural integration, the rural public service system is constantly improved, and the rural–urban migration becomes more frequent. Accordingly, the relationship between the two changes, and the relevant discussion should likewise shift from the former one-way cause-effect perspective to the exploration of the two-way correlation and interactive influence relationship. In addition, achieving urban–rural integration requires a holistic and systematic treatment of the development of the relationship between two regional processes: public services and population migration.

From the perspective of the complexity of the system association, the characteristics and trends of the spatiotemporal association between the two systems are examined [59]. Within the framework of the natural–humanistic complex, the analysis of the urban–rural development relationship can better provide scientific support for resolving urban–rural conflicts and redressing urban–rural imbalances [60]. Therefore, a new research framework is proposed in this paper, which treats public services and population migration as two systems of comparable importance, places them on an equal status for dynamic association analysis, and explains its spatial differences in regional natural geography.

This study concludes that the association between RPSs and PM in SCR increased overall between 2010 and 2020, indicating that the co-ordination between the two systems has improved. Influenced by the regional environment, the spatiotemporal association has a clear trend of transition across different topographical units, and spatial differences deepen, which suggested that RPSs do not have a unidirectional influence on the process of PM, but rather that their reciprocal associations show significant geographical differences. The direction of action of RPSs is becoming increasingly complex rather than merely spatially driven under different trends of urban–rural transformation. This implies that the weakening effect of rural public services on population migration shows clear regionality, not a consistent global trend, resulting in differentiated spatiotemporal association patterns. In addition, the heterogeneity of the association between RPSs and PM reflects the complex intertwining of the spatial distribution of both urban and rural resources and population factors that flow within the region [61]. The essence of integrated urban–rural development lies in the free flow of urban and rural factors and the optimal combination of their spatial allocation. Therefore, the two-way association and spatial co-ordination between RPSs and PM are among the structural forces supporting urban–rural integration, while the level of co-ordinated association is the externalization of the characteristics of the evolutionary stage of urban–rural relations in the geospatial pattern [62]. This shows that rural revitalization and urbanization in the SCR are in the process of a dynamic and synergistic tuning and are beginning to take on the characteristics of integration and transformation [63].

5.2. Main Association Types and Differentiated Optimization Strategy

The main type of spatiotemporal association between RPSs and PM in the SCR is moderately co-ordinated association, followed by highly co-ordinated association. Topography dominates the association micropattern, based on which urbanization and rural differences exacerbate the complexity of differentiation. Due to the urbanization in China, the rural population is constantly flowing to cities and towns, leading to the loss of overall factors in the rural regional system and gradually widening the gap between urban and rural development [64]. In parallel, along with the ongoing socioeconomic transformation, the conversion of fixed asset input effects is evident, further influencing the co-ordination process and leading to the differentiated local association patterns. The above shows that the special geographical environment of the SCR determines the diversity of development paths for urban–rural integration. There is a need to consider different aspects, such as natural, economic, social, and regional differences in urban–rural transformation, improving the timeliness of the association and achieving a deeper integration.

A differentiated development strategy should be implemented to improve RPSs in the SCR on the premise of clarifying regional urban–rural transformation trends. In the mountains of the SCR, there is little evidence of rural return migration and the labor out-

flows are shrinking populations, so the association is relatively low, and the weakening effect of RPSs on population outflows is not significant. That is, the spatial heterogeneity of mountainous rural areas is prominent, leading to the particularity of their demographic and social structures [65]. Considering the finitude of RPSs in reducing rural population loss in areas with lower association, taking the overall smart shrinkage as the development concept, an attempt is made to determine the input threshold of RPSs for cost control, implement spatial agglomeration and functional optimization on the basis of many abandoned or inefficient resource elements in rural areas, and realize the moderate and orderly concentration and differentiated integration of RPSs.

Conversely, the plain areas around cities tend to be higher in association. These areas are complementary to cities in terms of population, industry, and landscape and are driven by the inexorable urban–rural transformation, featuring both urban and rural characteristics. In particular, the new development and adaptive evolution of RPSs in these areas can weaken population outflow and enhance population concentration in interaction with cities so that they can further dovetail with urban demands and benefit from the situation by undertaking partial decentralization of urban functions, thus realizing the misalignment of urban and rural functions and promoting the synergistic pattern of rural revitalization and urbanization.

6. Conclusions

The SCR is characterized by a diverse topographic environment and significant socioeconomic differentiation, presenting a differentiated spatial pattern of urban–rural transformation and integration. This study analyzes the dynamic association between RPSs and PM and obtains various spatiotemporal association patterns with distinctive characteristics, confirming the complexity and heterogeneity of the role of urban–rural functional coupling and spatial association within the SCR.

The urban–rural relationship reflects the most basic social and economic structure of the region. As a reflection of the topography, the SCR is characterized by a gradient of socioeconomic development, containing not only the metropolitan areas of Chengdu and Chongqing, but also many remote mountain towns that are lagging in development. Recently, the national supply of public services has been tilted to the rural areas, and the level of RPSs in the SCR has improved overall. However, the future strategy of RPS needs to take into account the regional migration and urban–rural transition trends. In areas where rural migration is widespread, subjects of rural society also show an aging and fragile posture. In addition, the problem of spatial mismatch between RPS configuration and rural population transfer and human urbanization development is prominent, in which efficiency is crucial. Increases in RPSs should be focused on the outskirts of cities and small towns, and the supply needs to be appropriately contracted in areas of population loss, and important basic public services such as medical care and pensions should be guaranteed. In the key areas of urban–rural transformation, RPSs can be developed moderately in advance to bring into play their gathering and attraction functions and promote the urbanization of the rural population and urban–rural integration. In addition, there is a need to reduce the dependence on government public service supply and promote diversified development, such as co-operation between government, enterprises, and society. In the future, RPSs may be integrated with eco-tourism to increase their value and attract population clusters to promote regional high-quality development.

Reliable information is an absolute necessity if dynamic coupling association assessments are to fulfil their role in providing new insights and effectively advising urban–rural integration-related decision making. In future studies, it is important to incorporate more development factors and regional processes of urban–rural transformation to better understand the patterns and interaction relationships between rural revitalization and new-type urbanization and their drivers. In particular, in the process of urban–rural transformation, in addition to population, land, industry, and other features undergo drastic and profound changes in various dimensions, demonstrating the continuous development and evolution

of urban–rural territorial space and the deepening differentiation in their interaction. Further research should move beyond the simple association of coupling between two systems to the complex association, i.e., using network theory to qualitatively express the organizational pattern and dynamic interaction of complex systems, revealing the mechanism of mutual feedback between different aspects of urban–rural transformation. In previous studies, an urban–rural duality framework based on urban–rural distinctions was used to divide urban and rural societies, resulting in a differentiation between the two disciplines of urban and rural geography, and their research content primarily emphasized urban–rural differences and oppositions. In China, there is an evident tendency towards urban–rural transformation. We aimed to establish a conceptual framework of urban–rural integration, focusing on urban–rural linkage and interdependence, to break through the previously held belief that urbanization is the only path belonging to urban–rural transformation, to investigate rural revitalization and the urban–rural integration development mode in different regions, and to recognize the benefits and cogrowth of urban–rural geography research to form a continuous urban–rural research paradigm.

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Abbreviations

RPSs	rural public services	GDPPC	GDP per capita
PM	population migration	REC	rural electricity consumption
SCR	Sichuan–Chongqing region	UR	urbanization rate
MGWR	multiscale geographically weighted regression	NHB	number of hospital and health center beds
EH-CA	extremely highly co-ordinated association	NSWAU	number of social welfare adoptive units
H-CA	highly co-ordinated association	NSO	number of regional street offices
M-CA	moderately co-ordinated association	NTV	number of towns and villages
L-CA	low co-ordinated association	NEV	number of village employees
EL-CA	extremely low co-ordinated association	NEU	number of urban unit employees
TPI	topographic position index	RUSI	ratio of urban to total social fixed asset investment

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