

Article

Spatial Distribution Characteristics and Influencing Factors of Public Service Facilities for Children—A Case Study of the Central Urban Area of Shenyang

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Abstract

With the rapid advancement of urbanization, the increasing demand and insufficient supply of public service facilities for children have become urgent problems requiring resolution. This study employs the Shannon diversity index, the location entropy, spatial autocorrelation, and the Geographically Weighted Regression (GWR) to analyze the spatial distribution characteristics and influencing factors of children's public service facilities in the central urban area of Shenyang. The findings of the study are as follows: (1) There are significant differences in the spatial distribution of children's public service facilities. Higher quantity distribution and diversity index are observed in the core area and Hunnan District compared to the peripheral areas. The Gini coefficient of various facilities is below the fair threshold of 0.4, but 90.32% of the study units have location entropy values below 1, indicating a supply–demand imbalance. (2) The spatial distribution of various facilities exhibits significant clustering characteristics, with distinct differences between high-value and low-value cluster patterns. (3) The spatial distribution of facilities is shaped by four factors: population, transportation, economy, and environmental quality. Residential area density and commercial service facility density emerge as the primary positive drivers, whereas road density and average housing price act as the main negative inhibitors. (4) The mechanisms of influencing factors exhibit spatial heterogeneity. Positive driving factors exert significant effects on new urban areas and peripheral zones, while negative factors demonstrate pronounced inhibitory effects on old urban areas. Non-linear threshold effects are observed in factors such as subway station density and public transport station density.

Keywords: children's public service facilities; spatial distribution; geographically weighted regression; spatial heterogeneity



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1. Introduction

The acceleration of global urbanization and the sustained growth of urban populations have triggered multidimensional social and ecological issues [1]. China's urbanization rate had reached 67% by 2024, driving economic growth but intensifying socio-ecological challenges, such as social inequality, housing disparity, and inefficient public resource allocation [2–4]. As the core carrier of urban service supply, the quantity, quality, and diversity of public service facilities directly affect urbanization quality and residents' well-being [5,6]. However, the current supply model, dominated by centralized and large-scale approaches, while enhancing service efficiency, has resulted in inadequate facility coverage

and intensified spatial disparities [7]. This efficiency-oriented model often overlooks the differentiated needs of vulnerable groups, including children, the elderly, and individuals with disabilities, which impedes equitable urban development and undermines sustainability goals [8,9]. According to China's Seventh National Population Census, children aged 0–14 constitute 17.95% of the total population. Moreover, with the continuous implementation of the three-child policy, the population of this group is expected to further increase [10]. This trend has imposed higher demands on the scale of urban children's public service facilities (CPSFs), as well as the rationality of their spatial layout and functional appropriateness. However, the traditional "per-thousand-capita" allocation model fails to adapt to the dynamic growth and diversified needs of the child population [11]. There are spatial distribution imbalances, such as facility overloading in urban central areas and shortages in emerging communities, particularly evident as significant gaps in childcare facilities [12]. Therefore, against this backdrop, the allocation of CPSFs has emerged as a crucial issue.

In the fields of geography and planning, a comprehensive theoretical and practical framework has been established for the spatial layout and optimization of public service facilities [13–15]. Scholars have systematically explored this issue by constructing accessibility models, identifying factors influencing residents' satisfaction, and analyzing the mechanisms through which socio-economic factors interact with facility allocation [16–19]. In recent years, facility equity has emerged as a research hotspot, evolving through three stages: from geographical equality to spatial equity and then to social equity. On one hand, research on equity measurement based on spatial analysis has gained attention. For example, scholars such as Li HN and Zhang N have conducted studies on the spatial form, supply–demand matching, accessibility, and the coverage of facilities such as cultural, sports, and parks using methods like the two-step floating catchment area [2SFCA] method, space syntax, and the Gini coefficient [20–29]. On the other hand, research on demand response oriented toward social groups has also continuously deepened. With the deepening of the concept of social equity, scholars have begun to pay more attention to the differentiated needs of various social groups. For instance, Zhang LL and Cui XJ have explored the spatial distribution and territorial equity of public services for vulnerable groups in urban villages, rural areas, and affordable housing [30–33]. Meanwhile, Chang XY and Cheng T have examined the spatial equity of elderly service facilities from the perspective of age-friendly development [34–36].

As a vulnerable group in cities, children have limited mobility and scope of activities, making the equitable allocation of CPSFs particularly crucial. However, the current mismatch between children's needs and the supply of facilities is pronounced, and the macro-control environment, constrained by multiple factors, has become a critical bottleneck for the construction of CPSFs. Currently, the research on CPSFs mainly focuses on three aspects: First, analyzing the distribution patterns and influencing factors of CPSFs from the perspective of spatial planning. For example, Zhu PJ used the geographical detector to analyze the spatial distribution characteristics of CPSFs in 286 prefecture-level cities in China, pointing out the combined influence of demographic, economic, and natural factors [37]. Wang X employed the walkability index method to evaluate the walkability and rationality of CPSFs and found that the walkability index in the study area is generally low and unevenly distributed, mainly influenced by road network density, block size, and urban landscape patterns [38]. Secondly, based on children's behavioral characteristics and needs, the service quality of CPSFs and the factors influencing them are analyzed. Through interviews and regression models, key factors such as medical equipment, social workers' professional quality, and teachers' perceptions have been identified, and the impacts of socio-economic factors and spatial distance on facility quality have been revealed [39–42].

Thirdly, starting from children's rights and health, the institutional regulation and optimization strategies of CPSFs are explored. Through text analysis and questionnaire surveys, the deficiencies of existing facilities in terms of safety and services for special needs are assessed, and corresponding improvement strategies are proposed [43–45].

Despite the progress made in relevant research, there are still two major gaps: Firstly, existing research has predominantly focused on the micro-level scales of life circles and communities. Few studies have approached the subject from a single-city perspective to systematically explore the allocation disparities in CPSFs between core and peripheral areas, as well as between old and new urban zones, in combination with their development processes and spatial structures. Secondly, the existing research has not yet fully explored the spatial heterogeneity of the factors influencing CPSFs nor clarified the differentiated impacts of different factors on the spatial distribution of various facility types. To address this gap, this study focuses on the central urban area of Shenyang, integrating the child-friendly city framework with geospatial analytical methods. Utilizing the Shannon diversity index, locational entropy, spatial autocorrelation, and GWR, we investigate the spatial distribution patterns of CPSFs and assess the spatially heterogeneous effects of driving factors. Our findings offer a scientific foundation for urban planners to identify child facilities' supply–demand imbalances, optimize resource allocation, and advance child-friendly city initiatives.

The structure of the remainder of this paper is as follows. Section 2 outlines the research framework, data collection and processing, and the research methods employed in this study. Section 3 presents the research findings, including spatial distribution patterns and the spatial heterogeneity of influencing factors. Section 4 discusses planning recommendations, research contributions, and limitations. Section 5 is the conclusion of this article.

2. Materials and Methods

2.1. Study Area

Shenyang (Figure 1) is the core city of Northeast China, with a total area of 12,900 square kilometers. It is a typical representative of the transformation and upgrading of old industrial bases and an important population gathering center [46,47]. In recent years, with the continuous expansion of net population inflows and the corresponding growth in child population size, the demand for CPSFs has become increasingly urgent. The urban areas of Shenyang exhibit a distinct pattern of differential development. The core areas—Heping District, Shenhe District, and Huanggu District—serve as the political, economic, and cultural hubs of the city. These areas house major commercial hubs, such as Zhongjie and Taiyuan Street, and cultural landmarks, including the Shenyang Imperial Palace and Zhang's Mansion. Characterized by active urban renewal, compact spatial layouts, and a blend of traditional residential communities and modern commercial complexes, these districts face intensified pressure on public facilities due to high population density, despite their dense distribution. In contrast, the peripheral areas—Hunnan District, Tiexi District, Dadong District, Yuhong District, and Sujiatun District—display varying developmental dynamics. Hunnan District, a newly developed zone, benefits from forward-looking planning and abundant spatial resources. Conversely, Tiexi and Dadong Districts, historically significant industrial bases, are engaged in simultaneous industrial heritage revitalization and new urban construction. Early-stage development has constrained spatial resources and increased road network density in these areas. As a result, old urban areas struggle with outdated infrastructure that fails to meet growing demands, while new urban areas face a mismatch between facility provision and population growth [33,34].

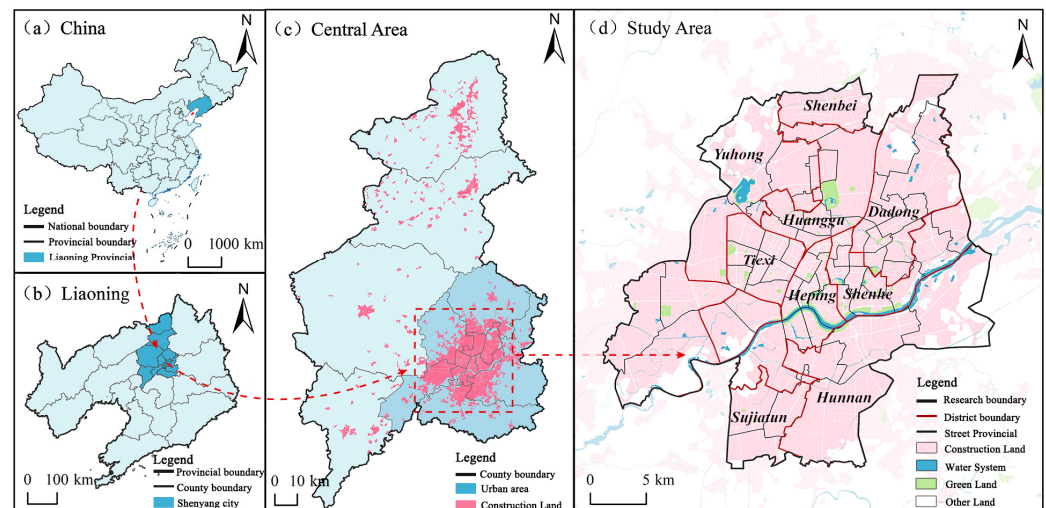


Figure 1. Location of the study area. (a) Location of Liaoning in China. (b) Location of Shenyang in Liaoning. (c) Shenyang's central urban area. (d) Location of the study area in Shenyang.

To address this contradiction, we selected 64 streets within the Fourth Ring Road, where the proportion of urban construction land exceeds 50%, as the research area. This area covers nine administrative districts, spans 741.66 square kilometers, and constitutes 59.8% of the main urban area. The 749,500 children in this area account for 72.51% of the total number of children in the city, and the area is characterized by a pronounced contradiction between the supply and demand of children's facilities. The findings provide a basis for the construction of child-friendly cities.

2.2. Research Framework

Based on the relevant standards and previous research, CPSFs are categorized into four types: education and growth, culture and sports, recreation and leisure, and safety and health [37,48,49]. Specifically, education and growth include facilities such as nurseries, kindergartens, and primary schools; culture and sports include facilities such as stadiums, cultural centers, and community activity centers; recreation and leisure include facilities such as parks, squares, and children's outdoor activity venues; and safety and health include facilities such as pediatric hospitals and community health service centers.

To eliminate the disruptive impact of geographical elements and administrative boundaries on spatial continuity, we divided the study area into 1000 m × 1000 m grids. After integrating point-of-interest (POI) data, socio-economic data, and transportation network data and standardizing them, we applied the Shannon diversity index, Gini coefficient, and location entropy to analyze the spatial distribution patterns of facilities from three aspects: quantity and scale, diversity, and degree of inequality. On this basis, global and local spatial autocorrelation analyses were conducted to examine the spatial agglomeration patterns of the facilities. Furthermore, we established a comprehensive indicator system encompassing four dimensions—population, transportation, economy, and environment—and employed GWR models to quantify the spatially heterogeneous effects of influencing factors across different facility types. These findings enabled us to formulate differentiated optimization strategies for the facilities, thereby providing scientific support for spatial layout optimization of CPSFs (Figure 2).

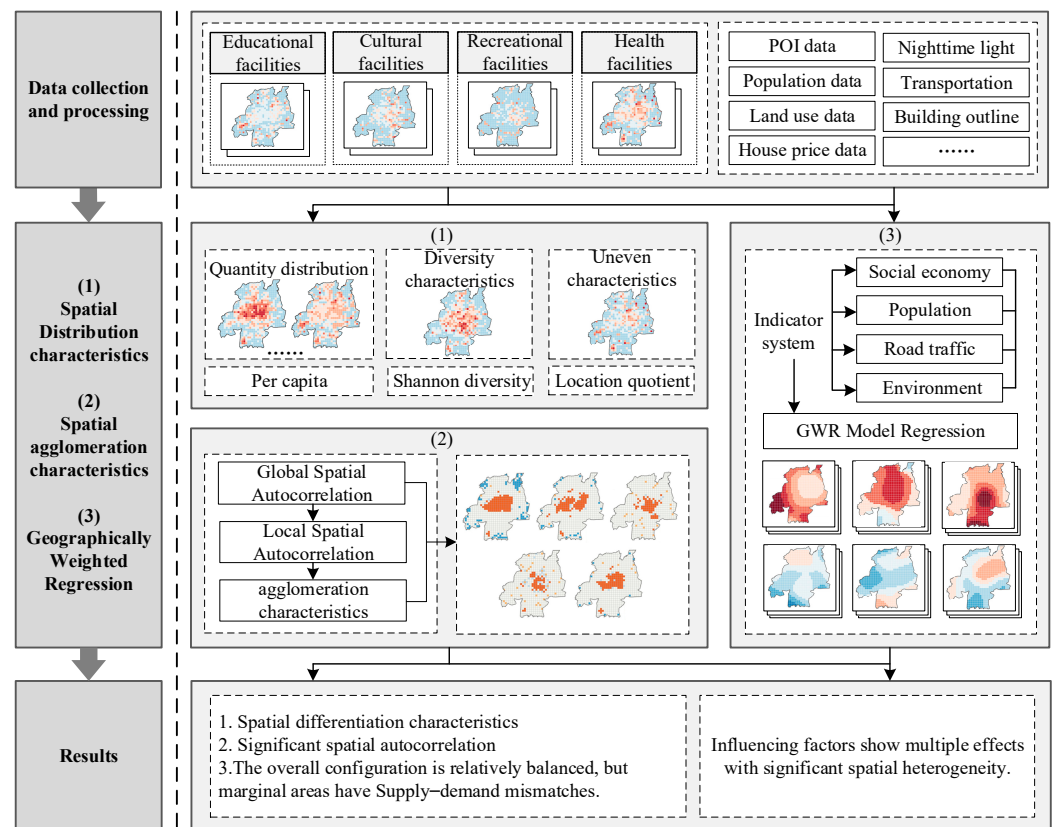


Figure 2. Research framework.

2.3. Data Source and Processing

The research data used in this study were primarily obtained from the following sources: (1) Child population data: The 2020 child population statistics at the sub-district level in Shenyang were derived from the Seventh National Population Census (<http://www.stats.gov.cn/>) (accessed on 10 May 2025). The population density data for Shenyang's central urban area at a 1000 m × 1000 m resolution were obtained from the WorldPop database 2020 (<https://www.worldpop.org>) (accessed on 1 May 2025). (2) POI data for CPSFs, including kindergartens, primary and secondary schools, children's parks, community service centers, and supporting facilities, were collected through the A Map Open Platform (<https://lbs.amap.com/>) (accessed on 20 April 2025) using Python 3.12. The dataset contains attribute information such as facility names, categories, addresses, and geographic coordinates (latitude and longitude). (3) Road network data of Shenyang (2022): Vector datasets including road classifications and lengths were extracted from OpenStreetMap (<https://www.openstreetmap.org/>) (accessed on 15 April 2025). (4) Administrative boundary data of Shenyang (2020): Spatial boundaries at the subdistrict level were obtained from A Map (<https://www.amap.com/>) (accessed on 20 April 2025). (5) Land use data of Shenyang (2023): Vector datasets containing urban construction land, green spaces, water bodies, and other land use classifications were derived from China's Annual Land Cover Dataset (CLCD) produced by Dr. Huang Xin's team at Wuhan University (<http://doi.org/10.5281/zenodo.4417809>) (accessed on 1 May 2025) [50]. (6) Other socio-economic data: The GDP data for 2020 were derived from the China GDP Spatial Distribution Kilometer Grid Dataset of the Resource and Environmental Science Data Registration and Publication System (<https://www.resdc.cn/DOI/DOI.aspx?DOIID=33>) (accessed on 20 April 2025). The 2024 housing price data were obtained from Anjuke (<https://www.anjuke.com/>) (accessed on 1 May 2025). The 2020 night-time light data

were sourced from NOAA (<https://eogdata.mines.edu/products/vnl/>) (accessed on 20 April 2025).

2.4. Methods

2.4.1. Methods for Analyzing Spatial Distribution of CPSFs

The spatial distribution rationality of CPSFs is crucial for the healthy growth of children and the improvement of urban public service systems. This study analyzes the spatial distribution characteristics from three aspects: quantity distribution, diversity, and non-equilibrium.

(1) Quantity Distribution Characteristics

Given the disequilibrium between urban population distribution and urban spatial development, this study adopts dual measurement indicators (per unit area and per capita) to evaluate the CPSF quantity distribution, with zonal statistics performed at the subdistrict level. The specific calculation formulas are as follows:

$$D_i = \frac{N_i}{S_i} \quad (1)$$

$$P_i = \frac{N_i}{POP_i} \quad (2)$$

where D_i represents the per unit area indicator for the i -th subdistrict; P_i represents the per capita indicator for the i -th subdistrict; N_i denotes the number of CPSFs in the i -th subdistrict; S_i denotes the area of the i -th subdistrict; and POP_i represents the population of the i -th.

(2) Diversity Distribution Characteristics

The diversity of CPSF distribution can reflect the richness of facility types and the equilibrium of spatial configuration, indicating the rationality and inclusiveness of urban public service supply structure [51]. We adopted the Shannon diversity index (SHDI) as a quantification index to analyze the diversity distribution characteristics of CPSFs at the subdistrict scale. Originating from information theory and widely used in ecology, geography, and other fields [52], the calculation formula is as follows:

$$H_j = -\sum P_{ij} \ln P_{ij} \quad (3)$$

where H_j represents the diversity index of the j -th subdistrict unit, with a value range of $[0, \ln(N)]$. When $H_j = 0$, it indicates that only one type of child public service facility exists within the subdistrict; when $H_j = \ln(N)$, it means that the quantities of all types of facilities are completely equal, and the diversity reaches its maximum value. N denotes the total number of subcategories of child public service facilities; P_{ij} represents the proportion of the i -th subcategory of facilities in the total number of facilities.

(3) Spatial Equilibrium Characteristics

The Gini coefficient, a classical metric for inequality measurement, has been extensively applied in spatial equity analyses of public service facilities [53]. This index systematically evaluates the equilibrium of CPSF distribution across spatial units by quantifying the divergence between facility allocation and population distribution. With a value range of $[0, 1]$, the coefficient approaches 0 when facilities are perfectly equitably distributed, while trending toward 1 indicates increasing spatial inequality in facility distribution.

Additionally, we employ the Location Quotient (LQ) metric to further evaluate the spatial matching degree between CPSF distribution and subdistrict-level child population

distribution, enabling precise assessment of facility allocation equity. The formulation is expressed as follows:

$$LQ_i = \frac{\left(\frac{N_i}{POP_i}\right)}{\left(\frac{N}{POP}\right)} \quad (4)$$

where N_i represents the number of CPSFs in research unit i , and POP_i represents the child population in research unit i . N and POP are the total number of CPSFs and the total child population in the central urban area of Shenyang, respectively. LQ_i is the locational quotient of fairness for the research unit. When $LQ_i = 1$, it indicates that the facility configuration in the unit is in equilibrium with the population size; $LQ_i > 1$ suggests that the facility supply is relatively sufficient and above the average level; $LQ_i < 1$ indicates that the facility supply is insufficient.

2.4.2. Methods for Analyzing Spatial Agglomeration Characteristics of CPSFs

The agglomeration characteristics of CPSFs intuitively reflect the spatial distribution trends of facilities, reveal the patterns and driving mechanisms of resource allocation, and are of great significance for optimizing layout, improving accessibility, and promoting balanced regional development. Spatial autocorrelation analysis is an important tool for revealing the correlation between the attribute values of spatial units and those of their adjacent units. It can be divided into global spatial autocorrelation and local spatial autocorrelation [54]. This study employs the global Moran's I index to quantify the agglomeration characteristics of CPSF spatial distribution, formulated as follows:

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n \sum_{j=1}^n w_{ij}} \quad (5)$$

where $\bar{x}$ represents the mean of the sample; x_i and x_j represent the spatial distribution attribute values of CPSFs for spatial units i and j , respectively; w_{ij} denotes the spatial weight matrix. The value range of I is $[-1, 1]$, where a positive value indicates positive correlation and spatial agglomeration of facilities, a negative value indicates negative correlation and spatial dispersion of facilities, and 0 indicates a random spatial distribution. The significance of the results can be assessed through a standardized test.

Further, the local Moran's I index is employed to analyze the local spatial association patterns between each subdistrict unit and its neighboring units in terms of facility configuration levels. The calculation formula is as follows:

$$I_i = \frac{1}{S^2} (x_i - \bar{x}) \sum_{j=1}^n w_{ij} (x_j - \bar{x}) \quad (6)$$

where parameter definitions align with global Moran's I. Local Moran's I identifies four spatial association types: H-H cluster ($I_i > 0, Z > 0$): High-service unit surrounded by high-service neighbors; L-L cluster ($I_i > 0, Z < 0$): Low-service unit with low-service neighbors; L-H outlier ($I_i < 0, Z < 0$): Low-service unit adjacent to high-service neighbors; H-L outlier ($I_i < 0, Z > 0$): High-service unit surrounded by low-service neighbors.

2.4.3. Factor Selection for CPSF Spatial Distribution

Building on established theoretical frameworks of CPSF spatial heterogeneity drivers, this study develops a multidimensional predictor system encompassing population characteristics, economic development, transportation accessibility, and environmental quality for quantitative analysis. The variables and their descriptions are shown in Table 1. Among them, NTLI, AHP, and ACYC are proxy variables used to indirectly characterize key features that are difficult to measure directly. NTLI supplements GDP by capturing in-

formal economic activities not covered by GDP and reflects real-time economic activity levels. AHP serves as a proxy for regional land value and residents' consumption potential through housing prices. ACYC infers the completeness of children's facility provisions based on the age of community buildings. All indicators were processed using the Z-score standardization method, with the calculation formula as follows:

$$Z_i = \frac{x_i - \bar{x}}{S} \quad (7)$$

where Z_i represents the standardized variable, x_i is the sample value of the variable, $\bar{x}$ is the mean of the variable, and S is the standard deviation of the variable.

Table 1. Influencing factors and explanatory variables of the spatial distribution of CPSFs.

Dimension	Variable	Abbreviation	Description
Population characteristics	Child population density	CPD	Reflects the spatial distribution density of children, which is the basis for planning CPSFs.
	GDP	GDP	Reflects the overall scale and level of regional economic development and measures the local government's financial capacity to invest in CPSFs.
Economic development	Night-time light index	NTLI	Indirectly reflects the real-time economic activity level through the intensity of surface night lighting.
	Average housing price	AHP	Reflects the regional land value and residents' consumption capacity.
	commercial service facility density	CSFD	Measures the distribution density of commercial facilities, representing the regional economic vitality and service supply capacity.
Transportation accessibility	Bus stop density	BSD	Quantifies the spatial coverage of public transport services, reflecting the convenience for children to use CPSFs.
	Subway station density	MSD	Measures the coverage of rapid rail transit, affecting the convenience of children using children's facilities over long distances.
	Road network density	RND	Statistics on the ratio of the total road length to the regional area, a key parameter for assessing transport infrastructure completeness.
Environment quality	Average community completion year	ACYC	Reflects the community renewal degree through the age of buildings (newer communities often have more complete children's facilities).
	Building density	BD	Calculates the proportion of building area to land area, reflecting the intensity of spatial development.
	Residential area density	RAD	Reflects the spatial agglomeration degree of residential land.
	Green space coverage rate	GSCR	Measures the proportion of public green space area, an important basis for assessing the quality of children's outdoor activity environment.

2.4.4. Regression Analysis of CPSF Influencing Factors

Using CPSF distribution density as the dependent variable and 12 dominant factors as independent variables, this study employs a Geographically Weighted Regression (GWR) model to explore the non-stationary effects of these factors on the spatial configuration of CPSFs. As a pivotal methodology in spatial econometrics, GWR incorporates spatial coordinates into the modeling framework, enabling regression coefficients to vary continuously across geographic locations. This approach effectively captures spatial heterogeneity in variable relationships across geographic space [55]. It can reveal local mechanisms of action

that traditional global regression models fail to identify. The mathematical expression is as follows:

$$y_i = \beta(u_i, v_i) + \sum_{k=1}^p \beta_k(u_i, v_i) x_{ik} + \varepsilon_i (i = 1, 2, \dots, n) \quad (8)$$

where y_i is the dependent variable for the i -th spatial unit; x_{ik} is the observed value of the k -th independent variable in unit i ; p is the total number of independent variables; (u_i, v_i) are the geographical coordinates of unit i ; $\beta(u_i, v_i)$ is the spatially varying intercept; $\beta_k(u_i, v_i)$ is the spatially varying coefficient function for the independent variable x_{ik} , reflecting the impact strength and direction of this factor on facility configuration at different locations; ε_i is the independently and identically distributed random error term.

3. Results

3.1. Spatial Distribution Characteristics of CPSFs

3.1.1. Spatial Distribution in the Quantity Distribution of CPSFs

The spatial distribution of CPSFs in Shenyang shows significant differences at the grid scale (Figure 3). Overall, the per-unit-area index presents a concentric-circle distribution structure centered on the urban core, with facilities highly dense in the core area. In contrast, the per capita index presents a patchy distribution, reflecting the spatial differences in the adaptability of facility allocation to population distribution. Specifically, the per capita index of educational facilities is higher in the urban fringe areas and lower in the urban core areas, such as Heping District and Shenhe District. The per capita index of cultural and sports facilities is higher in the east and lower in the west, with relatively higher values in Hunnan District and Dadong District. The per capita index of recreational facilities is scattered, with higher values in core urban areas such as Heping District and Shenhe District and lower values in areas such as Hunnan District and Sujiatun District. The per capita index of medical facilities generally decreases from the urban core area to the fringe areas, with relatively higher values in areas such as Dadong District and Tiexi District.

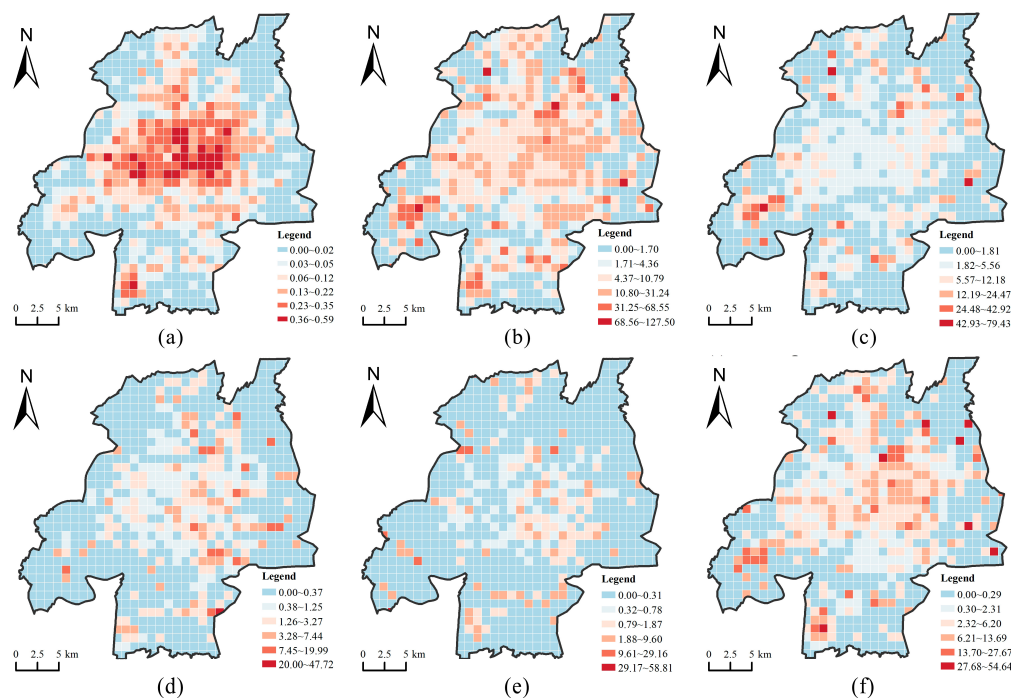


Figure 3. Quantitative distribution characteristics of CPSFs at the grid scale. (a) Comprehensive Index per Unit Area; (b) Comprehensive Index per Capita; (c) Per capita education index; (d) Per capita culture and sports index; (e) Per capita recreation index; (f) Per capita health index.

3.1.2. Spatial Distribution of the Diversity Characteristics of CPSFs

The mean value of the CPSF diversity index in Shenyang City is 1.09, with a standard deviation of 0.10, indicating balanced overall diversity but notable spatial variations. A clear gradient decline is observed from the core urban area to peripheral regions (Figure 4). Heping District, Shenhe District, and Hunnan District exhibit relatively high index values, suggesting a greater diversity of facilities. In contrast, Dadong District, Tiexi District, and Yuhong District show lower values, indicating a need for further facility diversification.

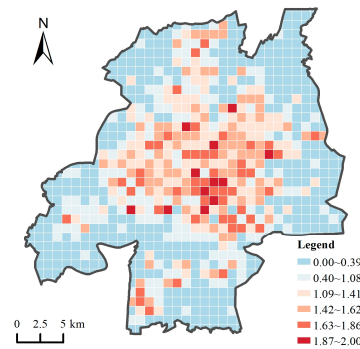


Figure 4. Diversity distribution characteristics of CPSFs at the grid scale.

3.1.3. Spatial Distribution of the Uneven Characteristics of CPSFs

The Gini coefficients of CPSFs in Shenyang are as follows: 0.28 for educational facilities, 0.39 for cultural and sports facilities, 0.27 for health facilities, and 0.35 for recreational facilities. All values are below the fairness threshold of 0.4, indicating a reasonable overall distribution. However, the distribution of location entropy values across different regions is uneven, with an average of 1.19, a minimum of 0.16, and a maximum of 3.44. Among these, the location entropy of 90.32% of the study units is below 1, while that of 9.68% of the units is above 1. This suggests that although the facilities in most study units meet the basic needs of children, the problem of spatial distribution imbalance still exists (Figure 5).

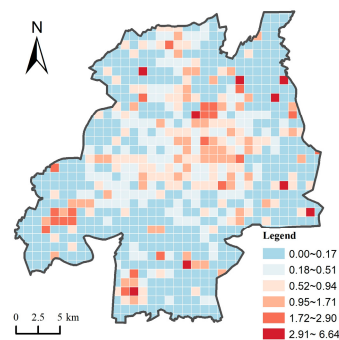


Figure 5. Uneven distribution characteristics of CPSFs at the grid scale.

3.2. Spatial Agglomeration Characteristics of CPSFs

The results of the global spatial autocorrelation analysis for CPSFs in Shenyang's central urban area (Table 2) show that both overall facilities and individual facility types passed the significance test ($p < 0.05$), indicating significant spatial clustering. Additionally, Moran's I index values greater than 0 suggest a positive correlation in the distribution of all facility types.

Table 2. Analysis results of Moran's Index of CPSFs.

Facility Type	Moran's I Value	Z-Score
Educational Facilities	0.5884	23.2133
Health Facilities	0.65 i	25.9134
Cultural and Sports Facilities	0.4758	18.8949
Recreational Facilities	0.3532	14.0905
Overall Facilities	0.7568	29.8452

Local spatial autocorrelation analysis and local LISA cluster maps reveal the local clustering characteristics of CPSFs (Figure 6). Overall, the central part of the study area constitutes high–high agglomeration, while the fringe area is dominated by low–low agglomerations with inadequate facilities. Specifically, children's educational facilities form dual-core high agglomeration areas in northern Tiexi District, southern Huanggu and Dadong Districts, and western Shenhe District. These areas are characterized by dense child populations and abundant educational resources, effectively meeting the demand for proximity to schools. In the urban core, high agglomerations of children's health facilities leverage concentrated professional medical resources, facilitating resource sharing and expanding service coverage. Influenced by cultural functional zone planning, children's cultural facilities exhibit high agglomeration in the central-eastern region, forming a hierarchical service network with significant positive agglomeration (high–high clustering). Children's recreational facilities form high agglomerations in the urban core north of the Hun River due to the concentration of public spaces such as urban parks and squares that provide abundant outdoor activity venues for children.

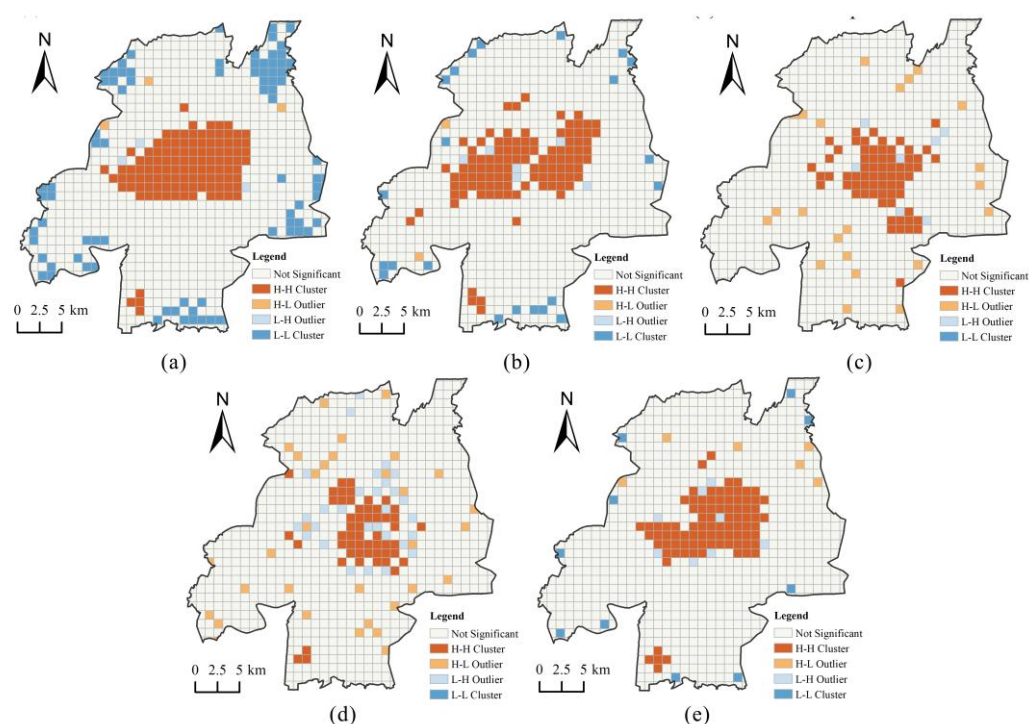


Figure 6. LISA map of the spatial distribution of CPSFs. (a) Overall children's facilities; (b) Educational facilities; (c) Cultural and sports facilities; (d) Leisure and recreation facilities; (e) Safety and health facilities. (Local spatial autocorrelation results show clustering patterns. "Not Significant" denotes units with $p \geq 0.05$ ($|Z| \leq 1.96$, no stable agglomeration)).

3.3. Regression Analysis Results of Influencing Factors on CPSFs

In this study, we conducted multicollinearity tests on the selected 12 variables. The results showed that the variance inflation factor (VIF) values were all below 5, indicating no significant multicollinearity issues among the variables. These variables were therefore suitable for investigating the influencing factors of CPSF spatial distribution. Table 3 presents the key parameters of the GWR model, demonstrating its applicability. Specifically, the adjusted R^2 of the GWR model reached 0.8883, implying that the selected variables could explain 88.83% of the spatial distribution characteristics of CPSFs. The bandwidth of the GWR model was determined via the leave-one-out cross-validation (LOOCV) method. It can thus be concluded that the combination of the GWR model and the selected variables effectively captures the spatial heterogeneity of the factors influencing CPSF spatial distribution.

Table 3. Estimated parameters of GWR model.

Statistics	Parameters
Bandwidth	6127.0680
Residual Squares	80.9364
Sigma	0.3344
AICc	605.5218
R^2	0.9033
R^2 Adjusted	0.8883

The GWR model was applied to analyze the relationship between CPSF distribution density (dependent variable) and 12 influencing factors (independent variables). The results are shown in Table 4.

Table 4. Statistics of GWR coefficients for overall CPSFs.

Variable	Min	Q1	Median	Q3	Max	Mean	Std. Dev.
GDP	−0.0862	−0.0265	0.0003	0.0224	0.0497	−0.0038	0.0322
NTLI	−0.3000	0.0686	0.1020	0.1449	0.2082	0.1020	0.0503
AHP	−0.3163	−0.1085	−0.0789	−0.0483	0.0676	−0.0720	0.0599
ACYC	−0.0300	0.0568	0.1029	0.1469	0.2546	0.1012	0.0665
CSFD	0.1233	0.2084	0.2875	0.3737	0.6710	0.3103	0.1310
RAD	0.1579	−0.3372	0.4085	0.4885	0.6539	0.4238	0.1040
BD	0.0112	0.0642	0.0903	0.1766	0.3054	0.1160	0.0714
CPD	−0.2517	0.0319	0.0749	0.1147	0.18843	0.0650	0.0725
BSD	−0.0218	0.0380	0.0719	0.1076	0.1482	0.0721	0.0397
MSD	−0.1080	−0.0635	−0.0445	−0.0168	0.1447	−0.0384	0.0383
RND	−0.1071	−0.0404	−0.0160	0.0177	0.0903	−0.0085	0.0447
GSCR	−0.0372	0.0427	0.0678	0.0992	0.3556	0.0753	0.0493

The main positive factors influencing CPSF distribution are RAD and CSFD, while the key negative factors are AHP and MSD. Figure 7 demonstrates that RAD exerts a stronger influence on facility distribution in peripheral areas. These regions typically feature underdeveloped facility infrastructure, abundant land availability, and flexible urban planning. Population growth in such areas may create supply–demand imbalances, thus stimulating facility expansion. Conversely, central areas with saturated facilities and constrained land resources show diminished responsiveness to demographic changes. AHP is generally negatively correlated with the distribution of CPSFs, with its inhibitory effect increasing from the core area to the peripheral area. Land development in high AHP areas is market-oriented and tends to focus on short-term, high-yield projects, which significantly squeezes the supply space of CPSFs. In the core area, however, the rigid demand for

functional supporting facilities promotes policy intervention to ensure the construction of CPSFs, thereby weakening the inhibitory effect of AHP on its distribution. The inhibitory effect of MSD is more significant in land-scarce central areas, while it gradually weakens towards the northern and southern surrounding areas and shows a positive effect in a small number of peripheral areas.

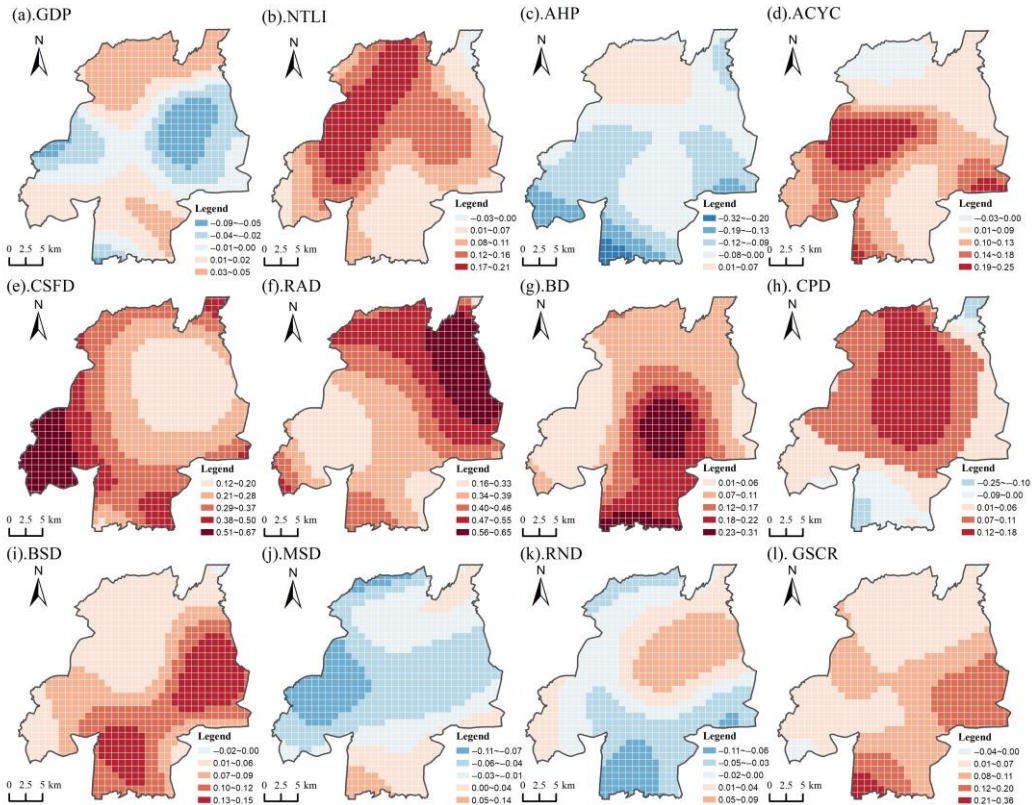


Figure 7. Spatial differentiation of GWR coefficients for overall CPSFs.

Table 5 presents the results of the regression analysis on the factors influencing the distribution of public facilities in children’s education, culture and sports, leisure and recreation, and safety and health.

Table 5. Statistical data of GWR coefficients for four types of CPSFs.

Variables	Education		Culture and Sports		Leisure and Recreation		Safety and Health	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
GDP	−0.0726	−0.1019	−0.0080	0.0275	0.1419	0.1280	−0.0012	0.0002
NTLI	0.0161	0.0379	0.2908	0.2875	0.1457	0.1359	0.0574	0.0613
AHP	−0.0473	−0.0308	0.0235	0.0314	0.0385	0.0363	−0.0817	−0.0736
ACYC	0.1606	0.1651	−0.0412	−0.0338	−0.0056	0.0106	0.0226	0.0199
CSFD	0.1682	0.2463	0.2121	0.2774	0.1472	0.1975	0.2985	0.2974
RAD	0.3871	0.4381	0.1276	0.1254	0.2184	0.2307	0.4540	0.4680
BD	0.1445	0.1524	0.0532	0.0526	−0.0340	−0.0410	0.0297	0.0510
CPD	0.0568	0.0668	0.0869	0.0827	0.1760	0.1648	0.0720	0.0776
BSD	0.1084	0.1047	0.0479	0.0602	0.0122	0.0142	0.0358	0.0358
MSD	−0.0585	−0.0584	−0.0344	−0.0137	0.0246	0.0313	−0.0364	−0.0244
RND	−0.0661	−0.0717	−0.0549	−0.0430	−0.0286	−0.0292	−0.0359	−0.0108
GSCR	0.0417	0.0572	0.1037	0.1288	0.1609	0.1723	0.0685	0.0631

As shown in Figure 8, the spatial distribution of educational CPSFs exhibits significant heterogeneity due to multiple influencing factors. CSFD has a strong positive effect ($\beta = 0.2463$), indicating that areas with concentrated commercial activities are more conducive to supporting the construction of educational facilities. Similarly, ACYC shows a strong positive correlation ($\beta = 0.1651$), though its effect weakens from core to peripheral areas. Newly developed areas prioritize educational infrastructure due to social demand and policy guidance, while core areas exhibit amplified effects owing to urban renewal intensity. Conversely, RND negatively correlates with educational CPSF distribution ($\beta = -0.0717$), with suppression intensifying toward peripheries. However, this effect diminishes notably in old industrial zones like the Dadong and Tiexi Districts.

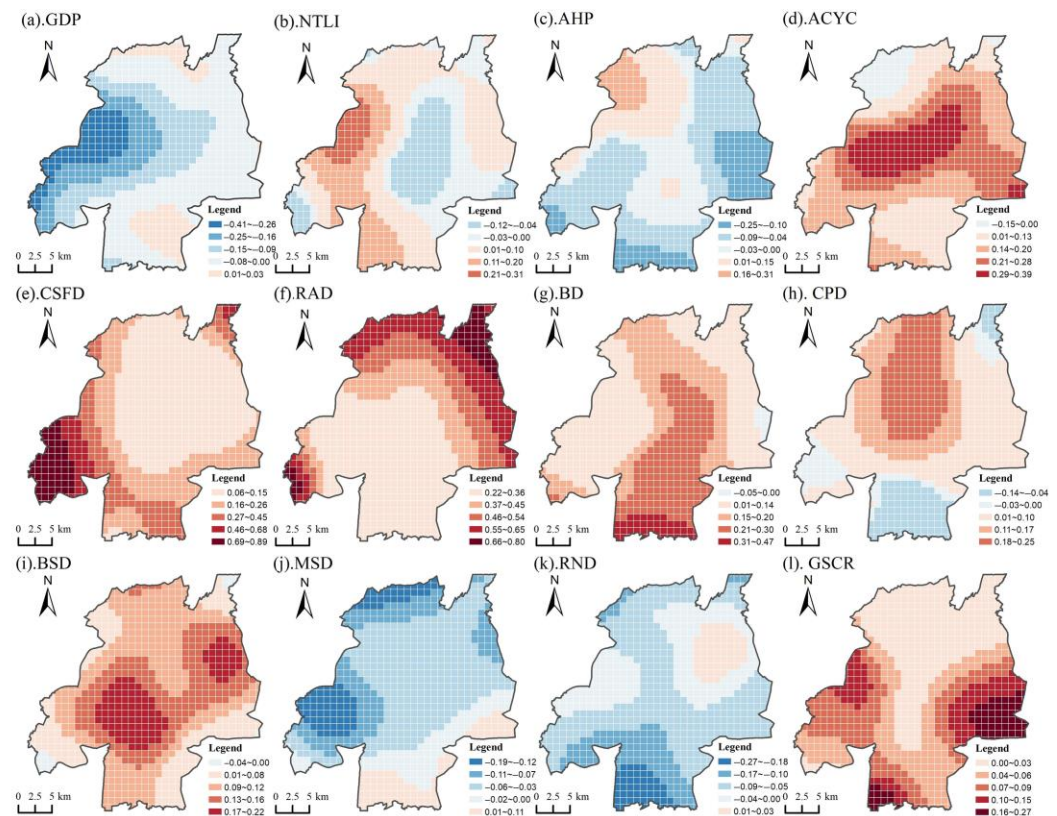


Figure 8. Spatial differentiation of GWR coefficients for educational CPSFs.

As shown in Figure 9, the spatial distribution of health and safety CPSFs is influenced by multiple socioeconomic and policy factors. RAD exhibits a significant positive association with facility distribution ($\beta = 0.4680$). Since communities are the main activity areas for children, the higher the RAD, the greater the demand for children's health services. In the Hunnan District, there is a large number of newly constructed residential buildings, a rapid influx of population, and relatively abundant land resources. Therefore, the positive effect of residential area density on the layout of health facilities is greater. AHP demonstrates a significant negative association with facility distribution ($\beta = -0.0736$). In high-priced housing areas, elevated land costs create three challenges for public health facility development: difficult land acquisition, high construction costs, and spatial competition from commercial real estate. The scarcity of land resources in the city center further intensifies this negative effect. In addition, the impact of GDP and NTLI on the distribution of facilities is relatively small ($\beta = 0.0002$ and 0.0613 , respectively). This suggests that health infrastructure placement is primarily demand-driven rather than correlated with macroeconomic indicators.

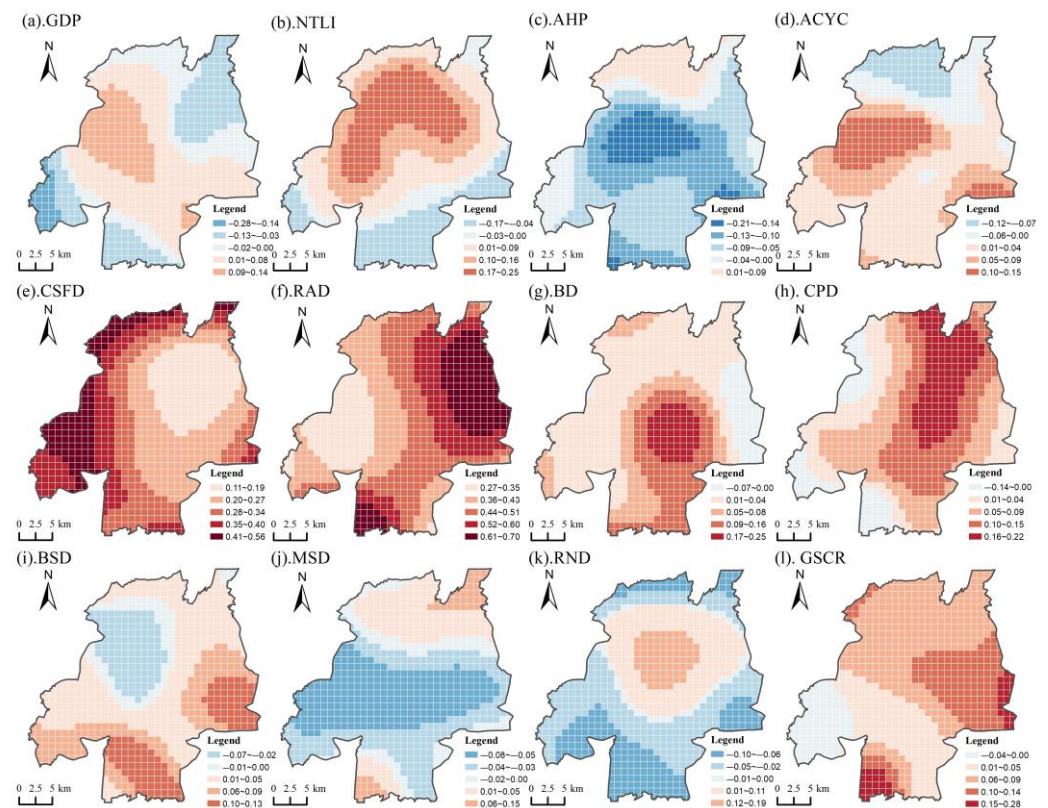


Figure 9. Spatial differentiation of GWR coefficients for health and safety CPSFs.

As shown in Figure 10, the spatial distribution of cultural and sports CPSFs exhibits significant spatial heterogeneity. NTLI demonstrates a significant positive association with cultural–sports facility distribution ($\beta = 0.2875$), exhibiting distance-decay effects from urban cores to peripheries. The core area, with its dense population and vibrant night-time economy, is more likely to attract investments in cultural and sports facilities from both the government and the market. In contrast, the peripheral areas have a smaller scale of night-time economy, which limits their capacity to drive the development of such facilities. MSD has a local negative effect on the distribution of cultural and sports facilities, with an average coefficient value of -0.0137 and a range of -0.1042 to 0.2588 . A high density of subways in the core area can lead to a sharp increase in land costs and a strain on spatial resources, thereby inhibiting the layout of cultural and sports facilities. In contrast, in the peripheral areas, moderately increasing MSD can improve accessibility and promote the layout of cultural and sports facilities. The impact of bus stop density on the distribution of cultural and sports facilities is characterized by significant spatial heterogeneity, with an average coefficient of 0.0602 , ranging from -0.0464 to 0.2303 . Specifically, in Hunnan District, an increase in bus stop density can effectively promote the layout of cultural and sports facilities. In contrast, in Tiexi District, the addition of new bus stops tends to encroach upon the already limited public space, thereby exerting a negative inhibitory effect on the distribution of cultural and sports facilities.

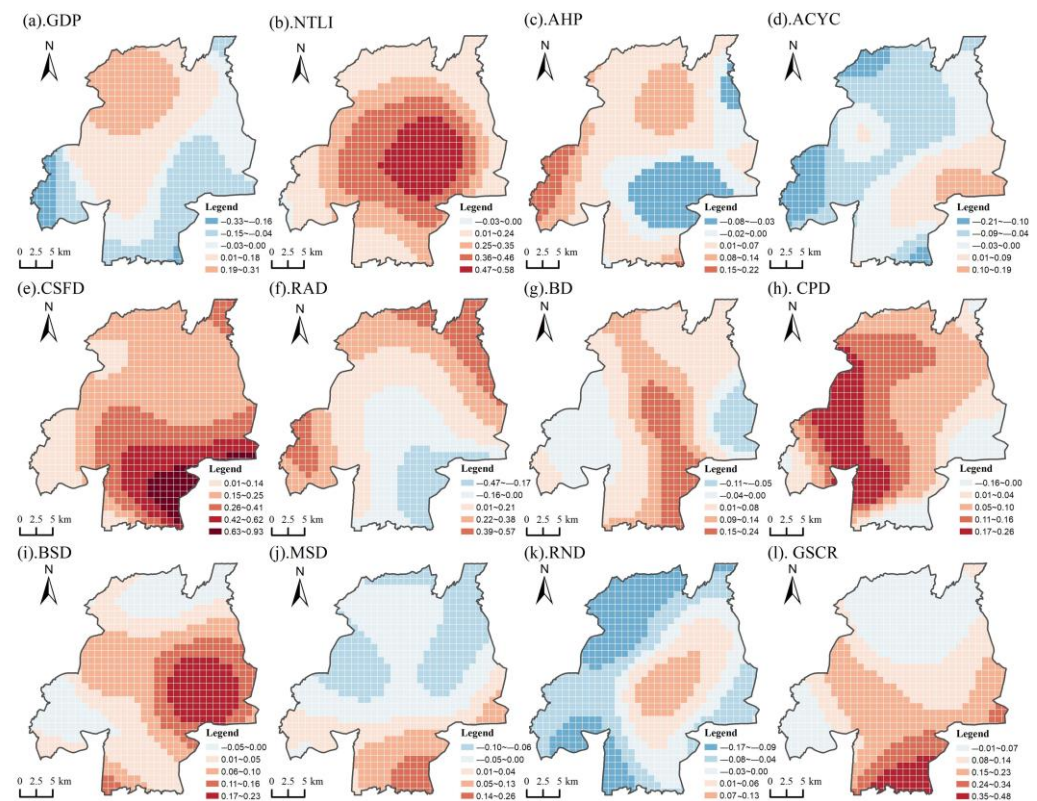


Figure 10. Spatial differentiation of GWR coefficients for cultural and sports CPSFs.

As shown in Figure 11, GSCR has a positive driving effect on the distribution of recreational CPSFs ($\beta = 0.1723$), and its impact intensity increases from the core area to the peripheral area. In the core area, land is scarce, and green spaces are mostly small-scale street-side green spaces, which focus on ecological regulation and landscape beautification; the construction space for recreational facilities is limited. In contrast, the peripheral area emphasizes the integration of ecological and recreational functions and has reserved space for large-scale parks and suburban green spaces, providing ample carriers for the layout of recreational facilities. BD has a negative impact on the distribution of recreational facilities ($\beta = -0.0410$). In areas with high building density, space resources are scarce, and public spaces are largely occupied, making it difficult to plan and construct recreational facilities for children. Moreover, the narrow activity spaces pose safety hazards and are not conducive to children's outdoor activities. The spatial effects of RND on the distribution of recreational facilities exhibit significant differentiation. In core areas, high RND generates heavy traffic volumes and high vehicle speeds, creating safety hazards and reducing the suitability for locating recreational facilities; thus, increased RAD exerts a negative impact. By contrast, in peripheral areas, a well-developed road network enhances the accessibility of recreational facilities. Roadside areas can be equipped with pocket parks and street-side recreational nodes, such that increased road network density actually promotes the development of recreational facilities.

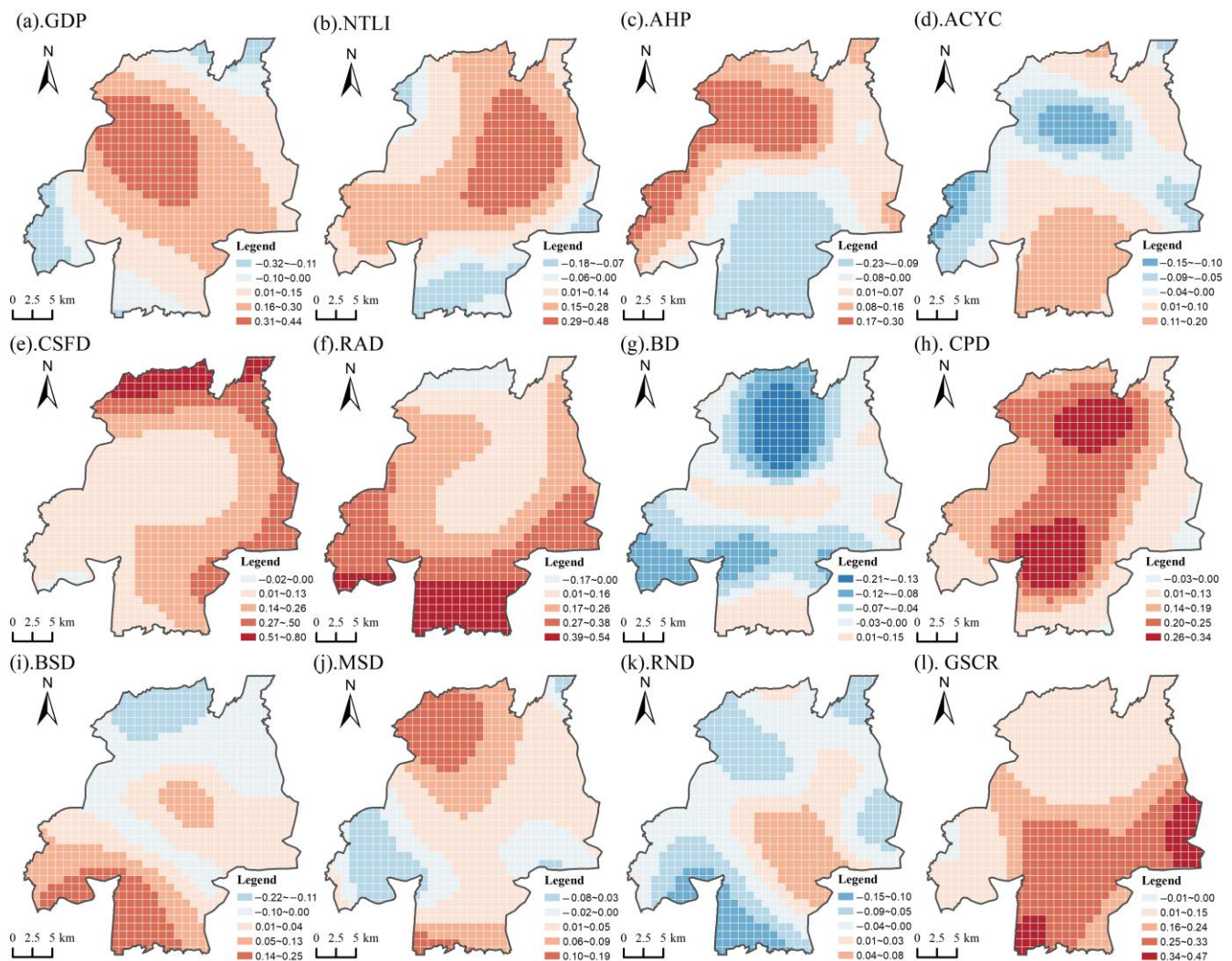


Figure 11. Spatial differentiation of GWR coefficients for recreational CPSFs.

4. Discussion

4.1. Spatial Distribution Differences of CPSFs

Currently, China's urban CPSFs face significant challenges, including supply–demand contradictions and spatial imbalances. Optimizing CPSF spatial distribution and enhancing facility accessibility and utilization efficiency are key to promoting child-friendly city construction and achieving high-quality urban development with equity [32]. Taking Shenyang's urban area as the study region, we analyzed the CPSF spatial distribution characteristics using the Shannon diversity index and location entropy. Facility agglomeration was evaluated using spatial autocorrelation. The results indicate significant spatial disparities in CPSF distribution across Shenyang.

The core area, comprising Heping District, Shenhe District, and Huanggu District, exhibits a high facility density per unit area. However, the concentration of the child population results in varying per capita facility indicators. While the per capita indicators for recreational and medical facilities are relatively high, those for educational facilities are comparatively low, indicating a demand gap. Influenced by urban renewal initiatives and policy measures, the core area boasts a high diversity index and a rich array of facility types. Spatial autocorrelation analysis reveals that the core area is characterized by a high–high agglomeration pattern. Medical facilities are highly concentrated, leveraging centralized professional resources to facilitate resource sharing. Recreational facilities form

high agglomeration areas due to the concentration of public spaces such as parks and squares. The emerging development area, specifically Hunnan District, shows relatively high per capita indicators for cultural and sports facilities but lower per capita indicators for recreational facilities. The supply of facilities in this area lags behind population growth. This area has a high diversity index and a relatively rich variety of facility types, influenced by the spillover effects from the core area. However, except for cultural and sports facilities, other types of facilities do not exhibit significant high–high agglomeration characteristics. In the old industrial areas, including Tiexi District and Dadong District, Tiexi District has a high agglomeration of educational facilities in the northern part, while Dadong District has relatively high per capita indicators for cultural and sports facilities and medical facilities. However, these areas have a low diversity index and a limited variety of facility types, which need to be further enriched. The northern part of Tiexi District and Dadong District form a dual-core agglomeration for educational facilities, relying on a dense child population and abundant educational resources to meet the demand for nearby schooling. In the peripheral areas, such as Yuhong District and Sujiatun District, Yuhong District has a low facility diversity index, and Sujiatun District has relatively low per capita indicators for recreational facilities. The location entropy of most areas is below 1, indicating an imbalance in the supply and demand of facilities. These areas are characterized by low–low agglomeration patterns with insufficient facility supply.

Overall, the spatial distribution of CPSFs in Shenyang exhibits core–periphery gradient differentiation. The core areas demonstrate high facility density yet experience substantial per capita pressure, whereas peripheral areas are characterized by monotypic facility distribution and supply inadequacy. Significant spatial autocorrelation patterns emerge: high-value clusters concentrate in core areas and selected old industrial zones, while low-value clusters predominantly occupy edge areas. These findings establish a critical empirical foundation for optimizing urban children’s public service facility allocation.

4.2. Spatial Heterogeneity of the Influencing Factors for CPSFs

Currently, research on the spatial layout of public facilities and its influencing factors has made significant progress [22,26,56–58], but there remains a notable gap in research specifically targeting CPSFs. Although some scholars have examined the distribution of facilities such as children’s outdoor activity spaces and commuting spaces [59–62], these studies generally lack a macroscopic perspective at the urban scale. Hence, this paper employs a GWR model to analyze the spatial distribution of CPSFs and the spatial heterogeneity of its influencing factors within the central urban area of Shenyang at the city-wide scale. The study selects 12 variables, covering multiple dimensions such as population, transportation, economy, and environment. The spatial heterogeneity of the influencing factors is manifested in the differences in the estimated coefficients across space in the GWR model. Spatial optimization strategies for CPSFs need to take this spatial heterogeneity into account to provide differentiated strategies for different regions.

The effects of influencing factors can be categorized into positive, negative, and threshold effects. Overall, RAD and CSFD are the main positive factors affecting facility distribution, while AHP and MSD are the primary negative factors (Table 4). Spatial heterogeneity analysis indicates (Figure 8) that the influence of CSFD, RAD, and GSCR is stronger in the peripheral areas than in the core areas due to the peripheral areas’ abundant land resources, high planning flexibility, and good ecological foundation. Specifically, the peripheral areas’ abundant land and low development costs allow for large-scale commercial and residential development, driving the coordinated development of commercial and children’s facilities and necessitating the synchronous provision of children’s facilities in new residential areas. Additionally, the peripheral areas’ good natural ecological base, with

low costs and ample space for green space construction, can be integrated with children's recreational functions. In contrast, the core areas have relatively saturated commercial and residential densities, fragmented green spaces, and high construction difficulties, resulting in a limited pull effect on children's facilities. The positive effects of BD, NTLL, and CPD are greater in the core areas than in the peripheral areas, mainly relying on the core areas' resource agglomeration advantage. The core areas' dense buildings and high functional complexity meet the demand for children's facilities through vertical space utilization and facility sharing. The core areas' vibrant night-time economy gathers people and consumption through lighting, creating demand for children's night-time activities and driving facility layout. The core areas' concentrated child population and strong, rigid demand lead to prioritized public services, while the peripheral areas' scattered child population makes it difficult to form a scale effect in demand, resulting in weak facility matching motivation.

Although MSD, AHP, and RND are negative influencing factors, they exhibit threshold effects in space, meaning they have positive effects in a few areas. A higher MSD station density in the core area tends to inhibit facility layout, while a higher station density in the peripheral areas, especially in emerging development areas like Hunnan District, can enhance accessibility and promote facility development. In the old industrial areas, such as Tiexi District and Dadong District, RND's negative impact on children's public service facilities is relatively weak and even shows a positive effect. These areas established a stable spatial relationship between facilities and roads based on early industrial support. During transformation, coordinated road reconstruction and functional renewal avoid spatial encroachment and enhance facility accessibility through improved road networks, mitigating the core area's common contradiction of increased road density squeezing facility space. In contrast, the core area's extremely limited land resources lead to road construction prioritizing high-density traffic demands, which encroaches on facility space. The core area's highly complex functions and mature development limit the adjustment space for the road network and facility layout, making it difficult to optimize the relationship between the two simultaneously, resulting in a more pronounced negative impact of increased road density on facilities.

The distribution of different types of facilities is driven by distinct mechanisms. The distribution of educational facilities is mainly driven by RAD and CSFD, reflecting their dependence on population distribution and community service networks, and is also subject to the rigid constraints of school district policies. Health facilities are strongly correlated with RAD but weakly associated with economic indicators such as GDP, highlighting their demand-oriented and inclusive nature. The distribution of cultural and sports facilities primarily responds to NTLL, with usage peaks coinciding with the city's active night-time periods, and they often have synergistic effects with commercial activities. Recreational facilities, on the other hand, rely on GSCR, as green spaces provide the spatial carrier for such facilities.

The same factor may exert different impacts on different types of facilities. BD has a positive effect on educational, health, and cultural-sports facilities, as these facilities can enhance efficiency through spatial compound utilization; however, it has a negative effect on recreational facilities, which require open space to ensure the realization of their functions. The positive impact of ACYC on educational, healthcare, and recreational facilities stems from the high planning standards, ample land resources, and modern-demand-oriented supporting facilities in newly developed areas. However, due to the long construction cycle of cultural and sports facilities and their dependence on population accumulation, the short-term supply in newly developed areas lags behind the pace of development, resulting in a negative impact on such facilities.

4.3. Optimization Strategies for CPSF Spatial Layout

Differentiated planning strategies should be formulated to address the spatial distribution characteristics of CPSFs in Shenyang's urban core area. The core area faces challenges such as rising demand from the child population and constrained land resources. Approaches like urban renewal can be leveraged to revitalize existing land use, thereby creating additional spatial capacity for CPSF siting. Concurrently, promoting functional integration of educational and health facilities with community service centers and parkland green spaces can mitigate the spatial pressure caused by single-function facility clustering. The Tiexi District should address issues such as homogeneous facility types and delayed upgrades by revitalizing fragmented land use and diversifying facility categories. It should transform industrial heritage sites into children's activity spaces, such as popular science education centers and cultural-sports complexes, to enhance space utilization efficiency, diversify facility types, and meet the varied needs of children. The Hunnan District should tackle the lag in facility supply behind population growth. In developing emerging clusters, a synchronous planning mechanism for population and facilities should be implemented to ensure standardized construction of childcare facilities, basic education facilities, and medical facilities. Additionally, recreational green spaces and cultural-sports facilities should be reserved in tandem with residential area planning to avoid the passive scenario of 'building first, filling gaps later.

4.4. Research Contributions and Limitations

This paper focuses on the central area, exploring differences in CPSFs between core and peripheral areas, as well as old and new districts. By revealing spatial distribution patterns of CPSFs and the differential effects of the influencing factors, this study breaks through the limitations of traditional micro community studies. Through a quantitative analysis of the spatial heterogeneity of facility types (education, health, cultural and sports, and recreation) under factors such as population density and land use, this research constructs a facility configuration analysis framework aligned with urban development dynamics and proposes differentiated strategies. The study provides a scientific basis for spatial planning in Shenyang's child-friendly city construction and offers reference solutions for other cities to address supply-demand contradictions in children's facilities.

However, several limitations warrant attention. First, the study's conclusions are constrained by the availability and detail level of data. Specifically, the lack of fine-grained micro-data on children's real-time activity trajectories and facility usage frequencies limits the depth of analysis into how spatial configurations influence actual utilization. Future research should refine the indicator system for influencing factors, address the scarcity of micro-scale data on children's activity patterns and facility utilization rates, and employ a mixed-methods approach (remote sensing imagery, questionnaire surveys, and in-depth interviews) to comprehensively evaluate the alignment between facility supply and children's spatial needs. Additionally, this research relies solely on static cross-sectional data and lacks real-time dynamic monitoring of facility performance and demand changes. To address this, subsequent studies should establish a dynamic monitoring mechanism that integrates urbanization trends and evolving children's needs, enabling continuous optimization of allocation strategies and promoting the long-term balanced development of CPSFs.

5. Conclusions

This paper employs methods such as the Shannon diversity index and location entropy to analyze the spatial distribution characteristics of CPSFs in the urban central area of Shenyang. It assesses the agglomeration degree of CPSFs through spatial autocorrelation

and finally uses GWR to explore the influencing factors and their mechanisms of action. The conclusions are as follows:

- (1) The spatial distribution of CPSFs exhibits significant disparities. In core urban areas, such as Huanggu District, Heping District, and Shenhe District, per unit area indices are notably high, whereas per capita indices are comparatively low. The per capita index for educational facilities is particularly low, indicating a demand gap. In old urban areas, such as Tiexi District, educational and recreational facilities are relatively sufficient, but cultural and sports facilities are scarce in quantity and diversity. In new urban areas, such as Hunnan District, facilities show high diversity with abundant cultural and sports resources, but medical and educational facilities are insufficient, and their supply lags behind population growth.
- (2) The Gini coefficients of all facility types are below the equity threshold of 0.4. However, the location entropy values across grid cells are unevenly distributed, with 90.32% of the study units recording values below 1, indicating imbalances between supply and demand.
- (3) All facility types demonstrate significant positive agglomeration characteristics. Educational facilities form a dual-core pattern in northern Tiexi District and southern Huanggu District. Health facilities cluster around core-area medical resources. Cultural, sports, and recreational facilities establish new agglomeration nodes in the eastern new district.
- (4) The spatial distribution of CPSFs is determined by five dimensions: population, transportation, economy, and environmental quality. Specifically, residential area density and commercial service facility density serve as primary positive drivers, whereas road density and average housing price act as key negative constraints. Moreover, the intensity of influencing factors varies across facility types. Educational facilities demonstrate additional dependence on the construction year of residential areas; healthcare facilities are significantly influenced by residential density; while cultural, sports, and recreational facilities exhibit strong correlations with both green space coverage and the night-time light index.
- (5) The impacts of influencing factors exhibit spatial heterogeneity. Positive drivers such as children's population density significantly affect peripheral and new urban areas. Negative factors like building density show pronounced inhibitory effects in old urban areas. Threshold factors, including subway station density and public transport station density, demonstrate spatial divergence: inhibitory in old urban areas but positively promoting in peripheral and new urban areas.

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Data Availability Statement: Public data (e.g., Shenyang's administrative boundaries, land use data from CLCD, urban planning documents) can be accessed via original sources, with links and DOIs in Section 2.3. Restricted data (e.g., detailed child population, commercial POI) are subject to privacy and licensing; access is via application procedures detailed in Section 2.3. Spatial analysis methods (GWR, spatial autocorrelation) were conducted using GIS software (ArcGIS 10.8, GeoDa 1.18), with details in Section 2.4. Contact the corresponding author Weisong Sun* for data inquiries.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CPSFs	Children’s Public Service Facilities
GWR	Geographically Weighted Regression
POI	Point-of-interest
SHDI	Shannon Diversity Index
LQ	Location Quotient
CPD	Child population density
GDP	Economic development
NTLI	Night-time light index
AHP	Average housing price
CSFD	Commercial service facility density
BSD	Bus stop density
MSD	Subway station density
RND	Road network density
ACYC	Average community completion year
BD	Building density
RAD	Residential area density
GSCR	Green space coverage rate

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