Evaluation of Spatial Configuration of Residential Communities and Public Service Facilities from the Perspective of the 15-Minute Living Circle: A Case Study of Urumqi City (Postprint)

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Abstract

High-quality development of new urbanization places greater emphasis on enhancing people' s sense of happiness and gain. Increasing the construction of public services within the "15-minute life circle" can effectively improve people' s life satisfaction. Based on national "15-minute life circle" construction requirements and using Amap POI data, this study employs methods such as kernel density estimation, buffer analysis, and raster analysis to evaluate the spatial coverage characteristics of public service facilities in Urumqi and comprehensively assess the spatial matching status between residential communities and various facilities. The research shows: (1) The spatial layout characteristics of different types of basic public service facilities vary, which is not only related to the agglomeration distribution of residential communities but also reflects the attribute characteristics of different facilities. (2) Different types of basic public service facilities have varying coverage rates within the "15-minute life circle" of residential communities. Public transportation facilities represented by bus stops have the highest coverage rate. Among convenience commercial facilities, daily service facilities such as supermarkets, fruit and vegetable stores, and barbershops have relatively higher coverage rates than banks and telecommunications business halls. Among educational facilities, kindergartens have the highest coverage rate, followed by primary schools, while middle schools have relatively lower coverage rates. The coverage rates of medical facilities show no significant differences across types, with community health service centers, pharmacies, and clinics basically achieving 95% coverage. (3) There are significant regional differences in the compliance rates of spatial configuration between different types of basic public services and residential spaces. In areas with denser population distribution, the proportion of residential communities where all four types of public service facilities (convenience commerce, education,

medical care, and transportation) meet standards is higher, while the compliance rates of medical and convenience commercial facilities are relatively low in peripheral areas and newly built urban districts with relatively low population density. (4) In building the "15-minute activity circle," Urumqi should focus on strengthening public service facilities in newly built urban districts, especially convenience commercial facilities and primary-level medical facilities, while old urban districts should enhance the renewal and supporting of public services during renovation processes.

Full Text

Evaluation of Spatial Configuration of Residential Communities and Public Service Facilities from the Perspective of a "15-Minute Life Circle" : A Case Study of Urumqi City

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Abstract

High-quality development of new urbanization places greater emphasis on enhancing people's sense of happiness and fulfillment. Strengthening public service construction within the "15-minute life circle" can effectively improve residents' life satisfaction. Based on national requirements for "15-minute life circle" construction and using high-precision POI data, this study employs kernel density estimation, buffer analysis, and raster analysis to examine the spatial coverage characteristics of public service facilities in Urumqi and comprehensively evaluate the spatial matching between residential communities and various facilities. The findings indicate that: (1) The spatial layout characteristics of different types of basic public service facilities vary, showing certain correlations with the agglomeration distribution of residential communities while also reflecting the distinct attributes of different facilities. (2) The coverage rates of different basic public service facilities within residential communities' "15-minute life circle"show notable differences. Public transportation represented by bus stops has the highest coverage rate. Among commercial facilities, daily service establishments such as supermarkets, fruit and vegetable shops, and barbershops have relatively higher coverage than banks and telecommunications business halls. Among educational facilities, kindergartens have the highest coverage, followed by primary schools, with middle schools showing relatively lower coverage. The coverage differences among medical facility types are not significant, with community health service centers, pharmacies, and clinics basically achieving 95% coverage. (3) Significant regional differences exist in the compliance rates of different basic public services with residential spatial configuration. In areas with

higher population density, the proportion of residential communities where all four categories of public service facilities (commercial, educational, medical, and transportation) meet standards is higher. In contrast, peripheral areas with relatively low population density and newly developed urban districts show lower compliance rates for medical and commercial facilities. (4) Constructing a "15-minute life circle"in Urumqi should focus on strengthening public service 配套设施 in newly developed urban areas, particularly convenience commercial facilities and primary-level medical facilities, while older urban districts should enhance public service updates and 配套设施 during renovation processes.

Keywords: public service facilities; residential community; 15-minute life circle; spatial configuration; Urumqi City

1. Introduction

In recent years, as China's urban construction and management level has steadily improved, the urbanization process has begun to shift from quantitative expansion to quality enhancement. High-quality urban development requires greater attention to residents' quality of life and spiritual and cultural needs, making urban life convenience and equity a crucial task for achieving high-quality urban development. The "15-minute life circle" represents the sphere most closely related to residents' daily lives, forming a circle encompassing various public service facilities that address basic needs within a 15-minute walk from residences. This concept serves as both a spatial carrier for quality living and a grassroots unit for improving social governance. Meeting residents' needs for accessing various public service facilities within a 15-minute walk can better respond to people' s aspirations for a better life and enhance citizens' sense of gain and happiness.

In recent years, cities such as Shanghai and Jinan have successively issued technical guidelines for constructing 15-minute community life circles, clarifying construction goals and requirements for different circles. In 2018, the newly promulgated "Standard for Urban Residential Area Planning and Design" further defined the hierarchical construction of life circles. How to examine current urban construction and public service spatial configuration according to 15-minute life circle requirements, evaluate existing urban basic public service facility planning and construction levels based on these requirements, identify problems, and propose development ideas and suggestions for improving urban basic public services have become hot research topics among scholars.

Foreign scholars have long emphasized research on public service facility spatial configuration, focusing initially on location selection and supply models for public service facilities, then on spatial equity of public service supply, and subsequently on spatial differentiation and accessibility of public service facilities, as well as evaluation and site selection using new methods and technologies. These research findings have profoundly influenced theoretical discussions and

empirical studies on domestic public service facility layout. Currently, Chinese scholars' research on public service facilities mainly involves spatial layout, optimized layout, accessibility, spatial distribution characteristics, and social differentiation, yielding substantial results. For instance, Zhan Dongsheng et al. analyzed public service facilities in Beijing and found that different facilities exhibit significant spatial agglomeration characteristics at various spatial scales, though spatial agglomeration intensity and characteristic scales differ markedly. Liu Jing et al. studied public medical service facilities in Beijing and found that while layout configuration basically meets residents'service radius demands, community health service facilities have low utilization efficiency. Zhu Yuanyuan et al. discovered that accessibility to public cultural facilities in Wuhan shows a spatial differentiation pattern of "better in the center, worse in the periphery." Wang Xingping analyzed the spatial distribution and construction of public service facilities in different communities in Nanjing' s main urban area and the spatial distribution characteristics of different types of public service facilities, proposing suggestions for optimizing spatial layout.

From the perspective of public service facility layout research, domestic scholars have focused more on urban overall public service facility configuration and accessibility, with relatively less research on correlations with residents' activity behavior. The "15-minute activity circle" research fills this gap, effectively combining residents' lives with basic public service facilities. Zhao Yanyun et al. conducted spatial measurement of Beijing' s "15-minute life circle" and found that coverage rates differ among facility types and contradict residents' needs. Chen Cheng found that Nanning' s "15-minute life circle" facilities have gaps in types and coverage scope, with imperfect configuration levels that fail to meet residents' differentiated demands for life facilities, and proposed corresponding planning strategies. Li Jun found that Changsha' s 15-minute life circle public service facilities are insufficient and unevenly distributed. Studying the configuration relationship between urban public services and residential space from the perspective of the "15-minute life circle" has become a new hotspot in domestic public service facility supply research. How to consider basic public service 配套设施 from the perspective of residents' living, and strengthen theoretical analysis and technical method exploration to meet the basic needs of the "15-minute life circle," remains a research frontier.

This paper takes Urumqi as a case study, exploring the coupling between residential communities and public service facility spatial configuration from the "15-minute life circle" perspective, and examining technical methods for evaluating the construction status of urban "15-minute life circles," providing a basis and reference for urban public service facility layout and construction.

1.1 Study Area Overview

Urumqi, the capital of Xinjiang Uygur Autonomous Region, is located at the northern foot of the Tianshan Mountains and the southern edge of the Junggar Basin, making it the inland city farthest from the ocean in the world. As a

typical arid oasis city, Urumqi has a total area of 1.38$\times$10^{4}$ km^2, with built-up area covering only 436 km^2 (3.16% of the total area), while its population is highly concentrated on artificial oases. The built-up area accommodates 3.5 million people, with over 95% of the population distributed across Shayibake District, Tianshan District, Xinshi District, Shuimogou District, and Toutunhe District. As an important regional central city in Northwest China, Urumqi has emphasized urban infrastructure and public service facility construction in recent years, improving its human settlement environment. This study selects these five central urban districts as the case area, which basically covers and reflects the core region of Urumqi' s "15-minute life circle" construction, making it typical and representative.

1.2 Data Sources

The use of Internet big data has become increasingly widespread in recent years due to its strong operability and availability, finding extensive application in urban public service facility layout and related research, such as identification of retail commercial centers, spatial pattern analysis of life service industries, and spatial layout studies of public service facilities. This study utilizes POI data to evaluate the configuration of residential communities and basic public services in Urumqi' s central urban districts under "15-minute life circle" construction requirements.

Data were primarily sourced from Gaode Map (https://www.amap.com), obtained through API programming in Python as of August 2019. The data include 2,087 residential communities, 13,829 commercial facilities (convenience stores, fruit and vegetable shops, laundry shops, beauty salons, hardware stores, banks, telecommunications business halls, and public toilets), 1,068 educational facilities (kindergartens, primary schools, and middle schools), 1,914 medical facilities (community health service centers/stations, clinics, and pharmacies), and 3,676 bus stops. The "15-minute life circle" is defined as a 1,000 m walking radius area centered on the geographic center of residential communities. After deduplication, correction, and spatial matching, each facility contains attribute information including name, longitude, latitude, and address. Due to limited quantities, elderly care and cultural/entertainment facilities were not analyzed in this study.

1.3 Methodology

1.3.1 Kernel Density Estimation Geographic information spatial density analysis calculates the data aggregation status across an entire region based on input point feature datasets, generating a continuous density surface. Kernel density estimation is a spatial density analysis method based on data density function clustering algorithms. During analysis, higher weights are assigned to events near the sample center point, while events farther from the center receive lower weights. The equation is defined as:

$$f(x) = \frac{1}{nhd} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

where K represents the kernel function form, typically a symmetric unimodal probability density function; h is the bandwidth, a free parameter defining the smoothing amount; d is the data dimension; and n is the number of points i within the bandwidth range. This study employs kernel density estimation to analyze the spatial distribution patterns of residential communities and various public service facilities.

1.3.2 Coverage Rate Within a 1,000 m range, people primarily travel by walking, which takes approximately 15 minutes. Locating various public service facilities within this walking range can effectively meet residents' daily needs. Therefore, this study evaluates the coverage rate of public service facilities within the "15-minute life circle" of Urumqi' s central urban residential communities. If a buffer zone of 1,000 m centered on a residential community contains type j facilities, the community is considered covered. The coverage rate is calculated as:

$$CR_i = \frac{\sum_{i=1}^{m_i} C_i}{m_i}$$

where C_i indicates whether public service facility F_j exists within the 1,000 m activity range of residential community i (1 if present, 0 otherwise); CR_i represents the coverage rate of public service facility F_j in district i, reflecting different regional coverage levels; m_i is the number of communities in district i; and TCR_j denotes the coverage rate of public service facility F_j in the central urban area, representing the overall level of the central city.

1.3.3 Spatial Matching Analysis Based on raster calculations of residential communities, commercial facilities, basic education facilities, medical facilities, and bus stops, this study assesses spatial matching between residential communities and various facilities, identifying five matching scenarios: extremely mismatched, mismatched, matched, well-matched, and very well-matched.

2. Results and Analysis

2.1 Spatial Distribution Characteristics of Residential Communities and Public Service Facilities

Kernel density distribution maps (Figure 3) reveal that both residential communities and various public service facilities exhibit spatial distribution patterns characterized by "multiple centers, circle layers, and edge distribution," with obvious agglomeration centers but relatively low spatial overlap.

Residential communities in Urumqi are relatively concentrated, forming a “three centers, circle layers” pattern. With the Hongshan Road area, Qitai Road area, and Nanmen area as agglomeration centers, they constitute a dense residential agglomeration circle that decreases outward in a circle-layer pattern. Commercial facilities, primarily convenience stores, beauty salons, fruit and vegetable shops, banks, and other types, form a “multiple points agglomeration, uniform distribution” pattern, which is related to their low population service threshold and limited service spatial range. This finding aligns with Zhan Dongsheng et al.’s analysis of Beijing’s catering facilities, which also formed numerous hotspot agglomeration areas due to low service threshold populations and limited service spatial ranges.

Basic education facilities, comprising kindergartens, primary schools, and middle schools, show a “multiple points agglomeration” pattern. The Tianshan District area is the largest agglomeration center, corresponding well with dense population and residential community agglomeration. As population has expanded from old urban areas to new urban areas year by year, secondary agglomeration centers have gradually formed in Yinchuan Road, Nanhu South Road, and the northern Liudaowan area, with agglomeration distribution centers also appearing in Xinshi District and Shuimogou District. Zhang Chun et al.’s analysis of Urumqi’s job-housing spatial evolution found that strengthened construction in Xinshi District and Shuimogou District increased comprehensive 配套设施 of various facilities, gradually dispersing the population, which aligns with the formation reasons for the secondary education facility agglomeration centers identified in this study.

Medical facilities are relatively dispersed overall, showing a single-center distribution pattern. The area with highest kernel density comprises Jiefang South Road, Erdaoqiao, Tuanjie Road, and parts of Xinhua South Road Street. Except for community health service centers (stations) uniformly planned and configured according to streets and communities, the distribution of pharmacies and clinics is uncertain, with low service thresholds, resulting in relatively dispersed distribution but with some concentrated areas that correspond to residential community agglomeration centers.

Bus stops show a single-center, circle-layer decreasing pattern outward, with the core comprising Xinhua North Road, Xinhua South Road, Jiefang South Road, and Jiefang North Road—the main population flow distribution area of Urumqi’s South Gate-Xiaoximen core business district and also the most concentrated area for residential communities. Zhan Dongsheng et al.’s analysis of Beijing’s public transportation facilities found that public transportation facility hotspots agglomerate near large residential agglomeration areas, corresponding with the spatial distribution characteristics of bus stops identified in this study.

2.2 Evaluation of Public Service Facility Supply Level in the "15-Minute Life Circle"

2.2.1 Coverage Rate of Public Service Facilities Calculation results (Table 1) show that the average coverage rate of various public service facilities is 95.13%, indicating that public service facilities in Urumqi' s central urban area basically meet residents' walking accessibility needs. Except for slightly lower coverage rates for primary and middle schools, other public service facilities have high coverage rates, with bus stops, convenience stores, fruit and vegetable shops, beauty salons, and pharmacies ranking highest—basically aligning with the frequency characteristics of daily life needs.

Different types of basic public service facilities show certain coverage rate differences. Public transportation represented by bus stops has the highest coverage rate, reaching over 99% in all districts, basically achieving full coverage. Among commercial facilities, daily service establishments such as supermarkets, fruit and vegetable shops, and barbershops have relatively higher coverage rates than banks and telecommunications business halls. Among educational facilities, kindergartens have the highest coverage rate, followed by primary schools, with middle schools showing relatively lower coverage. Medical facility coverage differences among types are not significant, with community health service centers, pharmacies, and clinics basically achieving 95% coverage.

Regional differences exist in public service coverage levels among central urban districts, with the comprehensive ranking being: Tianshan District > Shayibake District > Xinshi District > Shuimogou District > Toutunhe District, indicating that older urban districts have relatively better public service foundations. Tianshan District is the most densely populated area in Urumqi and the region with the densest commercial facilities, as well as relatively rich educational and medical resources. With long construction history and relatively complete community-level 配套设施 of various basic public service facilities, its comprehensive service capacity and level are most prominent. Shayibake District and Xinshi District are relatively densely populated areas that have developed over the past 10-20 years, with relatively high coverage rates for commercial service facilities, but lower coverage rates for basic education and medical services than Tianshan District. Toutunhe District is a newly expanded urban area in Urumqi in recent years, with high starting points for public service infrastructure construction, but its coverage rate is significantly lower than the other four central urban districts. This demonstrates that the coverage rate and 配套 level of basic public service facilities in the "15-minute life circle" are somewhat related to urban development stages and population agglomeration processes.

2.2.2 Compliance Rate of Public Service Facilities For residents, the compliance status of public service facilities directly affects their quality of life. This study defines the compliance rate as: within a residential community' s 15-minute life circle, the presence of all types of basic public service facilities constitutes compliance, while the absence of any facility type constitutes non-

compliance. Within each major category, considering substitutability among facilities, the presence of one substitutable facility suffices, while non-substitutable facilities must all be present (Table 2). For example, each subcategory of commercial facilities is functionally irreplaceable and must all be present to achieve compliance; in medical facilities, community health service centers and stations have similar functions, with at least one required, and at least one of pharmacies or clinics must also be present; in educational facilities, kindergartens, primary schools, and middle schools serve different age groups and are irreplaceable, requiring all to be present; transportation sites require only one or more bus stops to be present.

Research results show that the overall compliance status of basic public service facility configuration within the 15-minute life circle of Urumqi' s central urban residential communities is good, with an average of 3.79 compliant facility categories. However, there remains room for improvement. Figure 4 shows that residential communities with all four public service facility categories (commercial, educational, medical, and transportation) compliant mainly agglomerate in Tianshan District, Shayibake District, and southeastern Xinshi District—core areas of population agglomeration—while the number of compliant facility categories decreases in relatively peripheral areas of the central urban area. Specifically, 10.87% of residential communities have all four categories compliant, 4.02% have only one compliant category, and 8.24% have no compliant categories, indicating the main task for future public service facility configuration improvement.

2.3 Evaluation of Spatial Matching Degree Between Residential Communities and Public Service Facilities

Overall, the spatial matching degree between residential communities and basic public service facility configuration in Urumqi' s central urban area is relatively good. Figure 5 shows that bus stops have the best matching status with residential communities, reaching 99.83% matching degree, which aligns with their high coverage rate. Only small mismatched areas exist in Xishan Farm and Anning District Town, indicating that bus stops not only meet 15-minute walking needs but also correlate closely with population density.

The spatial configuration of basic education facilities shows relatively good matching with residential community agglomeration, with a matching degree of 99.18%, highest in southeastern Xinshi District. This indicates that education facility spatial configuration correlates with population agglomeration, though the 15-minute life circle coverage rate is slightly lower, suggesting that while education facility spatial configuration is consistent with population agglomeration, construction according to 15-minute walking accessibility requirements still needs strengthening.

Commercial and medical facilities show relatively more mismatches with residential communities. In Urumqi' s central urban residential communities' 15-minute

life circle, commercial facilities have numerous outlets and high coverage rates, but their layout does not match residential community agglomeration status. A possible reason is that this study selected small community-level commercial facilities and did not include shopping malls or large supermarkets. If large commercial complexes exist near some residential communities, community-level commercial facilities would correspondingly decrease.

The numerous mismatches between medical facilities and residential communities result not only from insufficient facility configuration itself but also because this study only included primary-level medical facilities such as community health service centers/stations, pharmacies, and clinics, without involving large specialized hospitals, potentially causing spatial matching deviations. However, this result also objectively reflects that current urban construction and management still lacks construction services for primary-level medical facilities, having not yet achieved the "treating minor illnesses within the community" requirement.

3. Conclusions and Discussion

Equalization of basic public services, convenience, and residents' sense of happiness and fulfillment are closely related, reflecting a people-oriented urban service concept and representing an inevitable requirement for high-quality urban development. From the perspective of the "15-minute life circle" and based on POI network data, this study utilizes ArcGIS spatial analysis tools to examine Urumqi' s central urban area, exploring spatial layout characteristics, coverage rates, and compliance rates of residential communities and various basic public service facilities, and comprehensively evaluating their spatial matching status. This helps better examine the current construction status and potential problems of urban "15-minute life circles," providing useful suggestions for urban spatial planning and construction management. The main conclusions are:

(1) Using POI data to analyze the spatial layout of residential communities, commercial facilities, medical facilities, basic education facilities, and bus stops in Urumqi' s central urban area reveals that spatial layout characteristics differ among various basic public service facility types, showing certain correlations with residential community agglomeration distribution while also reflecting different facility attributes. The circle-layer decreasing pattern from densely populated residential communities outward is a relatively obvious spatial configuration rule.

(2) Coverage rate analysis of residential communities and basic public service facilities reveals certain differences in coverage rates of different basic public service facilities within residential communities' "15-minute life circle." Public transportation represented by bus stops has the highest coverage rate. Among commercial facilities, daily service establishments such as supermarkets, fruit and vegetable shops, and barbershops have relatively higher coverage rates than banks and telecommunications business halls.

Among educational facilities, kindergartens have the highest coverage rate, followed by primary schools, with middle schools showing relatively lower coverage. Medical facility coverage differences among types are not significant, with community health service centers, pharmacies, and clinics basically achieving 95% coverage.

(3) Significant regional differences exist in compliance rates of different basic public services with residential spatial configuration. In areas with higher population density, the proportion of residential communities where all four categories of public service facilities meet standards is higher. In contrast, peripheral areas with relatively low population density and newly developed urban districts show lower compliance rates for medical and commercial facilities, representing the main direction for "15-minute life circle" improvement.

(4) Constructing a "15-minute life circle"in Urumqi should focus on strengthening public service 配套设施 in newly developed urban areas, especially convenience commercial facilities and primary-level medical facilities, while older urban districts should enhance public service updates and 配套设施 during renovation processes.

This study analyzes the spatial configuration level of basic public service facilities and residential communities from the "15-minute life circle" perspective. However, due to data limitations, elderly care, cultural/sports, and public activity spaces are difficult to define and accurately locate and spatially match, and thus were not included in this analysis. Future research should explore more effective technical methods for more comprehensive analysis. Additionally, according to national "Standard for Urban Residential Area Planning and Design" and differentiated requirements for hierarchical "life circle" construction, future studies could further deepen hierarchical facility walking accessibility analysis and conduct refined research according to different population groups' needs.

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Note: Figure translations are in progress. See original paper for figures.