

A Study on The Distribution of Various Production and Living Facilities in The Main Urban Area of Xining Based on POI Data

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Abstract: This study explores the distribution patterns of production and living facilities in the main urban area of Xining based on POI data. The research background focuses on the unique geographical constraints of Xining, a typical plateau valley city, which result in uneven facility distribution during the urbanization process, affecting residents' quality of life and urban operational efficiency. The high spatial precision of POI data provides a microscopic analytical perspective for this research. The significance of the study lies in filling the gap in research on the spatial structure of service facilities in plateau cities and responding to the call of the UN Sustainable Development Goals (SDG 11) for inclusive cities. The research objective is to reveal the multi-dimensional polarization characteristics of POIs in the service industry and their formation mechanisms through geospatial analysis, thereby providing a basis for optimizing urban planning and enhancing social equity. Methodologically, the kernel density estimation technique is primarily employed to quantify the spatial agglomeration intensity of eight types of facilities and identify hot spot distributions. This method integrates multi-type POI data to intuitively present the patterns of functional superposition and differentiation. The analysis results indicate that the facility distribution exhibits significant "core-periphery" polarization: Educational facilities show a three-level diffusion pattern with the old urban area as the core. Automotive services form a dual-center layout. Other living facilities, such as catering establishments and shopping centers, display a multi-core distribution; public toilets and bus stops present axial radiation, but their coverage in old communities is insufficient. The conclusion points out that the polarization mechanisms are dominated by topographic constraints, policies (e.g., educational parks), and transportation networks.

Keywords: POI, GIS, kernel density, spatial distribution, facilities.

1. Introduction

1.1. Research Background

Urban production and living facilities, as critical carriers of urban functions, their spatial distribution patterns directly affect residents' quality of life and urban operational efficiency. With the advancement of urbanization, understanding the rationality of facility layout has become a key issue in urban planning research. Point of Interest (POI) data, characterized by high spatial precision and rich attribute information, provides a micro-scale perspective for analyzing facility distribution.

Xining, a typical plateau valley city in western China, faces unique constraints from terrain and urban expansion, which may shape distinctive distribution features of educational facilities (primary schools, middle schools, colleges), automobile services, restaurants, public toilets, and bus stops. As a typical plateau valley city, its urban form is fundamentally constrained by the surrounding mountains and the Huangshui River valley, leading to a "valley-belt-shaped" spatial layout. The physical landscape, where lower elevations and gentle slopes are the primary targets for construction, acts as a foundational blueprint that guides urban sprawl and concentrates service facilities[1]. While such strategies are effective in fostering economic agglomeration, they often carry significant social costs. This approach can inadvertently intensify the core-periphery structure that is already prevalent in the Lanzhou-Xining urban agglomeration, of which Xining is a dominant core[2].

The contradiction between this growth-oriented,

agglomeration-focused strategy and the principles of urban social sustainability, particularly as articulated in the United Nations' Sustainable Development Goal 11 (SDG 11), which advocates for inclusive, safe, resilient, and sustainable cities. The unchecked agglomeration of service industry Points of Interest (POIs) can exacerbate social differentiation by creating "service deserts" in peripheral residential areas, disproportionately affecting vulnerable populations. This disparity in access to essential services—from healthcare and education to retail and recreation—directly impacts quality of life, widens well-being gaps, and undermines social cohesion[3][4]. Transportation infrastructure, a pivotal factor constraining urban advancement in Xining[5], plays a dual role in this dynamic. While it is essential for economic vitality[6], its development can either alleviate or aggravate spatial polarization, depending on its design and integration with land-use planning. Thus, Xining provides a compelling case study for examining the complex interplay of terrain, planning, and transportation in shaping service industry landscapes and their profound consequences for social sustainability.

1.2. Research Gaps and Objectives

Existing research predominantly focuses on describing polarization patterns rather than quantifying their social sustainability impacts. A significant portion of the literature employs descriptive spatial analysis techniques such as Kernel Density Estimation (KDE) to visualize agglomeration, Standard Deviation Ellipses to identify directional trends, and Getis-Ord G_i^* to map hotspots[7]. While these tools are

powerful for illustrating where service industry POIs are clustered, they fall short of measuring the tangible consequences of these patterns.

Moreover, the bulk of urban spatial research in China and globally has concentrated on large, coastal, or plains-based metropolises like Beijing, where the impact of infrastructure like ring roads on decentralization has been documented [8]. In contrast, systematic evidence evaluating the effects of transportation infrastructure on development in cities with severe topographical constraints is scarce. The foundational influence of Xining's valley terrain means that models and conclusions drawn from flatter cities may not be applicable[5]. Furthermore, KDE provides superior visualization of spatial agglomeration patterns by generating continuous density surfaces that intuitively display concentration gradients. Unlike discrete methods (e.g., quadrat density or Voronoi diagrams), KDE smooths density values across space, revealing hotspots and dispersion trends without artificial grid constraints[10]. This allows researchers to identify core agglomeration zones and transitional boundaries seamlessly, making it ideal for studying financial outlets, retail clusters[11], or tourism resources.

This research aims to analyze the multi-dimensional spatial patterns and formation mechanisms of service industry POI polarization in Xining city. This objective will be achieved through a sophisticated application of geospatial analysis techniques. It will begin by employing methods such as Kernel Density Estimation (KDE) to identify the intensity and location of service agglomeration hotspots [7]. Moreover, based on the POI kernel density distribution of points of different types of service industries, this study analyzes the causes behind their formation and makes possible predictions for future urban development in light of the current actual situation.

2. Research Area and Data Methodology

2.1. Characteristics of Xining's Main Urban Area

Xining is located in the northeastern part of the Qinghai-

Tibet Plateau, lying between 100°52'~101°54' east longitude and 36°13'~37°28' north latitude. It serves as the provincial capital of Qinghai Province. Its topographical feature is that the altitude is high in the southwest and low in the northeast. The urban area of Xining stands at 2,261 meters above sea level, making it a typical plateau valley city. Administratively, Xining administers five districts and two counties, namely Chengzhong District, Chengxi District, Chengbei District, Chengdong District, Huangzhong District, Datong County, and Huangyuan County. The city has a total area of 7,660 square kilometers and a population of 2.476 million under its jurisdiction.

This study focuses on the four main urban districts of Xining, namely Chengbei, Chengzhongt, Chengxi, and Chengdong., an area characterized by its strip-shaped valley terrain and multi-center cluster pattern. This spatial configuration creates natural corridors for urban expansion but constrains contiguous development, leading to fragmented service industry distribution[7]. The polycentric structure aligns with trends observed in other Chinese cities like Chengdu, where service industries exhibit "one center, multiple clusters" agglomeration[9].

2.2. Data Sources

The data utilized in this study consist of multi-category Point of Interest (POI) data for Xining, Qinghai Province. These data encompass various types, including restaurants, bus stops, companies and factories, shopping malls, office/residential complexes, public toilets, educational institutions (primary schools, middle schools, higher education institutions), and automotive services. All POI data were sourced from the Gaode Map API (2024), like Table 1. Following processing, geographic coordinates (latitude and longitude) and administrative district affiliations were extracted for subsequent kernel density estimation and other analyses.

Table 1. Types of POI data, their quantities in each district, and the percentage of the total points.

POI data	POI spots numbers	Chengxi	Chengdong	Chengbei	Chengzhong	Percentage
Education and culture Services	207	35	48	86	38	1.3440%
Automobile services	934	132	340	297	165	6.0641%
Restaurant	5914	1630	1611	1347	1326	38.3976%
Public toilets	332	130	57	78	67	2.1556%
Bus stops	752	143	204	230	175	4.8825%
Company	3257	873	612	1255	517	21.1466%
Shopping centers	2363	431	731	709	492	15.3422%
Business residences	1643	393	464	363	423	10.6674%

2.3. Research Methods

This paper primarily employs the Kernel Density Estimation (KDE) method. This technique is particularly suitable for quantifying the unit density of features within a specified search radius. By applying a smoothing function to discrete data points, KDE generates a continuous surface representing feature density, enabling the assessment of the spatial agglomeration patterns of six types of elements across Xining City. The formula for kernel density estimation is given by:

$$f(x) = \sum_{i=1}^n \frac{1}{\pi r^2} \left(\frac{x-x_i}{r} \right) \quad (1)$$

In the formula(1): $f(x)$ denotes the kernel density estimation value at location x ; n is the number of accommodation enterprises in Xining City; r denotes the search radius of the kernel density function; φ denotes the weight of the distance between point x and x_i ; and $x - x_i$ denotes the distance between x and x_i .

In identifying the intensity and spatial distribution characteristics of service agglomeration hotspots, as well as

studying the multi-polar pattern of regional spatial structures, compared with using different methods such as standard deviational ellipse and spatial autocorrelation to analyze single or a small number of Point of Interest (POI) data separately, the Kernel Density Estimation (KDE) technique, through comprehensive analysis of multiple types of POI data, can intuitively quantify the spatial superposition and differentiation of multi-type service functions, reveal agglomeration centers of multi-functional comprehensive services and their intensity gradients, and avoid missing secondary centers or emerging growth poles that lack significant dominant functions but possess strong comprehensive service capabilities. Meanwhile, analyzing the density distribution of multiple POIs can reveal the spatial correlations and coordinated agglomeration patterns of different service functions, thus avoiding fragmented understanding caused by difficulties in comparing and integrating conclusions when using multiple analytical

methods. Furthermore, as a standardized spatial smoothing algorithm, when applied to various types of POIs, KDE can ensure consistency in processing logic, parameters, and visualization standards, making the spatial distributions of agglomeration intensity of different services directly comparable. This avoids difficulties and biases in comparison and integration arising from the lack of unified indicators and expression patterns in mixed methods.

3. Analysis Results

3.1. Study on Kernel Density of Primary Schools, Middle Schools and Institutions of Higher Education

According to Figure 1, the distribution of primary schools presents a three-level diffusion circle with the old urban area as the core:

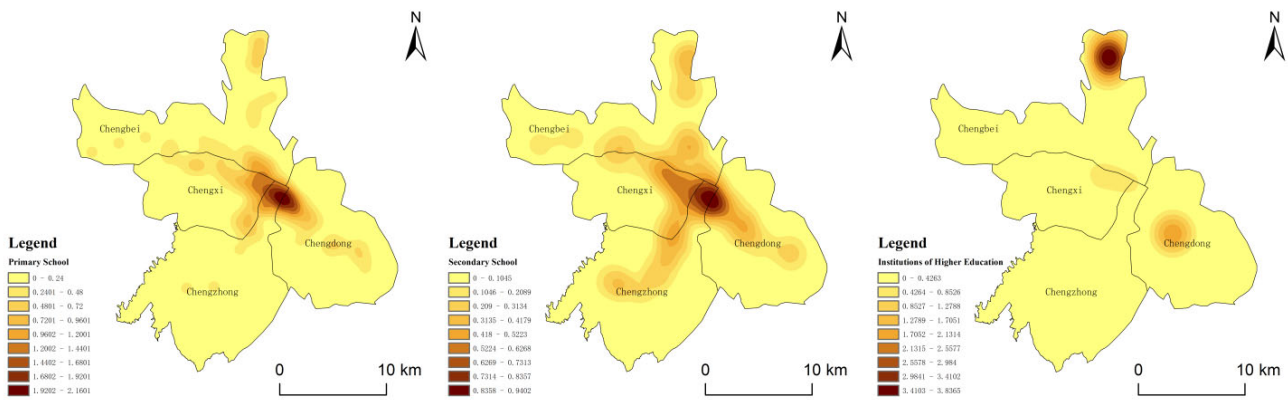


Figure 1. Kernel Density Distribution Map of Primary Schools, Middle Schools, and Institutions of Higher Education in Xining.

The spatial distribution of the three types of educational facilities in the main urban area of Xining exhibits distinct characteristics of functional differentiation and locational orientation. The high - value areas of primary school kernel density are highly concentrated in the core streets of Chengzhong District (Yinma Street, Renmin Street, and Nanda Street), with a peak range reaching 1.9202–2.1601. This reflects the "community - embedded" layout feature of basic education, which is highly coupled with residential land and whose service radius matches the community scale. The high - value areas of secondary school kernel density cover the core of Chengzhong District, Shengli Road in Chengxi District, and parts of Chengdong District, with a peak range of 0.8358–0.9402. Its distribution range is broader than that of primary schools. It not only continues to rely on the population support of the core area but also moderately expands to the periphery following the population density gradient, conforming to the spatial logic of "school - district radiation" for secondary schools. Institutions of higher education present a concentrated pattern of "north agglomeration and east dispersion": A strong kernel density

agglomeration area with a range of 3.4103–3.8365 has formed in Nianlipu Town, Chengbei District, and the eastern part of the city constitutes a secondary high - value area. This reflects the demand for contiguous land and scientific research facilities in higher education, as well as the spatial guidance of urban planning for science and education parks.

In the peripheral areas (such as Dabaozi Town and Zongzhai Town), the kernel densities of the three types of educational facilities all fall into the low - value range, highlighting the spatial differentiation pattern of "central agglomeration and peripheral sparsity". The locational differentiation between basic education and higher education essentially originates from the differences in service objects and functional demands. Basic education forms "micro - agglomeration" by attaching to residential spaces, while higher education achieves agglomeration by relying on specialized parks. Together, they shape the hierarchical pattern of the educational space in the main urban area.

3.2. Distribution of Automobile Services

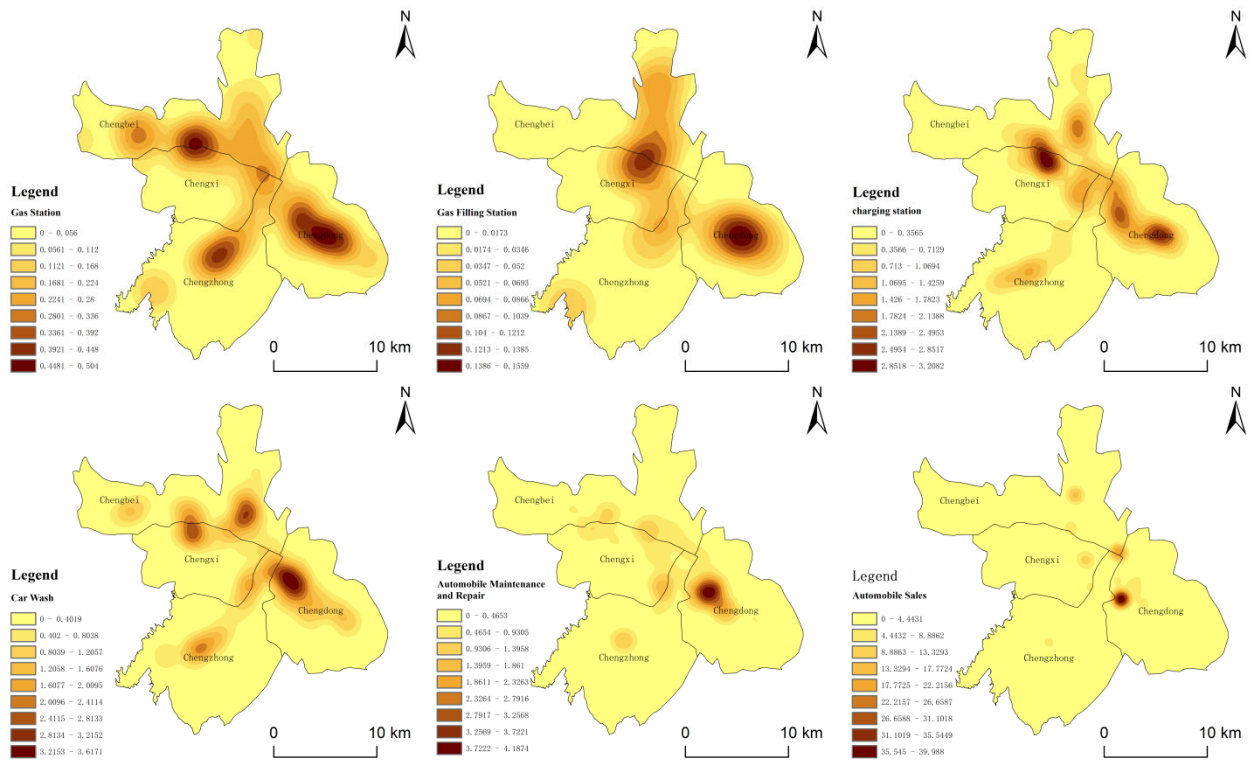


Figure 2. Kernel Density Distribution Map of Automobile Service-related POI Data in Xining

The six types of automobile-related service facilities in the main urban area of Xining exhibit significant spatial differentiation. Automobile sales take Bayi Road Sub-district, Chengdong District as the strong core, with a kernel density peak ranging from 35.345 to 39.988. The high-value areas of automobile maintenance (with a kernel density of 3.7222–4.1974) cover Renmin Street, Chengzhong District and Shengli Road, Chengxi District, adhering to the traffic-dense corridors along urban trunk roads. Car-washing services, with a kernel density peak of 3.2153–3.6171, cluster in Renmin Street, Chengzhong District and Huzhu Road, Chengdong District. Gas stations, with a kernel density peak of 0.481–0.504, present a dual-core polarization pattern. Gas-filling stations, with a kernel density peak of 0.1386–0.1559, focus on the industrial belt around Nianlipu Town, Chengbei District, matching the gas supply needs of freight vehicles. Charging stations, with a kernel density peak of 2.8518–3.2082, concentrate in Huochezhan Street, Chengdong District, aligning with the pilot layout of new energy vehicles at transportation hubs.

The six types of facilities have close spatial correlations. Renmin Street and Nanda Street, Chengzhong District, serve as "gas station + maintenance + car-washing" functional composite nodes, leveraging residential density and traffic agglomeration to construct a service chain for daily vehicle use. The Bayi Road – Huochezhan area in Chengdong District presents a "sales + charging" linkage, conforming to the spatial extension of the automobile consumption chain (sales→use→energy supplementation) and aligning with the layout logic of the new energy vehicle industry. Nianlipu Town, Chengbei District, forms an "oil + gas" energy supply zone, adapting to the dual fuel and gas demands of the logistics industry and reflecting the spatial matching between energy types and industrial functions.

3.3. Distribution of the Other Six Categories of Facilities

① Restaurants (Figure 3, (a))

The kernel density map of restaurants should present a significant "core-periphery" structure. According to the laws of urban commercial layout and with reference to the distribution of public toilets, most areas in Chengxi District and Chengzhong District are peak density zones, as they gather traditional food streets and comprehensive commercial complexes, catering to the high-frequency dining needs of citizens and tourists. Medium-density areas may extend along main roads to the vicinity of Chengdong Railway Station, covering the passenger flow at transportation nodes. The density in Chengbei District is relatively low, reflecting its characteristics dominated by residential and industrial functions. Notably, the multi-core density distribution indicates that Xining's catering industry not only focuses on the core business districts of the old city but also forms secondary centers with urban expansion, which is highly spatially coupled with population density and commercial vitality.

② Public Toilets (Figure 3, (b))

The distribution of public toilets presents a "dual-core and multi-point" pattern: peak density areas are concentrated in Chengxi District (Wanda Plaza in Haihu New District, People's Park) and Chengdong District (Railway Station, Jianguo Road Passenger Station), with dark brown color (density approximately 35-60). This distribution directly responds to the service needs of passenger flow hubs (stations) and public leisure spaces (parks/business districts). Medium-density areas (approximately 18-35) cover the vicinity of district government residences and main roads, reflecting basic municipal supporting facilities. Areas along Qaidam Road in Chengbei District and parts of the old city in

Chengzhong District have relatively low density (< 18), which may be due to difficulties in adding new facilities due to dense buildings or the need for layout optimization. Overall,

the density of public toilets is highly matched with the intensity of urban public activities, but the coverage rate in some residential areas needs to be improved.

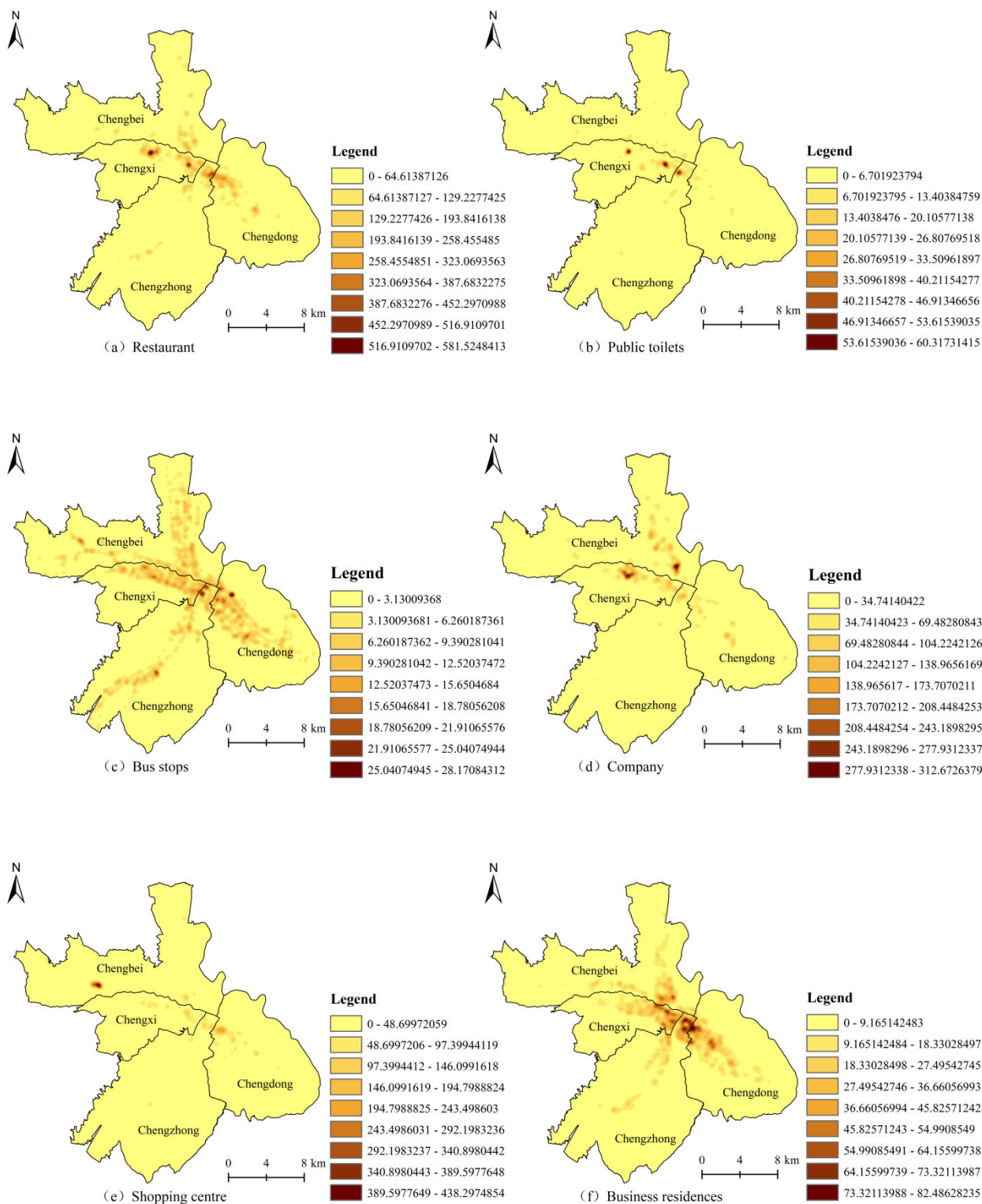


Figure 3. Kernel Density Distribution Map of Six Production and Living-related Categories in Xining City.

③ Bus Stops (Figure 3, (c))

The kernel density map of public transport stops is expected to show an "axial radial" pattern. The highest density areas will be densely distributed along east-west arteries (Qilian Road, Kunlun Road) and north-south trunk roads (Changjiang Road, South Street), especially forming peak nodes at transfer hubs such as Railway Station, Ximen,

and Xinning Square. Medium-density areas (medium brown) extend to secondary roads, covering entrances to major residential areas. Due to the presence of long-distance bus stations and railway marshalling yards in Chengdong District, the coverage rate of feeder buses may be relatively high; the new urban area in Chengxi District (Haihu Road) presents a grid-like medium-density area due to well-planned road

networks. The density along Chengbei Industrial Park and Nanshan Road in the south is relatively low, reflecting differences in passenger flow demand. This distribution conforms to the principle of public transport services: "connecting hubs, covering main roads, and radiating residential areas".

④ Company (Figure 3, (d))

The kernel density map of company POIs will highlight the characteristics of "multi-center agglomeration". Dark brown peak areas are concentrated in Chengzhong District (financial/commercial enterprises around Central Square), Chengxi District (Haihu New District CBD, such as Financial Building, Government Service Center), and Chengdong District (Entrepreneurial Park, logistics bases), reflecting modern service industries and characteristic industrial clusters. Medium-density areas (medium brown) spread along Bayi Road and Xiguan Street, covering small and medium-sized office spaces. Chengbei Biotechnology Industrial Park may form an independent high-density point (dark brown), representing specialized industrial agglomeration. In contrast, the density in purely residential streets is significantly lower. This distribution reveals that the spatial layout of enterprises in Xining is dominated by three factors: policy guidance, industrial chain correlation, and commercial location.

⑤ Shopping Centers (Figure 3, (e))

The density map of shopping centers highly overlaps with areas with large population distribution. Core peaks are locked in Chengxi Limeng Commercial Alley, Tangdao 637, and Chengzhong Dashizi Business District, forming an urban-level commercial "dual core". Secondary peaks are distributed in regional complexes such as Chengdong Zhongfayuan City Plaza and Chengbei Wuyue Plaza, forming a multi-level commercial system. Medium-density areas are scattered along secondary commercial roads (Xiaoqiao Street, Dongguan Street), covering community commercial complexes. The density along Chengbei Science and Education Zone and Nanshan Road in the south is the lowest, showing commercial radiation blind spots. Notably, the continuous dark-colored belt in Haihu New District reflects its planning-oriented "centralized commercial cluster" model, in contrast to the "point-like core" of traditional business districts.

⑥ Business Residences (Figure 3, (f))

The kernel density distribution of commercial apartments will directly respond to enterprise layout and commuting needs. The highest density (dark brown) is expected to agglomerate around core business districts (Haihu New District CBD, Chengzhong Business District) and industrial parks (Chengbei Biotechnology Park), providing short-distance residential options for employees. Medium-high density areas extend along main roads. Secondary density peaks may appear around railway stations and bus stations, serving mobile business travelers. The density in purely residential areas is relatively low. Due to restrictions on the renovation of old residential quarters and the demand from industrial workers, Chengdong District forms the characteristic of "decentralized medium density". This distribution reveals the spatial logic of commercial apartments as a "job-housing balance medium".

4. Conclusion and Discussion

4.1. Conclusions

Based on POI data, this study analyzed the spatial

distribution characteristics of 8 categories of service facilities in the main urban area of Xining using the kernel density estimation method. The results indicate that:

The spatial distribution of service POIs presents significant "core-periphery" polarization characteristics. High-density areas are concentrated in the traditional core zones of Chengxi District and Chengzhong District, while low-density areas are distributed in the peripheral regions of Chengbei District and Chengdong District as well as around industrial parks. This pattern is highly consistent with the urban expansion path constrained by Xining's "valley belt-shaped" terrain.

There are differences in the spatial agglomeration patterns of different types of service industries: educational facilities exhibit the characteristic of "three-level diffusion," with the old urban area as the core, extending along traffic arteries to new urban areas, and higher education institutions agglomerating toward the urban edge driven by policies; automobile services form a coexisting pattern of "core-periphery" and "dual centers," with energy supply services concentrated in transportation hubs and the after-sales market showing industry-linked agglomeration; living service industries such as catering and shopping centers present a "multi-core" distribution, which is coupled with population density and commercial vitality spaces; public service facilities such as public toilets and bus stops show "axial radiation" along main roads, but there are coverage gaps in some old residential communities.

Terrain constraints, policy orientation, and transportation networks are the main driving factors of spatial polarization: the valley terrain restricts land development, leading to a high concentration of resources in core areas; policies such as "education parks" and "construction of eastern urban agglomerations" promote the migration of specific service industries to the edge; main roads and hub nodes guide the distribution of service industries along traffic corridors.

4.2. Discussion

Through the comprehensive analysis of multi-type POIs, this study reveals the unique laws of spatial polarization of service industries in plateau valley cities, fills the gap at the micro-scale in the research on the spatial structure of urban service industries in the Qinghai-Tibet Plateau, and provides empirical support for understanding the equity of urban service resource allocation under terrain constraints.

At the same time, the study has certain limitations: POI data only reflect the spatial location of facilities, lacking attribute information such as service scale and passenger flow, making it difficult to quantify differences in service quality; kernel density analysis focuses on static distribution and does not incorporate dynamic evolution in the time dimension.

Future research can combine field surveys and mobile phone signaling data to analyze the impact of service industry polarization on residents' travel behavior; meanwhile, introduce spatial econometric models to quantify the coupling mechanism of factors such as terrain, policies, and transportation, so as to provide more accurate theoretical support for formulating urban service facility plans that balance efficiency and equity.

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