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Spatial Distribution Characteristics of Urban Parking Lot Based on POI Data: Take the Main Urban Area of Lanzhou as an Example

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Abstract

Parking lot is an important part of urban infrastructure. Whether the parking lot space layout is reasonable is not only related to the happiness and satisfaction of local residents, but also affects the basic factor of urban economic development. Taking parking lot POI data as the research object, this paper analyzes the spatial and temporal distribution characteristics and changing trends of parking lots in Lanzhou city in 2012, 2017 and 2022 by using "Standard Deviational Ellipse" , "Kernel Density ", "Global Moran's I" and "Local Moran's I". The results show that: 1) the public parking lot occupies the largest proportion of all kinds of parking lots, and develops from single-core cluster to multi-core cluster; The allocated parking lot is still in the growth stage of basic development. and the medium density value covers 72% of the streets; The layout of the dedicated parking lot is often to facilitate access to the city as the principle, the performance of Qing yang Road as the axis of the east-west strip; The overall density of the roadside parking lot changes not greatly, and its spatial distribution shows a planar development trend. 2) Except for the allocated parking lot, the standard deviation ellipse of the other three types of parking lot becomes shorter on the long axis, longer on the short axis and smaller on the flatness, indicating that the spatial distribution of the ellipse in the northwest to southeast direction is relatively saturated, so it expands in the north-south direction, which is consistent with the trend that Lanzhou city is limited in urban space and develops to the south and north to fully explore the available space. 3) In the main urban area of Lanzhou, there are large differences in the nuclear density of all kinds of parking lots, showing a state of multi-core aggregation, and significant differences in zoning, showing an unbalanced spatial distribution of "more in the southeast and less in the northwest". 4) Public parking lots were clustered significantly, with high-high values mostly appearing in Chengguan District, and low-low values mostly appearing in Qilihe District and Xi gu District. The streets with high-low and low-high outliers are gradually reduced, and the distribution of public parking lots in Lanzhou tends to be reasonable on the whole.

Keywords

Urban Parking Lot; POI Data; Lanzhou City; Temporal and Spatial Variation; Spatial Pattern.

1. Introduction

Spatial layout refers to the distribution of productive forces or economic layout within a region, and its research objects include industrial layout, major infrastructure layout and urban layout[1]. Public service facilities are the carrier of urban social service industries, which refer to the social infrastructure such as education, medical care, culture and sports, and commerce that are distributed in a point-like manner in cities and serve the general public[2]. Spatial distribution and agglomeration characteristics have become important means for quantitative research on the pattern and relationship of facility POI points[3].One of the main tasks in the

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"Implementation Plan for the Urban Master Plan of Lanzhou City (2011-2020)" in 2015 was "solving the problem of urban traffic congestion". In the 2021 government work report of Lanzhou City, it was mentioned that "improve the functions of the 'fifteen-minute refined living circle' in the city". Whether it is solving the problem of traffic congestion or improving the fifteen-minute living circle in the city, the rational layout of parking lots cannot be avoided as a key issue. Against the backdrop of continuous urbanization, as the urban population grows, the number of cars keeps increasing. It is urgent to figure out the spatial distribution of existing urban parking lots in Lanzhou City. Big data is an important data source for conducting human geography research. Kwan[4] (Kwan 2004) used community residents' activity point data to study the changes in community residents' activities, and Becker[5] (Becker et al. 2011) used mobile phone call data from the city of Moristone in the United States to study the simulation of urban population flow and changes. POI (Points of Interest) data is a type of big data, referring to the point data of facilities closely related to people's lives, including name, area, category, location, etc. Its application research directions mainly include identifying the aggregation status of element classes, and delineating urban regional functions and boundaries[6].Among them, the research results using POI data to explore the spatial distribution pattern of a certain type of facility are abundant. In the research, the scope of POI data can be wide or narrow. When the scope is wide, it can explore the spatial distribution of commercial facilities in a city[7-8], the spatial distribution of life-related service industries[9], the spatial distribution of public service facilities[10-11], the spatial distribution of educational facilities[12-13], the spatial distribution characteristics of cultural facilities[14-15], the spatial distribution characteristics of manufacturing facilities[16], etc. Among them, the research results using POI data to explore the spatial distribution pattern of a certain type of facility are abundant, with a wide range of research objects. It can investigate the spatial distribution of commercial facilities in a city [7-8], the spatial distribution of life-related service industries[9], the spatial distribution of public service facilities[10-11], the spatial distribution of educational facilities[12-13], the spatial distribution characteristics of cultural facilities[14-15], the spatial distribution characteristics of manufacturing facilities[16], etc. Within this, the POI data is further divided into different subcategories. It can also focus on a certain type of facility for in-depth analysis, such as the spatial distribution of retail[17], the catering industry[18], the accommodation industry[19-20], the spatial distribution of exhibition facilities[21], the spatial differentiation of logistics enterprises[22], the spatio-temporal evolution of shared cars[23], the spatial distribution of headquarters of multinational companies[24], the spatial distribution of public toilets[25], etc. Its research application fields have deeply penetrated into all aspects of life, and the research method system is relatively mature.

International research on parking lots is more detailed. Chen, Q. H. et al.[26] took Hangzhou, China as an example and constructed an index system from the dimensions of commercial and living facilities. They used the nearest neighbor index, kernel density, and stepwise regression model to study the local characteristics of knowledge-based industries' spatial distribution. Liu, X. M. et al.[27] based on the GPS trajectories of taxis in Qingdao and the data of interest points, used the geographically weighted regression (GWR) model to describe the influencing factors of spatial heterogeneity of taxi demand. The results showed that there were certain differences in taxi demand during peak hours on weekdays and weekends. Residential density and housing prices increased the number of taxi trips. Road density, parking lot density, and bus station density were positively correlated with taxi demand. Shen, T. et al.[28] used the publicly accessible online map service application and the traffic speed data of the dynamic urban road network during peak hours in Xi'an, Shaanxi Province in 2017, and adopted the multiple regression model to analyze the relationship between land use and parking availability. Domestic research on urban infrastructure is relatively lagging[1]. In recent years, there have been some new developments in the research on the spatial distribution of urban parking lots, such as improvements in methods. Xiaofeng Ji et al.[3] established a systematic method for extracting the spatial distribution characteristics of urban transportation facilities from three dimensions: direction distribution, spatial agglomeration, and hotspot estimation. Xingjuan Zhang et al.[29] used the Voronoi diagram to systematically analyze the spatial layout, spatial aggregation degree, and influencing factors of parking lots in Haizhu District, Guangzhou; in addition, some scholars such as Li Juan et al.[30], Zihao Wang et al.[31], and Jiali Wu et al.[32] conducted spatial distribution characteristic analyses of urban public parking lots and other public service facilities using ArcGIS spatial analysis tools.

At present, there are relatively few studies on the spatial characteristics of parking lots in western regions of China. Based on this, this article takes the main urban area of Lanzhou City as the research area and uses the high-definition map POI data from 2012, 2017, and 2022 as the research objects to analyze the temporal and spatial evolution characteristics of parking lots in Lanzhou City. With a five-year period as one stage, based on the street scale, the spatial distribution characteristics of parking lots in Lanzhou City over the past 10 years are analyzed. It is expected to provide more objective and effective references for related research on the spatial distribution of infrastructure in Lanzhou City and the future spatial planning of infrastructure in Lanzhou City. Additionally, it can also provide references for current urban traffic space management, such as the addition and adjustment of roadside parking lots.

2. Overview of the Research Area

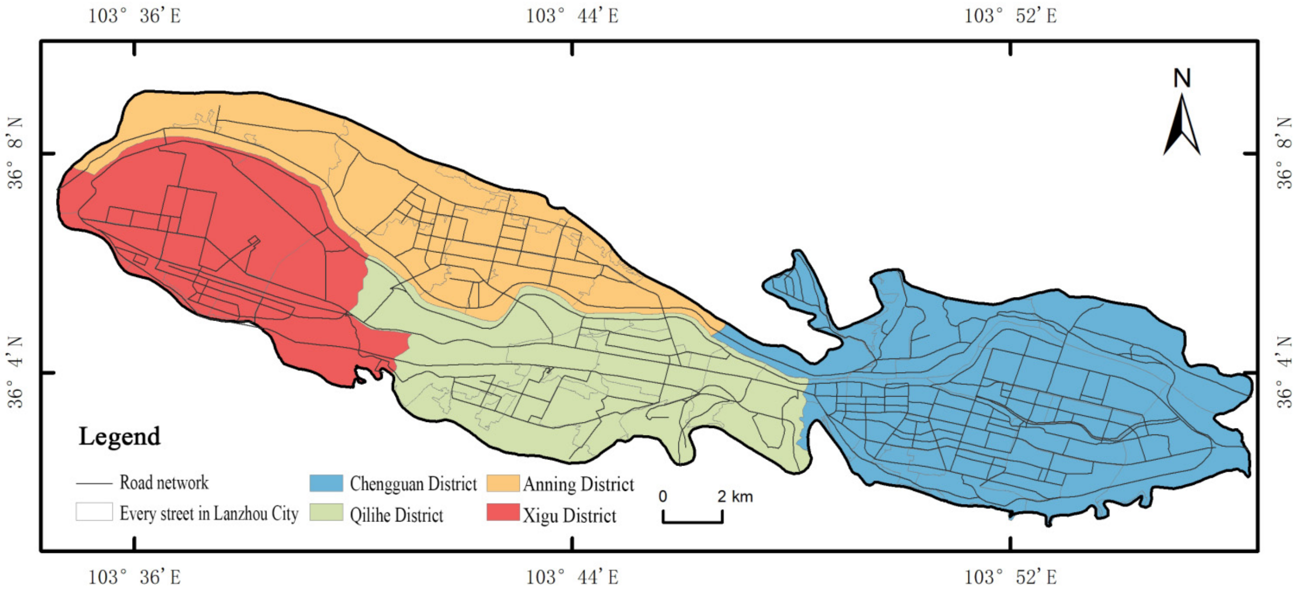

Fig 1. Study area

Lanzhou City is located between 35°5′ and 38° north latitude and 102°30′ and 104°30′ east longitude. It is situated in the northwest of China and in the central part of Gansu Province, approximately at the geographical center of the country. It is the provincial capital of Gansu Province and a transportation hub in the northwest region. Lanzhou City has five districts: Chengguan, Qilihe, Xigu, Anning and Honggu, and three counties: Yongdeng, Yuzhong and Gaolan. The total area of these five districts and three counties is 13,085.6 square kilometers. According to the seventh national population census, the population of Lanzhou City was 3,255,500. The selected central urban area of the study area includes four districts: Chengguan District, Qilihe District, Anning District and Xigu District. The population of Chengguan District is 936,000, that of Qilihe District is 577,700, that of Anning District is 187,200 and that of Xigu District is 325,800. The four districts are divided into 50 streets. Chengguan District is mainly characterized by politics, commerce and science and education; Qilihe District is mainly dominated by light industry, machinery and railway transportation hubs; Anning District is mainly focused on electronic instruments and education and research; and Xigu District is mainly engaged in petrochemicals[33]. The parking situation of each district is shown in Fig. 1.

3. Data Sources

Taking into account the availability of data and the high accuracy and wide coverage of POI data, this article selects three time sections (2012, 2017, and 2022) to analyze the spatio-temporal evolution characteristics of parking lots in Lanzhou City at the street scale based on the POI data. The POI data includes information such as the name of the parking spot, the area it belongs to, the latitude and longitude of the parking lot, and the type of the parking lot. The POI data is collected through the Python platform, the administrative boundary data is sourced from the Chinese Academy of Sciences' Resource and Environment Data Cloud Platform, and the road network data is from the OSM data platform (Open Street Map). The following processing is done on the original POI data: Firstly, the data belonging to the parking lot category for each year is screened. Then, according to the characteristics of its service objects, it is divided into public parking lots, built-in parking lots, dedicated parking lots, and roadside parking lots. After eliminating some duplicate and incomplete data, the following information is obtained: As of 2012, there were 534 pieces of data; as of 2017, there were 1,158 pieces of data; and as of 2022, there were 1,947 pieces of data. The spatial distribution is shown in (Fig. 2).

According to the latest "Urban Comprehensive Transportation System Planning Standard GB/T 51328-2018" issued by the Ministry of Housing and Urban-Rural Development, parking lots are classified into built-in parking lots and public parking lots. It is mentioned that the supply of parking spaces for motor vehicles should mainly rely on built-in parking lots in buildings and be supplemented by public parking lots. The main urban area of Lanzhou is distributed in a narrow and elongated strip due to the fact that the Yellow River runs through it, and the demand for urban public transportation is high. Currently, there is no unified standard for the classification of parking lots. By reviewing the "Lanzhou Motor Vehicle Parking Lot Management Measures" issued by the Lanzhou Municipal Government in 2012[34], 2016[35], and 2019[36], it was found that with the development of society and the continuous increase in the number of cars, in 2016, temporary parking spaces on roads were added as the third type of parking lot, which was placed alongside public parking lots and dedicated parking lots. In existing studies on parking lots, parking lots are generally classified as public parking lots, dedicated parking lots, and roadside parking lots. Public parking lots refer to places that provide parking services for social vehicles, including independently constructed public parking lots and public parking lots built in construction projects. Dedicated parking lots refer to places that provide parking services for the vehicles of the unit or the residential area, including dedicated parking lots built in construction projects and parking spaces marked on the common areas within the building district. Road parking lots refer to parking areas set up on urban roads, including free parking spaces and paid parking spaces[37-38].

This article reclassifies the POI data of parking lots based on the construction purpose of parking lots and the characteristics of the flow of service population. The parking lot data is divided into three categories: public parking lots, dedicated parking lots, and roadside parking lots. The facilities buildings that are accessible to the general public and have a high population mobility are classified as public parking lots; the parking lots that serve specific groups of people, have a relatively stable user population, and are dedicated to large units but not open to the public are classified as dedicated parking lots; roadside parking lots refer to the parking lots designated by government departments based on the maximum traffic volume of the road

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section and the size of the surrounding shops. The specific facility classifications for each type of parking lot are shown in Tab. 1

Table 1. Parking lot classification

classification	specific description
public parking lot	venues, entertainment venues, cinemas and theaters parking lots; shopping malls, comprehensive markets, supermarkets; hotels and inns; cultural centers, museums, exhibition centers, libraries, art galleries, archives, science and technology museums
dedicated parking lot	office parking lots; hospital parking lots; company, factory parking lots; primary and secondary schools, colleges and universities, research institutions, training institutions; old residential areas (affordable housing, family buildings) parking lots; bank, financial company parking lots
roadside parking lot	Temporary parking lot on the roadside

4. Research Method

The analysis methods for POI data have been continuously enriched, generally divided into two categories: spatial analysis methods (direction distribution, kernel density analysis, buffer analysis, centroid analysis, clustering analysis) and statistical analysis methods (spatial autocorrelation, spatial cross-correlation, diversity index).[6] This paper selects three methods: standard deviation ellipse, kernel density estimation, and spatial autocorrelation (Global Moran's I and Local Moran's I) to organize the spatial distribution of parking lots in the main urban area of Lanzhou. Layer information is loaded in ArcGIS10.6, including the road layer of the main urban area of Lanzhou, administrative division layer (including street level and four district level), and the parking lot coordinates retrieved from Gaode Map are superimposed for coordinate conversion, projection, and vectorization. Finally, corresponding analysis tools in the ArcGIS 10.6 toolbox are used for analysis.

4.1. Standard Deviation Ellipse

The Standard Deviational Ellipse (SDE) is an analytical method used to characterize the spatial directional distribution characteristics of geographical elements (points, lines). It was first proposed by Wirti Liffier, a sociology professor at the University of California, in 1926, and is therefore also known as Liffier Directional Distribution[39]. Its parameters include the average center, the standard deviation of the major axis, the standard deviation of the minor axis, the rotation angle (azimuth), and the area[40-41]. This method visualizes the spatial distribution direction, center, and range of geographical elements through the ellipse. Specifically: the average center represents the center of the spatial distribution of the geographical element; the standard deviation of the major axis represents the main trend direction of the spatial distribution of the geographical element; the corresponding standard deviation of the minor axis reflects the secondary trend direction; the rotation angle (azimuth) indicates the overall direction of the element distribution. The smaller the elliptical flattening, the smaller the gap between the major and minor axes of the ellipse, and the less obvious the spatial directional characteristics of the geographical element.

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n}} \tag{1}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i-\bar{y})^2}{n}} \tag{2}$$

In the formula, x_i, $y_i$represents the geographical coordinates of the element; $\bar{x}$ and$\bar{y}$ represent the average center in a mathematical sense; SDE_xandSDE_yindicate the center of the ellipse that has been calculated.

4.2. Kernel Density Estimation Method

The kernel density estimation method can reflect the interdependence characteristics of points in their spatial distribution. It is a commonly used non-parametric estimation method in spatial econometrics and can also visualize the distribution pattern of spatial point clusters[42-43].

$$f(x) = \frac{1}{nh^2\pi}\sum_{i=1}^{n} k\left[\left(1 - \frac{(x-x_i)^2+(y-y_i)^2}{h^2}\right)\right] \tag{3}$$

In the formula: k represents the kernel function; $(x - x_i)^2 + (y - y_i)^2$ denotes the square of the Euclidean distance between the center point of the grid to be estimated and the sample point i within the bandwidth range; h represents the bandwidth, and n indicates the number of points within the range.

4.3. Global Moran's I

Global Moran's I refers to the spatial correlation of the attribute values of objects. Corresponding indicators can be used to quantitatively measure the global and local characteristics of geographical spatial objects.[44]

$$I = \frac{n}{S_o} \cdot \frac{\sum_i^n \sum_j^n w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_i^n (x_i-\bar{x})} \tag{4}$$

The global Moran's I index is used to study the spatial correlation of the observed parking lot POI data throughout the study area: n is the number of spatial units in the study area, x_i and y_i are the observed values of the i and j spatial units respectively, $\bar{x}$ is the mean of the observed values, w_{ij} is the spatial weight matrix, and S_o is the sum of the spatial weight matrices.

The local Moran's I index is also known as clustering and outlier analysis (Anselin Local Moran's I), and is used to observe the heterogeneity of attribute values among different spatial units within the study area[45].

$$I_i = Z_i \sum_{i=1}^{n} W_{ij} Z_j \tag{5}$$

In the formula: z_i and $z_j$represent the standardized values of the spatial unit observations for $i$and j respectively, and w_{ij} represents the spatial weight. Local spatial autocorrelation can analyze the clustering relationship of a certain point with its surrounding points in terms of a certain attribute: including high-high clustering (HH), where the attribute value of this point is high and those of the surrounding points are also high; high-low clustering (HL), where the attribute value of this point is high but those of the surrounding points are low; low-high clustering (LH), where the attribute value of this point is low but those of the surrounding points are high; low-low clustering (LL), where the attribute value of this point is the same as that of the surrounding points; and no obvious clustering pattern[46].

5. Analysis of Parking Lot Spatial Distribution Characteristics in Lanzhou City

5.1. Overall Spatial Distribution

Based on Fig. 2, analyze the increase, proportion and corresponding spatial distribution of different types of parking lots in each district:

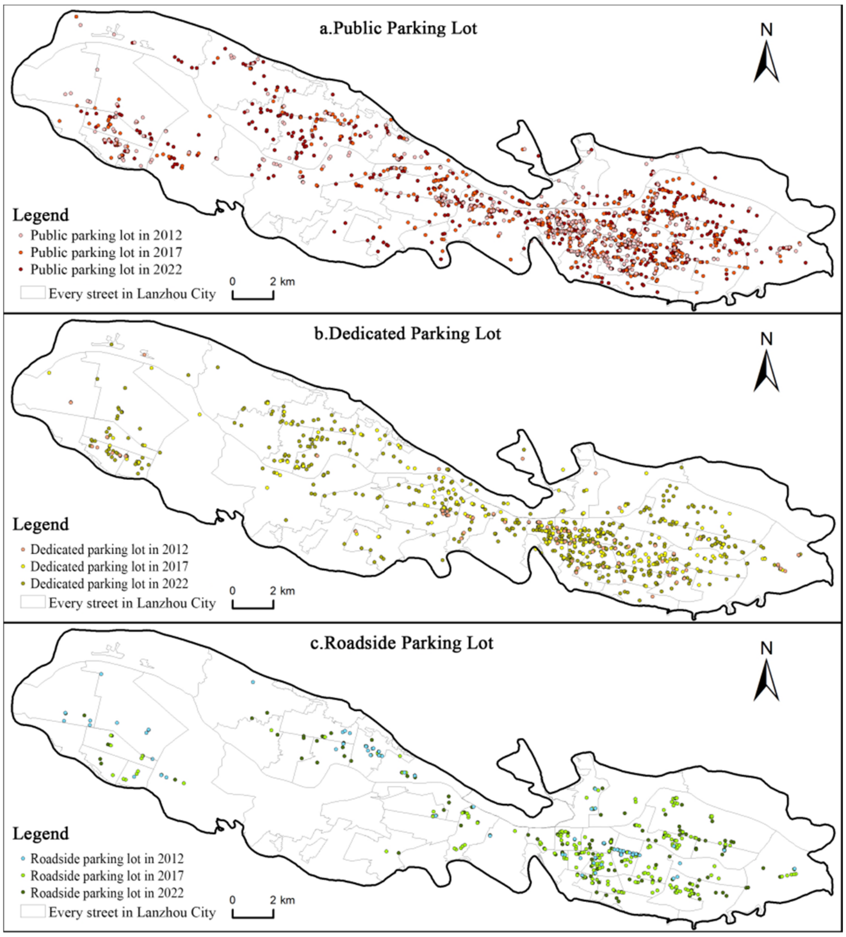

Fig 2. Distribution of parking lot

Table 2. Statistical table of the number of public parking lot

Year	2012		2017		2022	
	No. of Parking Lot	proportion	No. of Parking Lot	proportion	No. of Parking Lot	proportion
Chengguan	229	64.51%	394	65%	521	60%
Qilihe	55	15.49%	106	17%	151	17%
Anning	33	9.30%	55	9%	126	14%
Xigu	38	10.70%	54	9%	77	9%
Total	355	100%	609	100%	875	100%

Table 3. Statistical table of the number of dedicated parking lot

Year	2012		2017		2022	
	No. of Parking Lot	proportion	No. of Parking Lot	proportion	No. of Parking Lot	proportion
Chengguan	47	64%	133	66%	405	62%
Qilihe	16	22%	33	16%	115	18%
Anning	4	5%	19	9%	91	14%
Xigu	7	9%	16	8%	46	7%
Total	74	100%	201	100%	657	100%

According to Fig. 2a and Tab. 2, it can be seen that in 2012, public parking lots were most distributed in Chengguan District, followed by Qilihe District and Xigu District, with the least distribution in Anning District. Chengguan District was mainly located in Gailan Road Sub-district and Jiuquan Road Sub-district. The farther the other sub-districts were from

Dongfanghong Square, the fewer they were distributed. The proportion of Chengguan District generally showed a downward trend. Qilihe District was distributed along Xizhixin Road and Xizhidong Road in the north near the Yellow River. With the increase of years, the proportion of Anning District exceeded that of Xigu District, and it increased more along Jian'an East Road, Wenhuan South Road - Lanzhou Customs - Tongda Street. The situation was that Chengguan District had the most, followed by Qilihe District and Anning District, and Xigu District had the least. Later, Qilihe District saw growth in Jianlan Road Sub-district and along Nanbinhe Road. The overall distribution of the number of parking lots in each district became more complete.

According to Fig. 2b and Tab. 3, the proportion of dedicated parking lots in 2012 was as follows: Qinchang District, Qilihe District, Xigu District, and Anning District. From 2017 to 2022, the proportion of Anning District continued to increase, while the proportions of Qilihe District and Xigu District both decreased to varying degrees. Regarding the increase in the locations of each district: 1) Qinchang District had a relatively large increase in the early stage, and the increase in the later stage was smaller compared to other districts. Its distribution spread northward, such as Yanbei, High-tech Zone Street, etc. 2) Qilihe District had a smaller increase in the early stage and a larger increase in the later stage. The spatial distribution change was from north to south. 3) Anning District, the increase in the later stage was far greater than that in the earlier stage. 4) Xigu District had a large increase in the later stage, but the spatial distribution range of the increase points did not spread over a wide area. It was still concentrated in Weifei Road, Xigu City, Sichengqing Street.

Table 4. Statistical table of the number of roadside parking lot

Year	2012		2017		2022	
	No. Of Parking Lot	proportion	No. of Parking Lot	proportion	No. of Parking Lot	proportion
Chengguan	33	51%	175	75%	122	75%
Qilihe	3	5%	16	7%	12	7%
Anning	17	26%	23	10%	18	11%
Xigu	12	18%	19	8%	11	7%
Total	65	100%	233	100%	163	100%

According to Fig. 2c and Tab. 4, the proportion of roadside parking lots in each district in 2012 was in the following order: Chengguan District, Anning District, Xigu District, and Qilihe District. In 2012, the roadside parking lots in Chengguan District were mainly concentrated around Qingyang Road, with an increase of 24% in the early stage, which was a relatively large increase. They were mainly distributed in Zhangye Road Street, Gaolan Road Street, West Road Street, Jiayuguan Road Street, and Yan Nan Street. In the later stage, the expansion mainly occurred in Yan Nan Street and Jiayuguan Road Street. The proportion of Anning District decreased by 15% overall, and that of Xigu District decreased by 11%. In terms of spatial distribution: 1) The increase in Qilihe District in the early stage was mainly along Qilihe East Street and Qilihe North Street. 3) The increase in Anning District in the early stage was mainly in Peili Street, and in the later stage, it was mainly distributed along Anning East Road. 4) The increase in Xigu District in the early stage was relatively large, mainly distributed along Xigu Road, Fuli Road and other densely populated sections. The proportion of all types of parking lots in Chengguan District reached over 57%, while the proportion in other districts was no more than 20%, indicating a significant gap in economic development levels between Chengguan District and other districts. The proportion of all types of parking lots in Anning District showed a growth trend. The overall proportion of Qilihe District and Xigu District showed a downward trend.

5.2. Parking Lot Direction Distribution Characteristics

To objectively understand the macroscopic development and change situation of parking lots in Lanzhou City, the standard deviation ellipse analysis method was adopted for analysis. And a standard deviation size that includes approximately 63% of the elements in the clustering was selected to obtain the ellipse distribution diagrams of various parking lots at three time points as shown in Fig. 3, the spatial distribution changes were analyzed from the inter-annual comparison within the region and the overall inter-annual comparison:

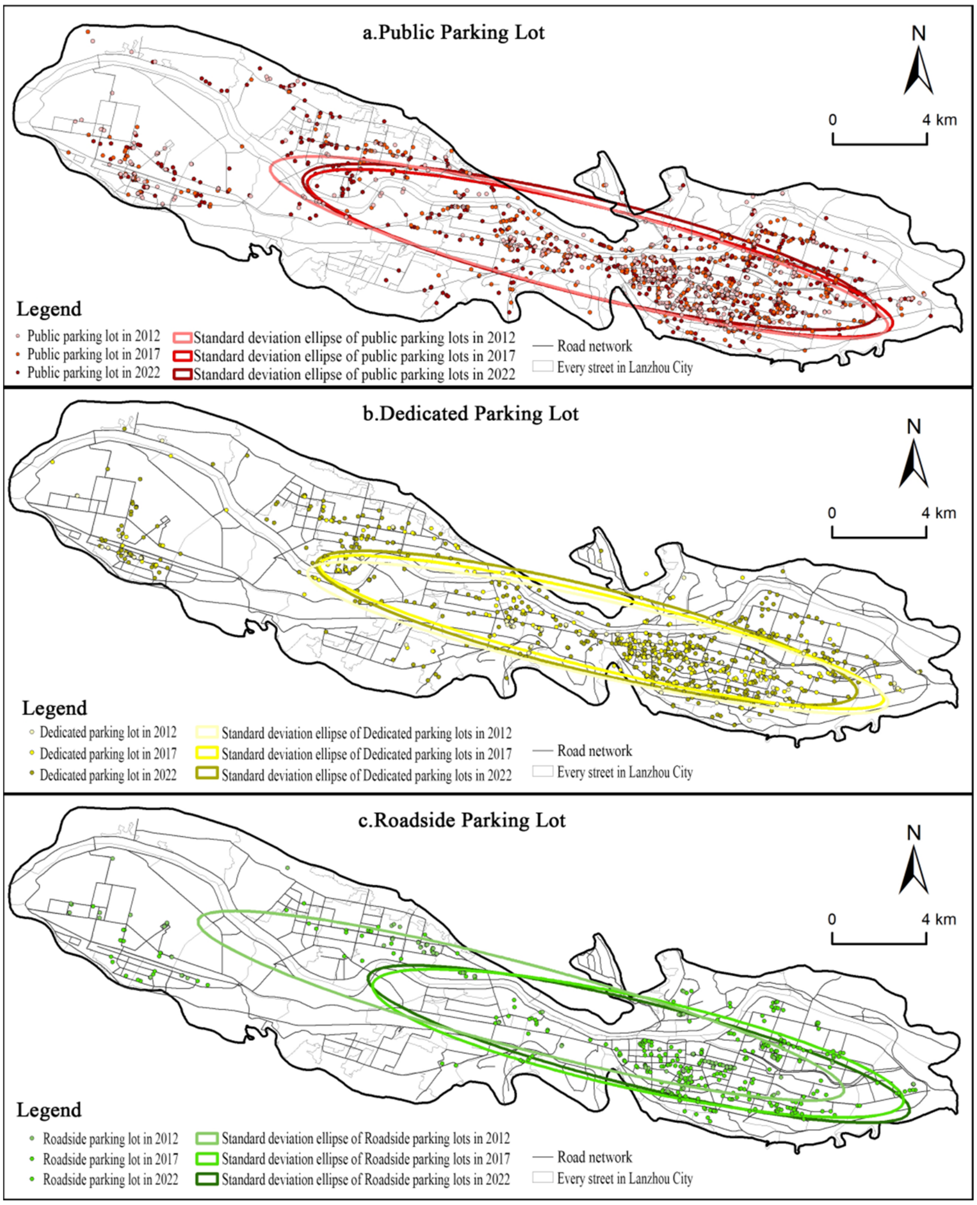

Fig 3. Elliptic distribution of standard deviation of parking lot

Table 5. Variation of ellipse parameters of standard deviation of a public parking lot

Year	Center point coordinates	Long axis length/km	Short axis length/km	flattening
2012	36°04′02.3″N,103°47′34.8″E	11.18	1.86	0.83
2017	36°03′54.4″N,103°48′04.1″E	10.54	1.87	0.82
2022	36°04′03.2″N,103°47′50.1″E	10.32	2.02	0.80

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Table 6. Variation of standard deviation ellipse parameter in dedicated parking lot

Year	Center point coordinates	Long axis length/km	Short axis length/km	flattening
2012	36°03′42.3″N,103°48′07.1″E	10.41	1.59	0.85
2017	36°03′50.0″N,103°48′12.2″E	10.15	1.54	0.85
2022	36°03′55.7″N,103°47′51.3″E	9.73	1.77	0.82

Table 7. Variation of ellipse parameters of standard deviation of roadside parking lot

Year	Center point coordinates	Long axis length/km	Short axis length/km	flattening
2012	36°04′35.1″N,103°46′21.3″E	11.72	1.75	0.85
2017	36°03′43.4″N,103°49′02.4″E	9.49	1.93	0.80
2022	36°03′42.4″N,103°49′03.5″E	9.77	1.75	0.82

Combining Fig. 3, Tab. 5, Tab. 6 and Tab. 7, the overall spatial distribution changes of various parking lots were analyzed: 1) Based on Fig. 3a and Tab. 5, The center of the ellipse of public parking lots remained almost unchanged from 2012 to 2022, the long axis decreased by 0.86 kilometers, and the short axis increased by 0.16 kilometers, indicating that its spatial distribution expanded towards the north and south, and the overall spatial distribution became more complete. The direction angle shifted 1.32° to the south, indicating that there was an increase in the areas of Xigu District and the southern part of Qilihe District. 2) Based on Fig. 3b and Tab. 6, it can be concluded that: The long axis of the dedicated parking lot has decreased by 0.67 kilometers and the short axis has increased by 0.18 kilometers, indicating a polarization in the northwest-southeast direction, showing a contracting trend and a tendency to spread southward and northward. The azimuth has increased by 0.95°, and the aspect ratio has decreased, suggesting that the northeast-southwest directionality has weakened. 3) Based on Fig. 3c and Tab. 7, The long axis of the roadside parking lot has decreased by 1.95 kilometers while the short axis remains unchanged. This indicates a contracting trend in the northwest-southeast direction and an expansion trend along the south-north direction. The azimuth has deviated 1.04° to the north, and the aspect ratio has decreased by 0.03, suggesting an increase in the city district of ChengGuan and Anning. This indicates an enhancement of the northwest-southeast directionality.

5.3. Kernel Density Distribution Characteristics of Parking Lots

The kernel density analysis method was used to calculate the kernel density values of various parking lots in Lanzhou City. The kernel density values were divided into 9 levels using the natural breakpoint method.

According to the density change chart of public parking lots in Fig 4 over three years, it can be observed that: 1) There is a development trend from single core to multi-core. In 2012, the high-density values ranging from 12 to 17 were mainly distributed in 8 core streets including Gailan Road Street, Jiuquan Road Street, Donggang West Road Street, Guangwu Men Street, and Zhangye Road Street, accounting for 16% of the total number of streets. They were distributed in a core-edge pattern within each area, and the main urban area showed a clustered distribution. Compared with 2012, the high-density value of 17-24 in 2017 increased by 41%, distributed in 10 streets, accounting for 20% of the total number of streets. It spread in a north-south direction and showed a distinct band-like distribution. In 2022, the density of public parking lots in the eastern and western ends of Gailan Road Street exceeded the original high value of Dongfanghong Square, distributed in 12 streets, accounting for 24% of the total number of streets, and showed a planar distribution. 2) In 2012, the medium-density values ranging from 5.6 to 11 were distributed in 15 streets, accounting for 30% of the total number of streets. In 2017, the medium-density values ranging from 8.1 to 16 increased by 45%

compared with 2012, distributed in 21 streets, covering 42% of the total number of streets. In 2022, the density remained basically unchanged, distributed in 27 streets, covering 54% of the total number of streets. Overall, the public parking lots extended eastward and westward, expanded north-south, and the distribution became more complete.

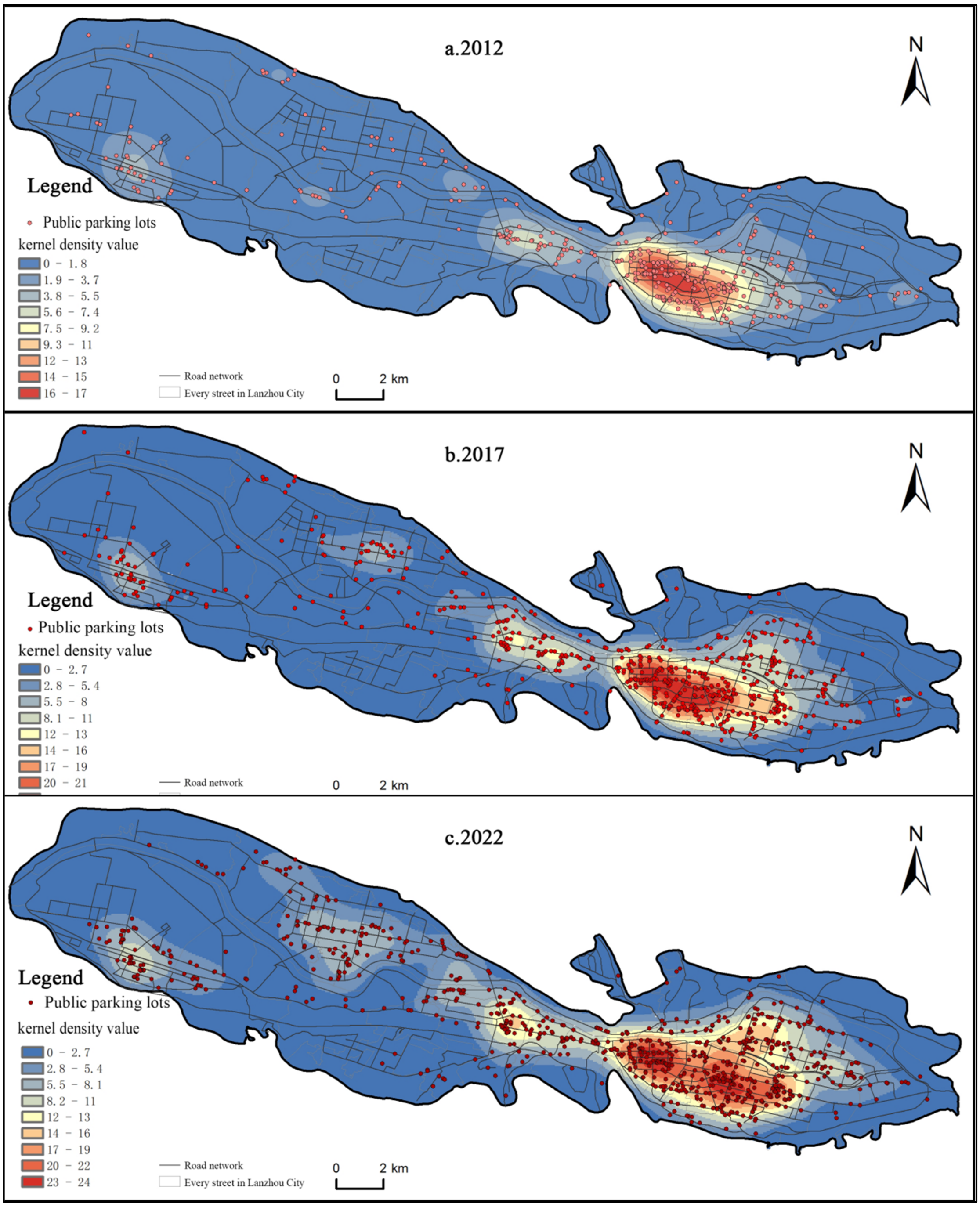

Fig 4. 1 Nuclear density changes of public parking lot

According to the density change chart of dedicated parking lots in Fig 5 over three years, it can be observed that: 1) In 2012, the high-density values ranging from 2.4 to 3.5 were distributed in 6 streets. In 2017, the high-density values increased by 1.86 times compared with 2012, distributed in 8 streets. In 2022, compared with 2017, it increased by 2.3 times, covering 7 streets. The coverage area of high-density values decreased, indicating a polarization phenomenon. That is, the density of dedicated parking lots around Zhangye Road Street was exceptionally high, while the surrounding areas were relatively low. 2) In 2012, the medium-density values ranging from 1.3 to 2.3 covered 18 streets, in 2017, the medium-density values increased by 1.87 times compared with 2012, covering 22 streets, and in 2022, it increased by 2.47 times, covering 17 streets. It showed a process of rapid growth followed by polarization. The reason is that dedicated parking lots are parking lots for government agencies, schools, hospitals, commercial office buildings, etc., which are decision-making institutions. Their layout often follows the principle of facilitating access throughout the city, so they show an east-west band-like distribution along the Qingyang Road axis.

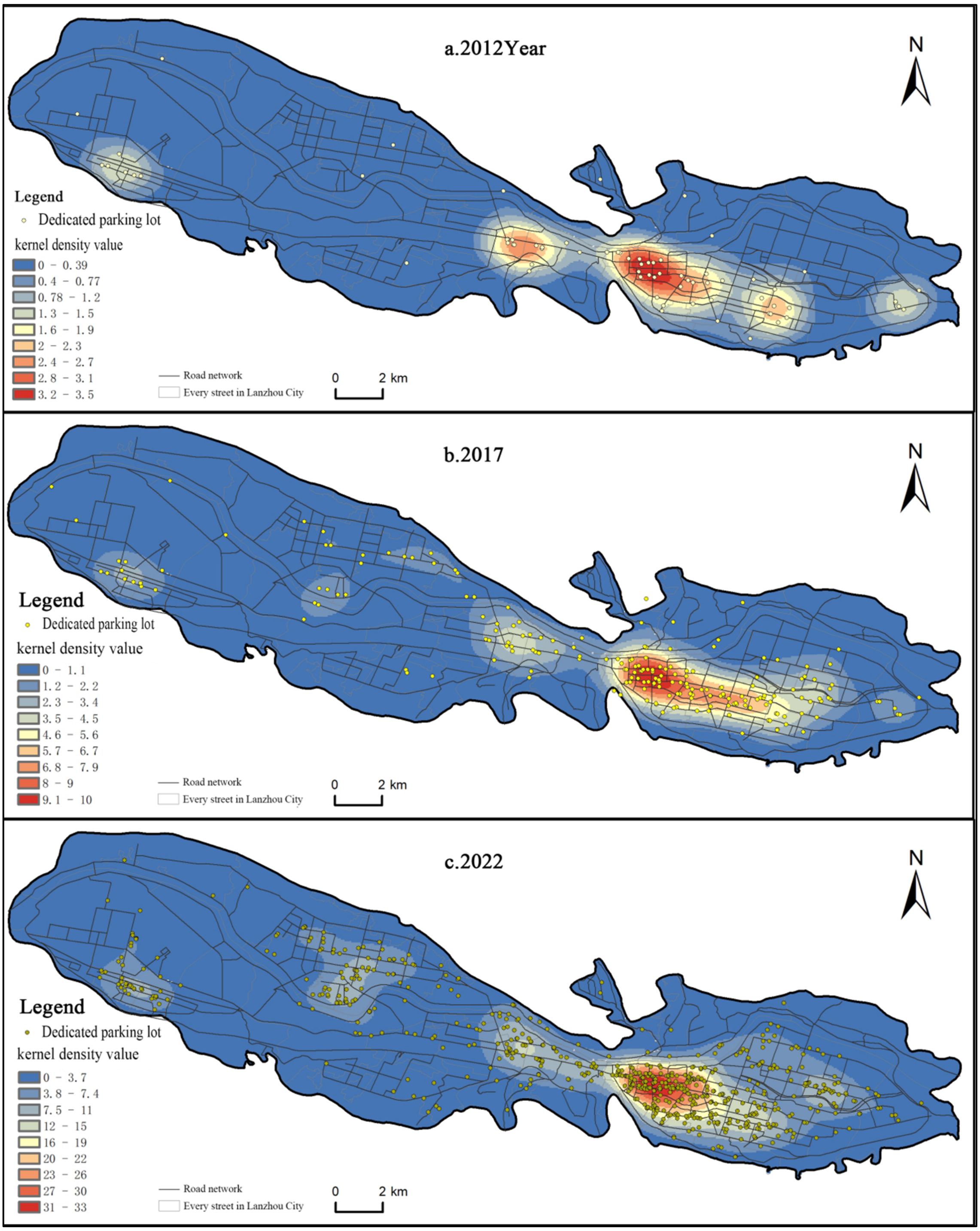

Fig 5. Nuclear density changes of dedicated parking lot

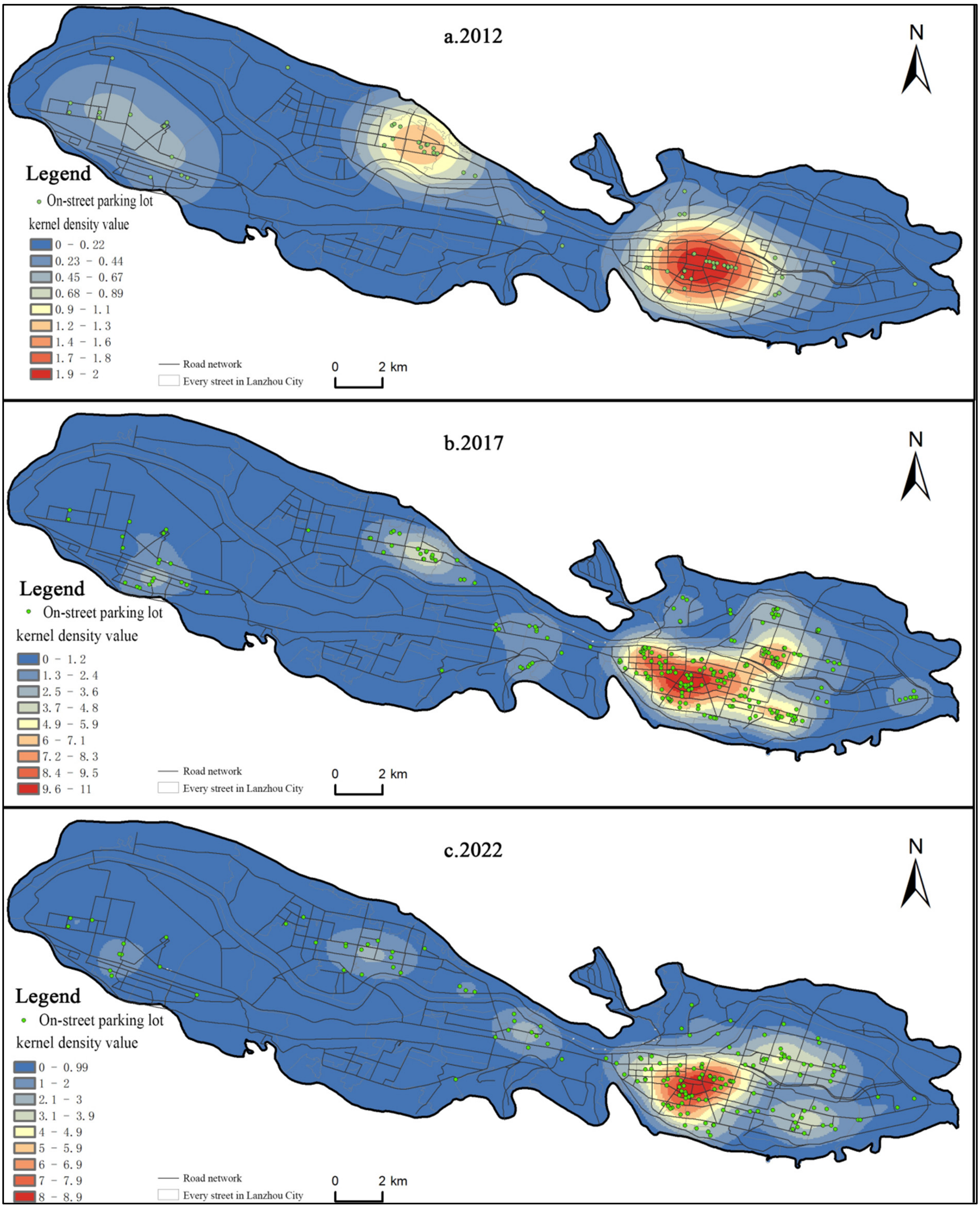

Fig 6. Nuclear density changes of On-street parking lot

According to the density change map of roadside parking lots shown in Fig 6. 1) In 2012, the high-density values ranged from 1.4 to 2 were distributed in 10 streets. In 2017, the high-density values ranged from 7.2 to 11, which were 3.94 times higher than those in 2012 and were distributed in 10 streets. In 2022, the high-density values ranged from 6 to 8.7, which were lower than those in 2017 and were distributed in 7 streets. The distribution area of high-density values shows a shrinking trend. 2) In 2012, the medium-density values ranged from 0.68 to 1.3 were distributed in 22 streets. In 2017, the medium-density values ranged from 3.7 to 7.1, which were 4.44 times higher than those in 2012 and were distributed in 22 streets. In

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2022, the medium-density values were 3.1 to 5.9, which were distributed in 18 streets. The overall density values have changed significantly. The reason is that roadside parking lots are positioned as supplements to other types of parking lots in the traffic planning standards, so there is a large growth space.

5.4. Analysis of Aggregation Distribution Characteristics

5.4.1. Global Aggregation Distribution Feature Analysis

The Z score is expressed as a multiple of the standard deviation, indicating the degree of dispersion of the data. When the Z score is positive, it indicates a concentrated distribution; when it is negative, it indicates a dispersed distribution. The larger the absolute value of the Z score, the more significant the concentrated or dispersed characteristics. If the absolute value of the Z score is less than 1.65, the test cannot be passed. The P value is used to test the reliability of the data, that is, to determine the probability of rejecting it as being generated by a random distribution. If the P value is greater than 0.1, it means there is more than 10% possibility that it is generated by a random distribution, and thus the test cannot be passed.

Table 8. Results of global Moran I index of various parking lots in 2012

	Public parking lot in 2012	Dedicated parking lot in 2012	On-street parking lot in 2012
Moran I :	0.174585	0.19241	0.1868
expectations index:	-0.020408	-0.02041	0.02041
variance:	0.00841	0.009253	0.00764
Z-score:	2.12633	0.237212	0.76881
P-value:	0.033476	0.31249	0.442

Table 9. Results of global Moran I Index of various parking lots in 2017

	Public parking lot in 2017	Dedicated parking lot in 2017	On-street parking lot in 2017
Moran I :	0.272169	0.125005	0.264811
expectations index:	0.020408	-0.02041	-0.02041
variance:	0.00959	0.009366	0.007097
Z-score:	2.987645	1.502552	3.385743
P-value:	0.002811	0.13296	0.00071

Table 10. Results of global Moran I Index of various parking lots in 2022

	Public parking lot in 2022	Dedicated parking lot in 2022	On-street parking lot in 2022
Moran I :	0.181358	0.413118	0.334364
expectations index:	-0.02041	-0.02041	-0.020408
variance:	0.006819	0.007427	0.006868
Z-score:	2.44327	5.030589	4.280876
P-value:	0.01456	0.00	0.000019

As shown in Tab. 8, in 2012, the P value of public parking lots was less than 0.05, the Z value was greater than the critical value of 1.96, and the Moran index was all positive, indicating that their spatial correlation was aggregation. The larger the absolute value of the index, the stronger the aggregation. The P values of the other three types of parking lots were greater than 0.1, and the Z values were less than 1.65. They could not reject the null hypothesis, meaning that there was a 10% probability that the spatial distribution of these three types of parking lots was random. No further local spatial autocorrelation test could be conducted.

As can be seen from Tab. 9, in 2017, the Z scores of both public parking lots and roadside parking lots were greater than 2.58, and the P values were all less than 0.01. There is a 99% certainty to ensure that they are not randomly distributed. The Z values of the built-up parking lots and the dedicated parking lots were all less than 2.58, and the P values were greater than 0.1, meaning that the probability of random distribution was greater than 10%. Therefore, the next step of local spatial autocorrelation test cannot be carried out.

From Tab. 10, it can be seen that in 2022, the Z score of public parking lots was greater than 1.96, and the P value was less than 0.05, indicating that the distribution of parking lots is directly proportional to the degree of spatial aggregation. The data shows a significant clustering. The P values of the built parking lots and roadside parking lots were both less than 0.01, indicating that the probability of random distribution was only 1%. The Z value was greater than 2.58, indicating that the data is highly aggregated. The P value of the dedicated parking lot was 0, the Morans index was positive, and the Z score was greater than 2.58, indicating that it is 100% aggregated.

5.4.2. Analysis of Local Aggregation Distribution Characteristics

The global Moran index can represent the overall characteristics of the entire area, but it may mask the local aggregation or dispersion features. Therefore, further local spatial autocorrelation analysis is conducted. The premise for conducting local spatial autocorrelation analysis is to pass the global autocorrelation test. Thus, analyses are carried out for public parking lots in 2012, 2017, roadside parking lots, and all types of parking lots in 2022. As shown in Fig. 7a, the eight streets of Lanzhou City's Chengguan District, including Gaolan Road Street, Donggang West Road Street, Guangwu Men Street, Zhangye Road Street, Jiuquan Road Street, Yanan Street, Weiyuan Road Street, and Railway East Village Street, are characterized by high-high value aggregation. That is, Yanjiaqin Street in Qiyi District is characterized by low-low value aggregation. Chengguan District's Baiyuan Road Street and Jingyuan Road Street show low-high spatial anomalies, while XiuChuan Street in Qiyi District and Anning District's Anningbao Street show high-low spatial anomalies.

From Fig. 7b, it can be seen that: 1) In 2017, public parking lots showed a high-high spatial clustering in Jiuquan Road Sub-district, Guangwu Gate Sub-district, Donggang West Road Sub-district, Wei Yuan Road Sub-district, and Tuanjie Xin Village Sub-district. In Gongjiawan Sub-district of Qilihe District, Xiguo District's Sijiqing Sub-district and Xilugou Sub-district, it was a low-low spatial clustering. In Chengguan District's High-tech Zone and Caotasi Sub-district, it was a low-high spatial dispersion. Xiu Chuan Sub-district of Qilihe District was a high-low spatial dispersion. 2) The high-high value aggregation of roadside parking lots was similar to that of public parking lots. The low-low value aggregation was mainly distributed in Qilihe District, with high-low outliers being Xihu Sub-district and High-tech Zone Sub-district, and low-high outliers being Yanchang Road Sub-district and High-tech Zone Sub-district.

From Fig. 7c, Fig. 7d and Fig. 7e, we can see that: 1) In 2022, the public parking lots were highly concentrated in Donggang West Road Subdistrict, Guangwu Men Subdistrict, Zhangye Road Subdistrict, Yan'an Subdistrict, Yanshang Road Subdistrict, and Gaoxin Subdistrict. The seven Lihe District Pengjiaping Subdistrict and Gongjiaowan Subdistrict, as well as the Xigu District Sijiqing Subdistrict and Xiliujiu Subdistrict, had low-low concentration distribution. Qingbaishi

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Subdistrict had low-high abnormal distribution. 2) The dedicated parking lots were highly clustered in Gaolan Road Subdistrict, Donggang West Road Subdistrict, Guangwu Men Subdistrict, Zhangye Road Subdistrict, Linxia Road Subdistrict, Fulongping Subdistrict of Gaoxin Subdistrict, and Gongjiaowan Subdistrict. In Gongjiaowan Subdistrict, they had low-low clustering distribution. Jingyuan Road Subdistrict, Caocang Street Subdistrict, and Yan'an Subdistrict had low-high abnormal distribution. 3) The roadside parking lots were highly clustered in Gaolan Road Subdistrict, Jiuquan Road Subdistrict, Guangwu Men Subdistrict, Donggang West Road Subdistrict, Yan'an Subdistrict, and Gaoxin Subdistrict. In Xiliujiu Subdistrict, Sijiqing Subdistrict, Chenping Subdistrict, Pengjiaping Subdistrict, Gongjiaowan Subdistrict, Tumendun Subdistrict, Dunhuang Road Subdistrict, Jianlan Road Subdistrict, Qingbaishi Subdistrict, Weiyuan Road Subdistrict, and Railway East Village Subdistrict, they had low-low clustering distribution. In Xigu Cheng Subdistrict and Xihu Subdistrict, they had high-low abnormal values distribution.

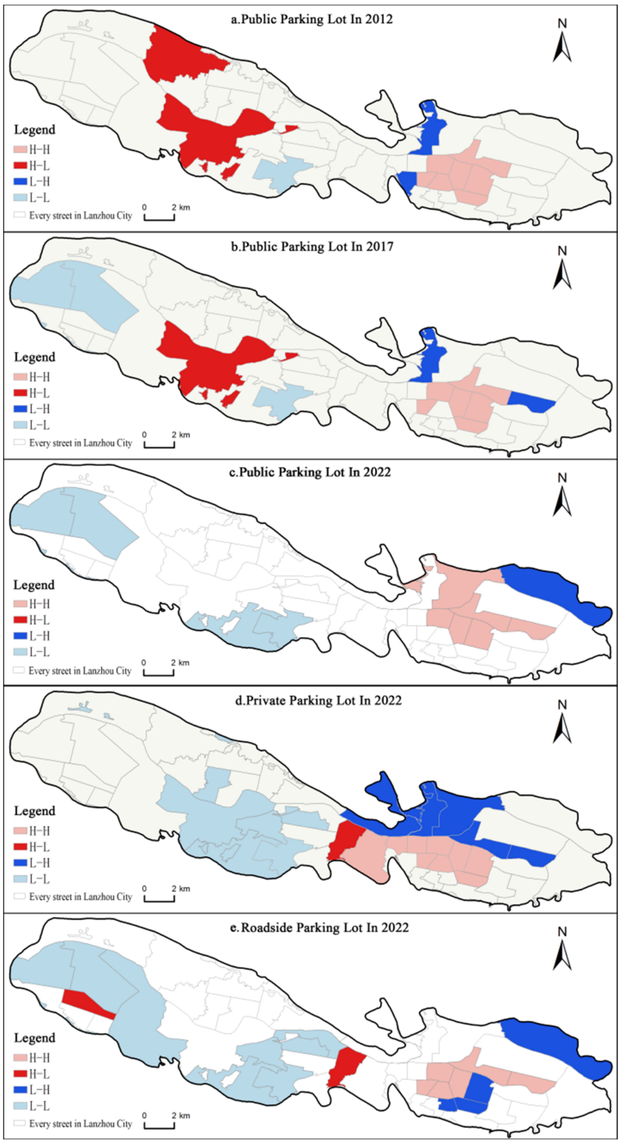

Fig 7. Clustering and outliers of parking lot

6. Conclusion

(1) Public parking lots are established for the convenience of residents' travel. They account for the largest proportion among all types of parking lots. 1) In the early stage, the proportion of various parking lots in Anning District was relatively low, but it increased

later, which was consistent with the overall economic development level improvement of Anning District. The overall distribution of the proportion in each district has become more complete. 2) In dedicated parking lots, government institutions, schools, hospitals, commercial office buildings, etc., which have decision-making nature or are large-scale public infrastructure, their layout often follows the principle of facilitating access throughout the city. Therefore, Chengguan District has a relatively large proportion, presenting a belt-like pattern along the axis of Qingyang Road. 3) The proportion of various parking lots in Chengguan District is the largest, exceeding 57%. The reason is that the Zhangye Road Sub-district, Linxia Road Sub-district, and Xihu Sub-district of Qiyi District, Dunhuang Road Sub-district, Xizhang Sub-district of Liulihe District are all commercial economic centers with a large population flow and obvious geographical advantages, and there are a large number of parking lots [47].

(2) The major axes of the standard deviation ellipses for various parking lots have shortened, while the minor axes have lengthened and the aspect ratio has decreased. This indicates that the spatial distribution in the northwest-southeast direction is relatively saturated, and thus it has been expanded in the north-south direction. This is consistent with the trend of limited urban development space in Lanzhou, where it expands both southward and northward to fully utilize the available space.

(3) The parking lots in various districts of Lanzhou City have significant differences in density and are in a multi-core aggregated state. There are significant differences in the zones, and the overall spatial distribution shows an unbalanced characteristic of "more in the southeast and less in the northwest". 1) Public parking lots: They have developed from a single-core cluster pattern to a multi-core planar pattern. Overall, public parking lots extend eastward and westward, and expand north-south, and their distribution has become more complete. 2) dedicated parking lots: The number of streets with high density values in the three years was 6, 7, and 8 respectively. The coverage area of high density values has shrunk, but the density value has increased significantly. The number of streets with medium density values in the three years was 18, 22, and 17 respectively, showing a process of rapid growth followed by polarization. 3) Roadside parking lots: The high density values were distributed in 10 streets in 2012, and in 2017, the high density values increased by 3.94 times, and in 2022, the high density values were lower than those in 2017, with a huge increase in density values, showing a polarized planar development trend. The number of streets with medium density values in the three years was 22, 22, and 18 respectively, and the medium density value increased by 4.44 times in 2017. The overall density value has changed significantly. The reason is that roadside parking lots are positioned as a supplement to other types of parking lots in the traffic planning standards, and there is a large growth space, so the increase in density values is significant. The spatial distribution range shows a planar development trend, that is, the overall density value increases.

(4) Aggregation and Distribution Feature Analysis: 1) Public parking lots show a significant aggregation. In 2017, roadside parking lots also showed significant aggregation, and in 2022, all types of parking lots exhibited an aggregated pattern. 2) By comparing the spatial distribution of outliers of public parking lots and roadside parking lots in 2017, it was found that the high-high value aggregation distribution and the low-high value abnormal distribution, as well as the low-low value spatial distribution were relatively similar. Attention should be paid to the streets with high-low or high-low abnormal value distributions, such as Xiu Chuan Street, where the public parking lot is a high-low abnormal distribution, indicating that the public parking lot in Xiu Chuan Street is relatively more sufficient compared to the surrounding streets. 3) By comparing the spatial distribution of outliers of various parking lots in 2022, it was found that the low-low values mostly

appeared in Qilihe District and Xigu District. The high-high values were relatively stable in Chengguan District. 4) By comparing the local autocorrelation values of public parking lots over the three years, it can be found that in the four streets of Chengguan District, Donggang West Road Street, Guangwumen Street, Zhangzhe Road Street, and Yanan Street, a relatively stable performance of high-high aggregation was observed, that is, the adjacent streets of the streets with aggregated distribution also have an aggregated distribution. Gongjiawan Street has always been a low-low aggregation, and the streets with high-low or low-high abnormal value distributions gradually decreased, indicating that the overall distribution of public parking lots in Lanzhou City is generally reasonable.

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