Spatial Accessibility Evaluation on the Public Charging Facilities for New Energy Vehicles in Anning District, Lanzhou City, China

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Abstract. This paper analyses the whole process of charging behaviour of new energy vehicles in Lanzhou City through the travel chain, adopts the two-step mobile search method based on the segmentation function, conducts a spatial accessibility study on public charging facilities in Lanzhou City's Anning District, and analyses the spatial pattern of public charging services from the perspective of supply and demand, with a view to providing scientific basis for the siting and construction of public charging facilities for new energy vehicles. The results of the study show that: ① The spatial accessibility of public charging facilities in Anning District, Lanzhou City, is distributed in the form of "patches", which is different from the "concentric circle structure" in the plain area, and has significant regional characteristics. ② The spatial distribution of public charging facilities in Anning District does not match the population distribution, and there is an imbalance between supply and demand. ③Anning District, Anningburg Street and Shajingyi Street south of the waterfront, Kongjiaya Street and Peili Street south of the waterfront, West Street and Yinchuan Road Street junction and the middle of Shilidian Street, should be equipped with public charging facilities to meet the demand for new energy vehicle charging.

Keywords: Public service facilities, new energy vehicles, accessibility, balance between supply and demand

1 Introduction

With the new round of global scientific and technological revolution and industrial change, new energy vehicles have become the main direction of the transformation and upgrading of the global automotive industry. The cross-fertilisation of automobiles with energy, transportation, communication and other fields has led to profound changes in the form of automotive products, traffic and travel modes, and the structure of energy consumption, providing unprecedented development opportunities for the new energy automobile industry [1]. In the "14th Five-Year Plan" and the "double carbon" goal of energy saving and emission reduction in the context of China's new energy vehicle sales in 2023 reached 9.495 million units, market share of 31.6%. Among them, 1.203

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million new energy vehicle exports, production and sales accounted for more than 60% of the global proportion, ranking first in the world for nine consecutive years [2]. By the end of 2023, China's new energy vehicle ownership has reached 20.41 million, along with the rapid development of new energy vehicles, electric vehicle (EV) charging facilities construction and layout has become the top priority of the city's new public infrastructure construction.

With the large-scale construction of automobile charging facilities in recent years, the problem of optimising its site selection has gradually attracted the attention of many scholars at home and abroad. For example, Keawthong et al [3] analyzed the effects of queuing delay and charging travel time on charging behavior based on the GPS trajectory data of Bangkok cabs and constructed a scientific method to determine the number and location of charging piles, which effectively reduces the charging travel time and queuing time of cabs. Kavianipour et al [4] used Michigan road network and OD travel data for charging behavior simulation and proposed a fast charging station planning model based on real road network environment. Hamed et al. [5] innovatively introduced the "stochastic parameter method" to predict the day and night charging power demand, and used the maximum coverage model to study the optimal location of charging stations under different charging scenarios. Currently, the mainstream charging station siting models based on point demand have different application scenarios, and each method has its own advantages and disadvantages, but none of them can comprehensively consider the interaction between the supply point (charging station) and the demand point (electric vehicle), and solve the charging station siting problem from the perspective of supply and demand, which makes it difficult to achieve the scientific siting of automobile charging facility construction.

In the field of urban planning, the spatial accessibility is often used as an important indicator for evaluating the coverage, fairness and reasonableness of the layout of public service facilities. The "two-step mobile search method" is the most commonly used measurement method, which can comprehensively consider the interaction between supply and demand points from the perspective of supply and demand relationship. However, at present, relevant research mainly focuses on public service facilities such as medical care, green space, elderly care, education, etc., and car charging facilities, as a new type of urban public service facilities, have relatively few relevant studies in this field.

2 Data sources and Methodology

2.1 Research Area

Lanzhou City is the capital city of Gansu Province, a typical river valley city, its urban form, traffic road network and so on are developed in the form of a belt, so its electric vehicle charging facilities construction layout has significant regional characteristics. However, because this paper uses the Baidu map path planning service to obtain travel data between supply and demand points [6], limited by the platform API call quota, so this paper only selected Anning District in Lanzhou City as the study area. Anning District is located in the northwestern part of Lanzhou city centre, on the north bank of the Yellow River, and is the only one of the five districts under the jurisdiction of Lanzhou City that is relatively independent of the influence of topography and is not affected by the public facilities in other areas. (Figure 1).

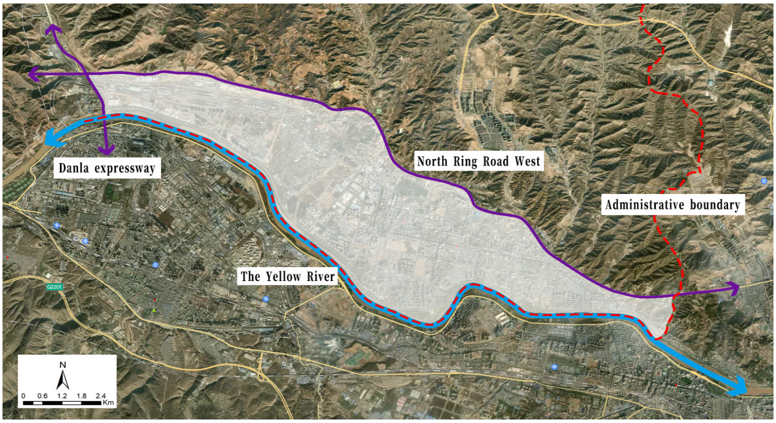


Fig. 1. Study area: Anning District, Lanzhou City

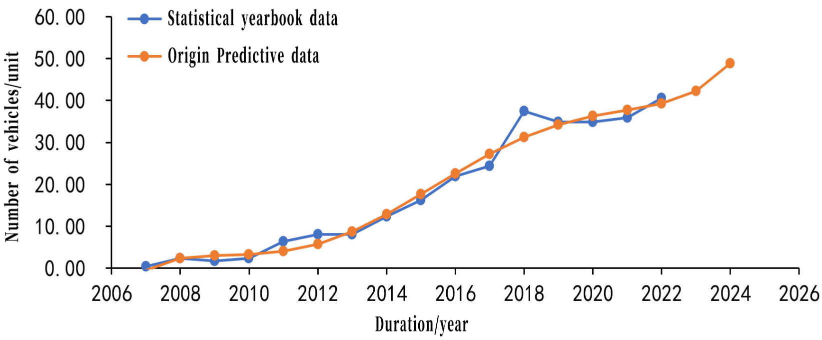


Fig. 2. Domestic cars owned per 100 households at end of year

2.2 Data Sources

According to the 2023 Lanzhou Statistical Yearbook, at the end of 2023, there were 488,100 civilian cars in Lanzhou, of which 43,920 were new energy cars, and the ratio of fuel cars to new energy cars was 11.113:1. Based on the data of year-end household car ownership per 100 households of residents in the 2007-2023 Statistical Yearbook of Lanzhou City, it can be predicted that the year-end household car ownership of residents at the end of the year 2024 will be 48.801 cars per 100 households (Figure 2). The data of automobile charging facilities mainly come from the open platform of Gaode map, and the information of POI data of charging station, type and number of charging piles can be obtained through python crawler technology (Figure 3). Similarly the number of households in residential neighbourhoods can be obtained from websites such as China 58 Tongcheng and Anjuke. The user charging travel data comes from Baidu map open platform, by calling Baidu map path planning service, to obtain the real-time distance and travel time of new energy vehicle owners from the demand point to the supply point. New Energy Vehicle Ownership in Residential Areas = Number of Households × Vehicle Ownership of 100 Households × Percentage of New Energy Vehicles, according to which the new energy vehicle ownership can be more accurately deduced.

2.3 Research Methods

2.3.1. Electric Vehicle Charging and Travel Chain

In the current urban scenario, domestic new energy vehicle travel destinations can be divided into five categories, home, H, work, W, shopping and errands, SE, social and recreation, SR, and other, O [7]. Because home EVs are bound to return to the owner's residence eventually, residential trips can be artificially divided into 16 travel modes with the residence as the node (Figure 4), and this type of travel chain is known as the home based (HB) travel chain.

Analysing the HB travel chain based on the proximity principle reveals that there are only two options for users to choose the starting point (place of residence) or the end point (place of work/activity) when the charging behaviour occurs (Figure 5), but regardless of where charging takes place, the key factors affecting the user's choice of charging station are the walking distance and the economic cost (in this paper, we focus on the study of spatial accessibility, and therefore do not consider the economic cost). Research has been done to support this assertion, in a survey of factors influencing car owners' choice of charging station in the Hanyang district of Wuhan, China[8], it was found that 76% of 127 participants were influenced by walking distance when choosing a charging station site, 0.13% by the type of charging post, and only 0.09% by the price of charging. In addition, a survey of London in *Electric vehicle charging infrastructure: location guidance for London* showed that 93% of users were willing to walk 5 minutes to a charging station, 73% were willing to walk 10 minutes to a charging station and only 37% were willing to walk 15 minutes to a charging station. Which shows that walking distance has a significant impact on the willingness of vehicle owners to travel when charging.

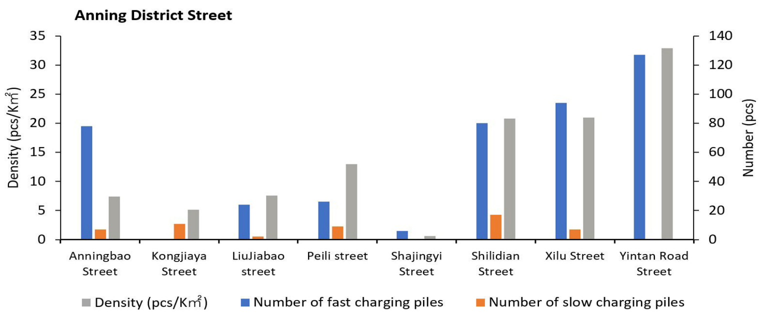


Fig. 3. Distribution of public charging posts

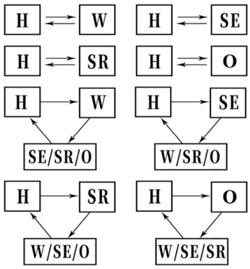


Fig. 4. Daily travel patterns of residents

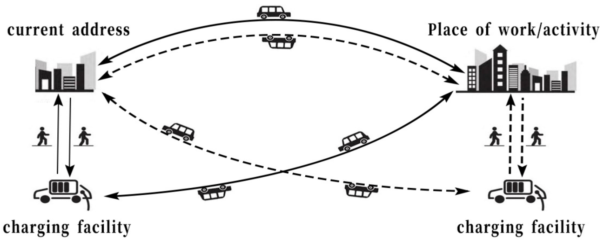


Fig. 5. Schematic diagram of charging travel chain

On the other hand, according to the Charging Infrastructure Monitoring Report for Major Cities in China 2023, it is known that the scale of charging trips for new energy vehicles reaches its peak between 23:00 and 1:00, and the demand for charging in various residential areas at night rises significantly, with the place of residence being the first choice of charging for most new energy vehicle owners. Therefore, this paper analyses the accessibility of public charging facilities using residential areas as the starting point.

2.3.2. Two-Step Moving Search Method Based on Segmented Functions

Aiming at the characteristics of HB travelling chain, this paper adopts the two-step mobile search method [9], which considers the user's travelling willingness to decay with distance, to calculate the accessibility of public charging facilities for automobiles in Anning District. It has been shown that residents' travelling intention almost does not decay with distance in the initial 5 minutes, and their travelling intention decreases with increasing distance after 5 minutes [10]. Therefore, the distance decay function in the two-step moving search method is more in line with the actual situation by using segmented function [11] (Figure 6).

The calculation of public charging facility accessibility using the two-step mobile search method can be divided into two steps, which are as follows:

Step 1: Starting from supply point j (public charging facility), determine a distance threshold d_0 and construct a catchment area. Then, based on the "Baidu map path planning to obtain real-time walking data between two points" to aggregate the demand of all demand points k within the catchment area (the number of new energy vehicles in each district), to obtain the total potential demand (P_k) of the supply point j.

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} P_k} \tag{1}$$

Where S_j is the total supply at supply point *j*; P_k is the total demand at the demand point in the catchment area; and d_{kj} is the actual distance between demand point *k* and supply point *j*.

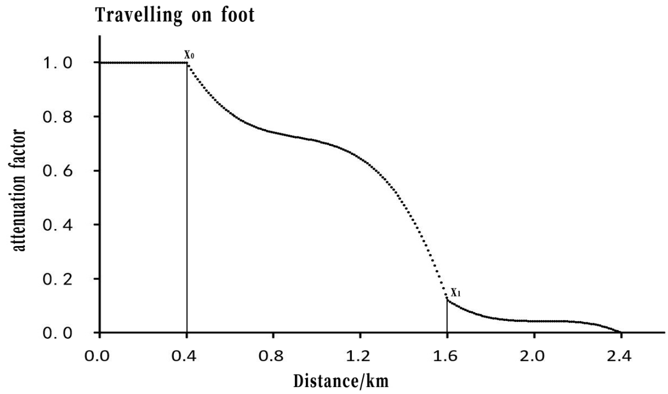


Fig. 6. Schematic diagram of the decay function

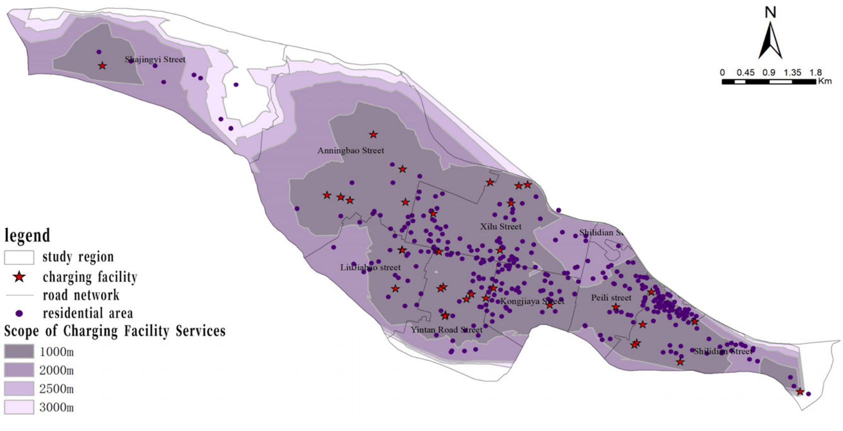


Fig. 7. Scope of charging facility services

The spatial distance threshold for supply point j in this paper is set at d_0 = 2000 m. This is because the service range measurement of the existing facilities based on the urban road network found that the public charging service radius in the urban core area of Lanzhou City has to reach 2 km in order to basically cover all the residential neighbourhoods (Figure 7).

Step 2: Take demand point *i* (residential neighbourhood) as the starting point and construct its catchment area given a distance threshold d_0. Aggregate the supply-demand ratio R_l for all supply points l within the scope of this catchment area and assign weights to them using the decay function [11] when aggregating (Table 1), The weighted R_l is then summed to obtain the spatial accessibility A_i of demand point i, calculated as follows:

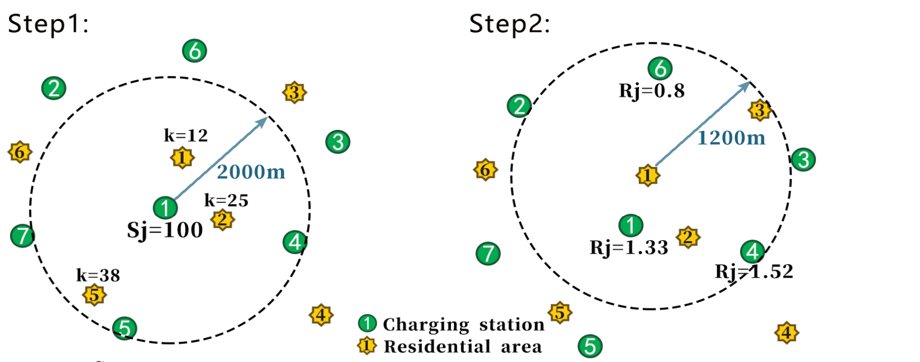
$$A_i = \sum_{l \in \{d_{il} \le d_0\}} G\left(d_{kj}, d_0\right) R_l \tag{2}$$

Where: R_l is the supply-demand ratio of supply point l in the catchment area of demand point i; $G(d_{kj},d_0)$ is the distance attenuation coefficient(Table 1); d_{il} is the spatial distance between demand point i and supply point l; A_i is the accessibility of demand point i to the neighbouring supply points to obtain the service, and the larger the A_i is, the better the accessibility is (Figure 8).

In this paper, the spatial distance threshold of demand point i is set as d_0=1200 m. Because with the rapid development of new energy vehicles, the construction of a 15-minute charging circle has become a mainstream trend in the construction of charging facilities. For example, in the Chengdu New Energy and Intelligent Networked Vehicle Industry Development Plan (2023-2030), Chengdu City has explicitly proposed the construction of a 15-minute charging circle[12].

Table 1. Distance attenuation pattern table

Time	Travel distance	Attenuation function $G(d_{kj},d_0)$	Note
5min	400m	G=1	No attenuation
20min	1600m	$G = -153.6558d_{kj}^3 + 419.4604d_{kj}^2 - 395.9706d_{kj} + 201.1086$	Rapid decay to 12 per cent at 1600m
30min	2400m	$G = -92.8d_{kj}^3 + 566.6d_{kj}^2 - 1153.1d_{kj} + 786.6$	Decay slows down to 2400m, where the decay rate is >1



$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} P_k} = \frac{100}{12+25+38} = 1.33 \quad A_i = \sum_{l \in \{d_{il} \le d_0\}} G\left(d_{kj}, d_0\right) R_l = 0.8\text{x}1.33 + 0.5\text{x}1.52 + 0.2\text{x}0.8 = 1.984$$

Fig. 8. Improved 2SFCA flowchart

3 Analytical Results

3.1 Public Charging Point Spatial Distribution Characteristics

From the point of view of the type of car charging pile, the ratio of fast and slow piles in Anning District of Lanzhou City is 8.2:1, and the number of fast charging piles has an absolute advantage in the actual construction. From the point of view of the construction scale of public charging facilities, there is a significant difference between the streets in Anning District (Figure 3), and the construction scale of public charging facilities in Yintan Road Street, West Road Street, Anningburg Street and Shilidian Street is much higher than that of the rest of the four districts, among which Kongjiaya Street and Shajingyi Street have the smallest construction scale, which is 11 piles and 6 piles, respectively. In terms of construction density, Yintan Road Street, Shilidian Street, Xilu Street and Peili Street have higher density. Shajingyi Street has the smallest construction density of 0.65 piles/km^2 .

From the results of the core density analysis (Figure 9; Figure 10), the spatial distribution of public charging facilities in Anning District is characterised by a "one-main-three-four-core structure". The distance between the four cores is moderate, the connection is relatively close, and they complement each other. However, the density distribution on the east and west sides is obviously unreasonable, with low density and far away from high-density areas. In addition, the spatial layout of public charging facilities does not match the population distribution in urban areas, macroscopically, the spatial distribution of public charging facilities and residential areas are in a state of agglomeration, but the peak centres of the two do not overlap, there may be an imbalance between supply and demand.

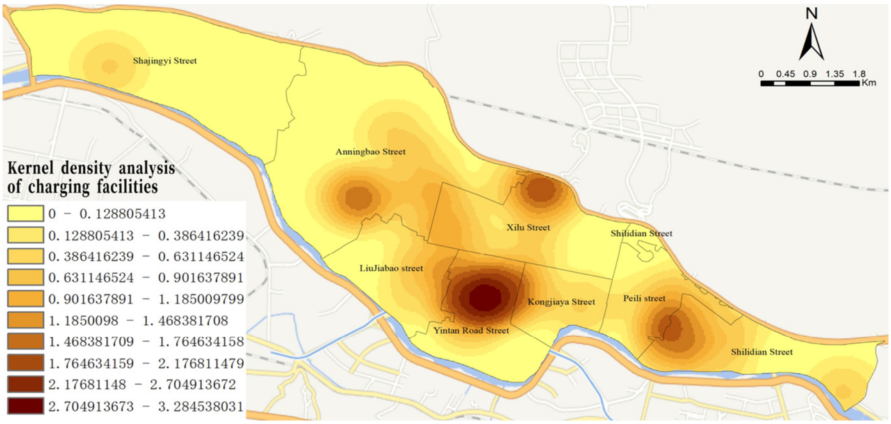


Fig. 9. Charging facility kernel density analysis

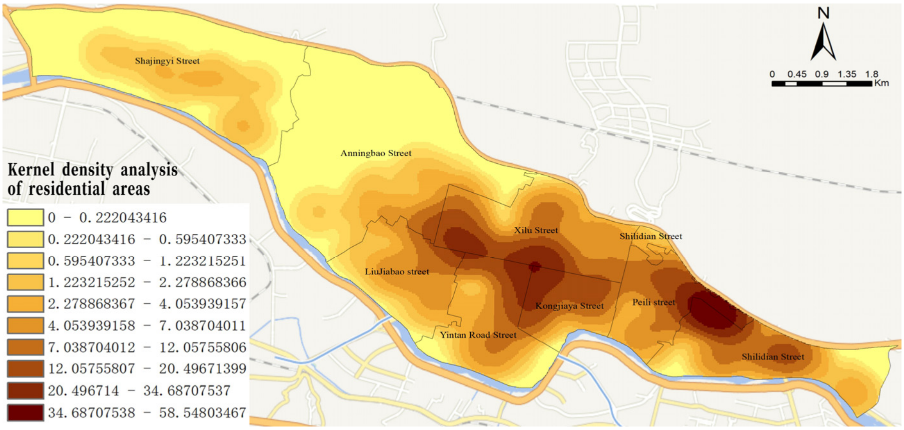


Fig. 10. Kernel density analysis of residential areas

3.2 Spatial Accessibility Evaluation of Public Charging Facilities

Huang Jie et al. [13] showed that the accessibility of public charging f acilities in the plains area has an obvious "concentric circle structure", which coincides with the structure of the city's circular road network (Figure 11). In this paper, we found that the areas with better accessibility in Lanzhou City are distributed in the form of "patches", and there is a "vacuum zone" with lower accessibility between patches (Figure 12), which can be seen that the distribution of charging facilities in Lanzhou City has significant regional characteristics.

Combined with POI data, satellite remote sensing and field research, we found that(Figure 13):

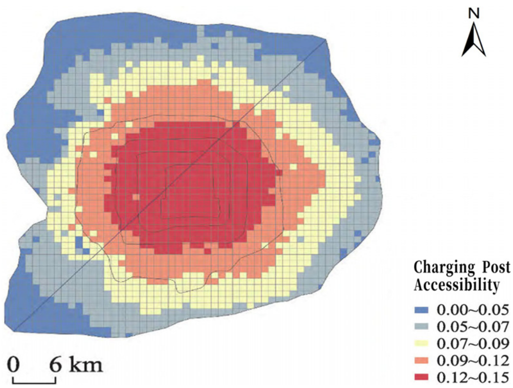


Fig. 11. Beijing Charging Post Accessibility[13]

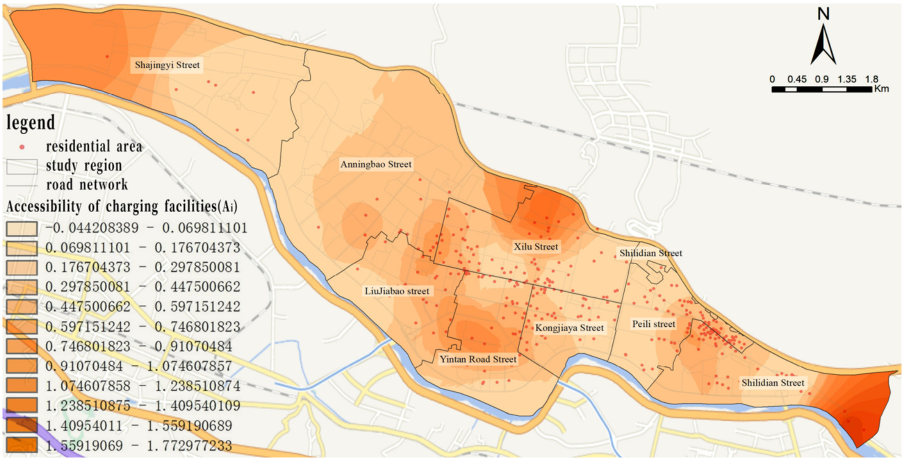


Fig. 12. Spatial accessibility of public charging facilities

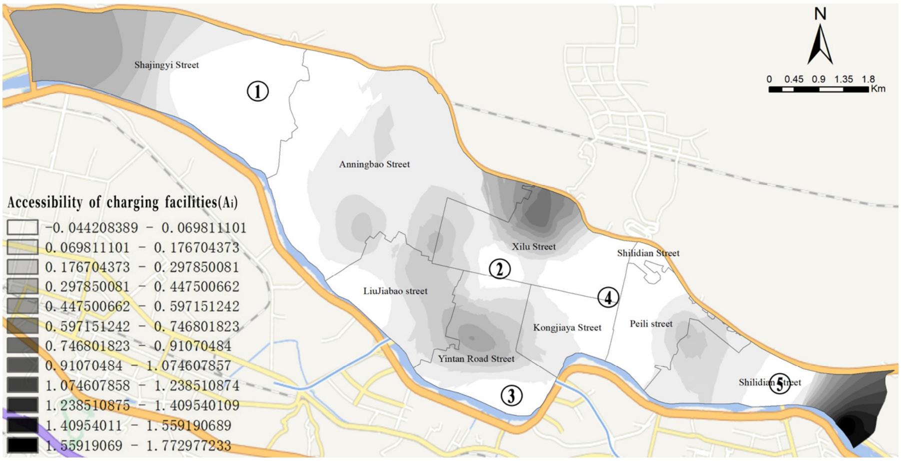


Fig. 13. Schematic of the "patchy" distribution of accessibility

① There are many residential areas along the Yellow River in the south of Anningbao Street and Shajingyi Street (e.g. Jingyi Home, Yujing Apartment, etc.), which are in the area of low accessibility of vehicle charging facilities and should be equipped with relevant charging facilities. ③ The Yellow River waterfront area in the south of Yintan Road Street belongs to "Lanzhou Yintan Wetland Park", so the low accessibility of its charging facilities is in line with the relationship between supply and demand and the actual situation, and there is no need for construction.④ Kongjiaya street and Peili street south of the riverfront area distribution of Jinhe Liyuan, Kangju district and other small communities, are in the charging facility accessibility of low value areas, there is an imbalance between supply and demand, should be equipped with relevant charging facilities. ② The junction of West Road Street and Yinchuan Road Street and ⑤ Shilidian Street in the middle, there are many residential districts and the geographical location is superior, from the viewpoint of supply and demand, the potential demand for charging in the two residential areas in the area of low accessibility is 754 and 542 respectively, and the charging service gap is large, and the current poor accessibility of the charging facilities is mainly due to the irrational distribution of the public charging facilities space. Therefore, there is an urgent need to build relevant charging facilities.

4 Conclusion

The main conclusions of this paper are as follows:

(1) The high accessibility areas of new energy vehicle public charging facilities in Anning District of Lanzhou City are distributed in the form of "patches", and there are "vacuum zones" with poor accessibility between the patches.

(2) The spatial distribution of existing public charging facilities does not match the population distribution in the urban area, and there is an imbalance between supply and demand.

(3) Public charging facilities should be allocated in the junction of Anningburg Street and Shajingyi Street, Kongjiaya Street and Peili Street in the southern riverfront area, West Road Street and Yinchuan Road Street, and the central part of Shilidian Street.

This paper suggests that the future construction of public charging facilities for cars in the central area of Anning District can be based on existing stations, additional charging piles, and expanding the supply to improve facility accessibility. The areas with low population density and lack of supporting facilities on the east and west sides can start from the siting of facilities, and allocate charging stations to improve the spatial pattern of accessibility and achieve a balance between supply and demand.

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