Heliyon 8 (2022) e11993

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Evaluating spatial accessibility of cultural urban land use by using improved 2SFCA method in Xi'an, China

Ziliang Zhao [a], Xiaolong Li [a,b], Yuqian Xu [a,b], Siran Yang [a], Yuan Jiang [a], Shusheng Wang [a,b,*]

[a] College of Architecture, Xi'an University of Architecture and Technology, Xi'an 710055, China
[b] State Key Laboratory of Green Building in Western China, Xi'an University of Architecture and Technology, Xi'an 710055, China

HIGHLIGHTS

- Revealing the accessibility characteristics of cultural urban land use in a typical ancient city.
- Improving the 2SFCA model, and obtaining different results based on three travel modes.
- Analyzing the results of accessibility in scientific methods, and exploring the potential of building the evaluation system.

ARTICLE INFO

Keywords:
Spatial accessibility
Urban cultural study
Urban land use
2SFCA
Evaluation system
Ancient city

ABSTRACT

With rapid urbanization, contradictions between rapid economic development and a lack of spiritual culture become increasingly complicated. Accessibility is a useful spatial quantitative index to evaluate the spiritual and cultural construction of the city. Amongst various accessibility methods, the two-step floating catchment area (2SFCA) method is suitable for evaluating cultural urban land use (CULU) based on its advantage of flexibility and rationality. This study selects Xi'an as the representative ancient city. Based on comparing accessibility results between different travel modes (walk, bus, subway, and total), and analyzing through statistics, Z-score, and comparison of classification, comparison of a particular area, we obtain the characteristics of CULU accessibility in Xi'an. Firstly, for different travel modes, the distribution of CULU accessibility value in Xi'an is imbalanced, and the accessibility value of bus and subway is closely related to public transport resources. Secondly, CULU in Xi'an has apparent features of being dense in the center, sparse in the suburbs, and lack edge, which correspond to the development of the city. Finally, about 60% accessibility value is contributed by historical CULU, which reflects the typical characteristics of Xi'an as an ancient city with rich historical resources. This study profoundly analyses the attributes of CULU in Xi'an and provides essential data for decision-makers. Furthermore, it gives a significant exploration for building a CULU evaluation system in the future.

1. Introduction

With rapid urbanization, Chinese cities are facing an increasingly complicated contradictions between rapid economic development and a lack of spiritual culture. It has caused the problem of urban historical context rupturing and citizen happiness declining. To explore the issue, we learn about the experience of combining a humanistic spirit with urban land use from traditional Chinese urban planning, and put forward a new research concept, “Cultural Urban Land Use” (CULU). CULU is a kind of urban land use for urban cultural function, which includes carrying spiritual and cultural values, condensing the emotional memory of the city, and serving the cultural life of residents (Wang et al., 2018). The study of CULU is related to people's spiritual well-being in the city.

The scientific and quantitative indicator is necessary to identify urban-related phenomena (Hu et al., 2016), and effectively guide the distribution of urban public resources (Batty, 2007). Given that accessibility is a widely accepted concept in urban planning, transportation planning, geography, and other various scientific fields (Geurs & Van Wee, B., 2004), accessibility is a helpful indicator for describing CULU's spatial distribution characteristics and basis of rational allocating cultural resources.

The well-known concept of accessibility is defined by Hansen as ‘the potential of opportunities for interaction’ (Hansen, 1959), which clearly

* Corresponding author.
E-mail address: wss@xauat.edu.cn (S. Wang).

https://doi.org/10.1016/j.heliyon.2022.e11993
Received 11 October 2022; Received in revised form 2 November 2022; Accepted 23 November 2022

explains the meaning of accessibility. Since then, the concept and different methods have been applied in many research (Ingram, 1971; Keeble et al., 1982; Handy and Niemeier, 1997; Vickerman et al., 1999; Geurs & Van Wee, B., 2004). The measure of accessibility has two main approaches: place-based, which focuses on the location of individuals and measures the physical separation; individual based, which focuses on individuals themselves and measures the space-time restrictions (Harris, 2001; Horner, 2004; Vale, 2009). Individual-based accessibility is not based on geographical location, which mainly reflects the difference amongst characteristics of the selected individuals (Kwan, 1998). Therefore, place-based accessibility is the appropriate and rational method for measuring the equity of the spatial distribution of public resources (Xiao et al., 2017). Measuring place-based accessibility has three main approaches: infrastructure-, activity- and utility-based measures (Halden et al., 2000; Geurs and Ritsema van Eck, 2001). Activity-based measures are based on the gravity model and weight opportunities according to a travel impedance function (Vale et al., 2016). This method comprehensively considers the influence of various factors. It shows that the accessibility of a place depends not only on its location in the transportation network but also on the distribution of geographical entities of different sizes in the network, which can reflect the actual situation in the city.

As an increasingly popular technique of accessibility, the two-step floating catchment area method (2SFCA) has the same theoretical framework as the gravity model (Radke and Mu, 2000), and they both fully consider the influence of supply scale, demand scale, and distance between supply and demand on accessibility. 2SFCA was first proposed by Radke (Radke and Mu, 2000) and further improved and named the two-step FCA (floating catchment area) search method by Luo (Luo and Wang, 2003). As a flexible method for measuring spatial accessibility, 2SFCA has wide application in measuring healthcare accessibility (Luo and Qi, 2009; Fransen et al., 2015; Luo et al., 2018; Yin et al., 2018), green space accessibility (Dony et al., 2015; Wei, 2017; Wu et al., 2018; Xing et al., 2018), urban emergency shelter accessibility (Zhu et al., 2018), job accessibility (Wang et al., 2015), public transit (Lee et al., 2018) and other aspects (Yu et al., 2012; Cheng et al., 2012; S. Liu et al., 2016; Yu, 2017). For the application, 2SFCA shows the advantage of overcoming the restriction of pre-defined regional boundaries (McGrail, 2012). The flexibility of the method allows researchers to develop methodological improvements, and the improved 2SFCA has over 15 significant extensions based on four types, according to Tao's research (Tao and Cheng, 2016).

Considering the characteristic of CULU and the advantage of 2SFCA, we propose a modification for three different travel modes. Walk reflects the essential accessibility of CULU. Bus and subway are critical components of public transportation that show the condition of public rights and welfare through bus and subway accessibility. We designed different processes for different travel modes, and modified the original model based on various processes. Besides, we introduce the Gaussian function to increase the accuracy.

This study explores the spatial accessibility of CULU in Xi'an through an improved 2SFCA method. The result detailed describes the spatial distribution of CULU of Xi'an that can help policymakers make reasonable decisions in urban planning. Beyond the result, we discuss the potential of constructing CULU's evaluation system. The object of this paper includes the following aspects: (1) improving the 2SFCA model for CULU's accessibility study, (2) providing detailed research of CULU accessibility for the city, and (3) finding the experience of CULU's evaluation system.

2. Method

2.1. Study area and data

Xi'an's accessibility study is valuable because of the contrast between its long history and inadequate development. Although the Silk Road and 'World Historic City' were recognized by UNESCO in 1981 as the starting point, the current CULU cannot match the long history and brilliant culture. Thus, Xi'an is a representative object of finding the accessibility feature in an ancient city. The study area is 832.17km^2 downtown area of Xi'an that, includes six districts. The supporting urban land use data is from Gaode Map. The 2018 population data in spatial distribution is from the WorldPop open-source data, which presents as the spatial raster. Moreover, we use the 2018 bus data and the 2018 subway data of the Xi'an downtown area, which is from Gaode Map open-source data to study public transportation. And for walk distance, we use spatial Euclidean distance. The location of Xi'an shows in Figure 1.

2.2. Method of identifying CULU

Different from other kinds of urban land use, which is mainly classified by functions or human activities, CULU is classified according to spiritual and cultural values. Through fieldwork and literature, we summarized the five most common values of CULU, which are national spirit value, memorial value, religious value, cultural heritage value, and public cultural service value (Wang, 2018; Wang et al., 2021). Table 1 shows the type of land use of each matter.

We used the POI data of Xi'an in 2018 from Gaode Map data to select CULU. First, we identify the keywords of CULU by literature review and academic discussion. Second, we process data cleaning according to the keywords of CULU. Third, we import the CULU POI data into ArcGIS to determine the spatial location of CULU. Finally, we determine the scope of CULU through fieldwork. The distribution of CULU and population are shown in Figure 2.

2.3. Basic method of walk accessibility

For walk accessibility, we combine the method of Variable 2SFCA and Gaussian 2SFCA. Gaussian 2SFCA was first applied by Dajun Dai in the healthcare facility and urban green space (Dai, 2010, 2011). Based on the feature of the Gaussian function, the method has a low decay rate in near and far distances and a significant decay rate in the middle-distance areas (Tao and Cheng, 2016). Walk accessibility has two steps.

Step 1 is to calculate the walk supply-demand ratio of CULU. Firstly, for each CULU j, we define the area of CULU as the service catchment S_j. Secondly, for each CULU j, search all population location points within a search radius d_0 and count the total service population (P_k). Thirdly, for P_k of each CULU j, weighted by the distance decay function G (d_{kj}, C_j). Finally, calculate the ratio between S_j and P_k as the walk supply-demand ratio for each CULU. The formula is shown as follows:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\le C_j\}} G(d_{kj}, C_j) P_k} \tag{1}$$

Where Rj is the supply-demand ratio of CULU location j, which reflects the serviceability of the CULU. S_j is the area of CULU. P_k is the total service population in the search radius d_0. According to the standard service radius of cultural facilities in the Standard for Urban Comprehensive Transport System Planning (GBT+51328–2018), we select 1,500 m as the search radius d_0. G (d_{kj}, C_j) is the Gaussian function, and d_{kj} is the walking distance between CULU location j and population location k. The formula of the Gaussian function is shown below:

$$G(d_{kj}, C_j) = \begin{cases} \dfrac{e^{-\left(\frac{1}{2}\right)\times\left(\frac{d_{kj}}{C_j}\right)^2} - e^{-\left(\frac{1}{2}\right)}}{1 - e^{-\left(\frac{1}{2}\right)}}, d_{kj} \le C_j \\ 0, d_{kj} > C_j \end{cases} \tag{2}$$

Where Cj is the reasonable walking distance between CULU location j and population location k, which could show the distance people are willing to walk daily. According to the research of correspondences between path distance, walking time, the evaluation value of walk accessibility,

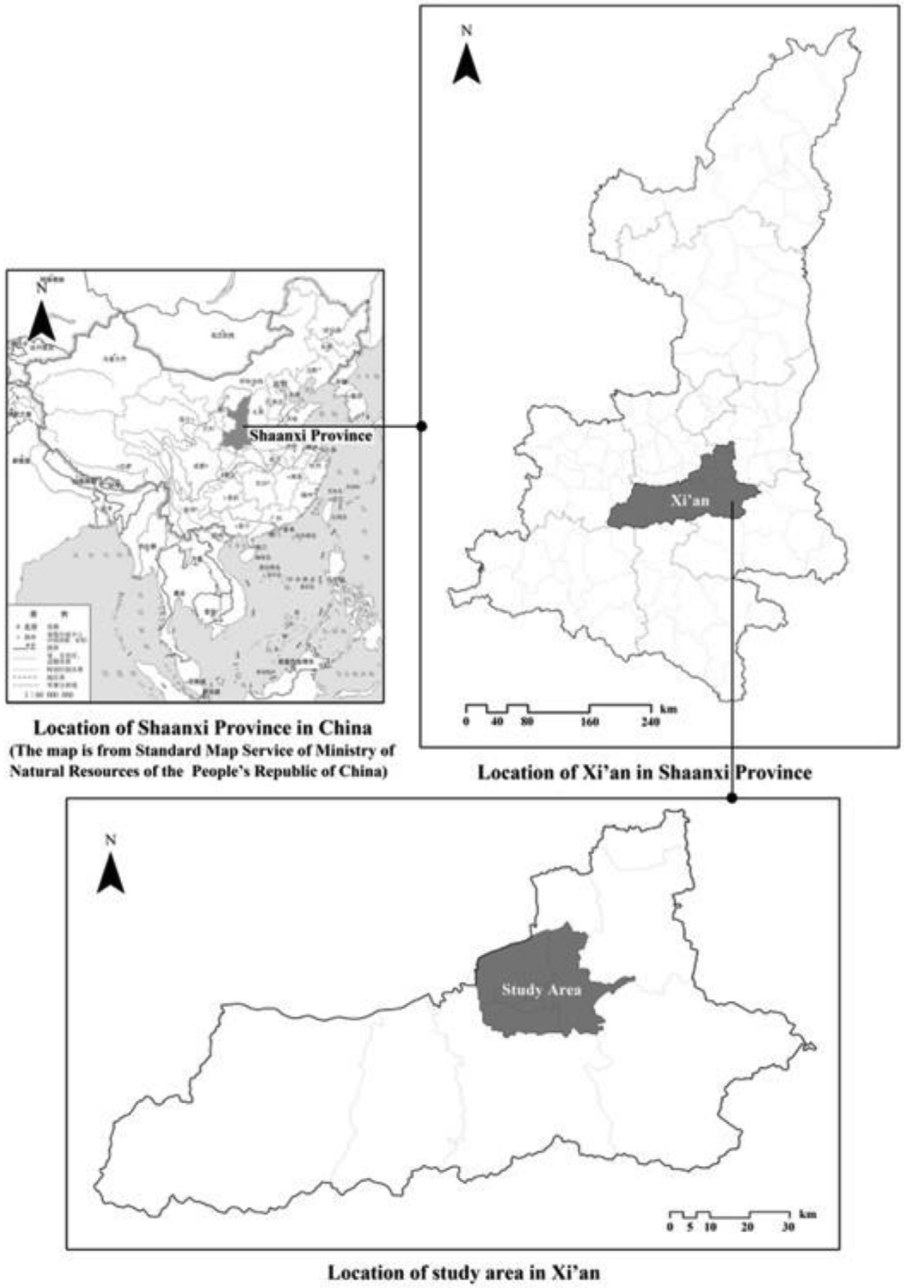


Figure 1. Location of study area.

and the status of walk accessibility from Wang (Wang et al., 2013), we select 1,200 m as the reasonable walking distance C*j*.

Step 2 is to calculate CULU accessibility. For each population location *i*, search all CULU location *l* within a comfortable walking distance radius d_l. Then, compute the CULU accessibility (A_i) of each population location *i* by summing up the supply-demand ratios (R_l) in Step 1, which are weighted by the distance decay function G (d_{kj}, C_j). The formula is as follows:

$$A_i = \sum_{l \in \{d_{il} \le C_j\}} G(d_{il}, C_i), R_l \tag{3}$$

Where A_i is the CULU accessibility of population location *i*, which represents the CULU area per person of the location in the search radius of d_l, also, we choose 1,200 m as the threshold of comfortable walking distance d_l according to Wang's research as aforementioned. d_{il} is the minimum walking distance between population location *i* and CULU location *l*; G (d*il*, C*i*) is the previous Gaussian function.

2.4. Method of bus and subway accessibility

Instead of the Euclidean distance on the map, bus/subway is based on the bus/subway route and bus/subway stop, which has a more complicated counting procedure. We create a new counting model based on Variable 2SFCA and Gaussian 2SFCA to reflect the spatial characteristics of accessibility. Based on the method mentioned above, the new counting model adds bus/subway stop location as a new variable. The steps diagrams are shown in Figure 3. Firstly, people must acquire a nearby original bus/subway stop. Secondly, people take the bus/subway to the destination bus/subway stop, which is distributed close to CULU. Thirdly, people reach CULU from nearby target bus/subway stops. The

Table 1. Main type of CULU.

Values	Main Types
National Spirit Value	Land use with national spirit value
Memorial Value	Memorial park, memorial hall, memorial museum, memorial square, ancestral hall, ancestral temple, cemetery, memorial site
Religious Value	Church, cathedral, chapel, monastery, Buddhist temple, Taoist temple, mosque
Cultural Heritage Value	Ancient sites, ancient tomb, heritage park, historic buildings
Public Cultural Service Value	Cultural park, Cultural square, museum, library, gallery, cultural center, theater, concert hall, exhibition hall, archives

new counting model can be achieved in ArcGIS by using the OD Cost matrix. Moreover, similar to walk accessibility, bus and subway accessibility has two steps. Ultimately, because of the lack of data availability, we adopt the method of Morrison and Shearer (2000), which uses average travel speed along the road network to estimate travel time (O'Sullivan et al., 2000). For the mind map of bus and subway accessibility, see Figure 3.

Step 1 is to calculate the bus/subway supply-demand ratio of the CULU. Firstly, for each CULU j, define the area of CULU as the service catchment S_j. Secondly, for each CULU j, search all nearby target bus/subway stop location points m within a search radius d_0. Thirdly, for each target bus/subway stop m, search all original bus/subway stops n within a search radius d_m based on the bus/subway route. Fourthly, for each original bus/subway stop n, search all population location points within a search radius d_n and count the total service population (P_k). Fifthly, for P_k of each CULU j, weighted by the distance decay function G (d_{kj}, C_j). Finally, calculate the ratio between S_j and P_k as the bus supply-demand ratio for each CULU. The formula can be found in Formula (1), and the Gaussian function formula can be found in Formula (2).

Step 2 is to calculate CULU accessibility. For each population location i, search all CULU locations (l) within a comfortable walking radius d_l. Then, compute the CULU accessibility (A_i) of each population location i by summing up the supply-demand ratios (R_l) in Step 1, which are weighted by the distance decay function G (d_{kj}, C_j). The formula can be found in Formula (3).

For parameter settings of the bus, we set search the radius d_0 600m as the most comfortable distance from the target bus stop to nearby CULU based on Wang et al.'s study in 2013 (Wang et al., 2013). Considering the average speed of Xi'an in the whole day is 27.96 km/h from the 2017 Traffic Analysis Report of Major Cities in China from Gaode Map, we set d_m 4,660m as the distance of a 10 min bus travel. In addition, we select 500m for the search radius d_n according to the standard service radius of the bus stops in the Standard for Urban Comprehensive Transport System Planning (GBT+51328–2018).

For parameter settings of the subway, the value of radius d_0 remains unchanged, which is 600 m. Considering the limited subway speed is 35 km/h from the Code for Design of Metro (GB 50157–2013), we set d_m 5,833m as the distance of the 10min subway travel. We select 800m for the search radius d_n according to the standard service radius of the bus stop in the Standard for Urban Comprehensive Transport System Planning (GBT+51328–2018).

2.5. Method of CULU distribution balance

The accessibility measurement by 2SFCA mainly reflects the overall situation of CULU, which is insufficient to demonstrate the equity of CULU based on population distribution. We measure the equity of CULU by the match level between the accessibility and the population distribution (Kong et al., 2017; Kelobonye et al., 2019). We calculate the Z-score (also called the standard score) of accessibility and population density separately:

$$Z_{A_i} = \frac{A_i - \overline{A}}{\sigma_A} \tag{4}$$

$$Z_{PopD_i} = \frac{PopD_i - \overline{PopD}}{\sigma_{PopD}} \tag{5}$$

Where Z_{A_i} is the Z-score of A_i. A_i is the accessibility of spatial unit i, representing the ratio of the CULU area and corresponding population. $\overline{A}$ is the average of accessibility in the study area, and σ_A is the standard deviation of accessibility in the study area. Z_{PopD_i} is the Z-score of $PopD_i$. $PopD_i$ is the population density of spatial unit i. $\overline{PopD}$ is the average population density in the study area and σ_A is the standard deviation of population density in the study area. The Z_{A_i} and Z_{PopD_i} can be used to study the matching level between CULU supply and demand. We define the positive Z-score (above zero) as a high assessment and describe the negative Z-score (below zero) as a low assessment.

3. Result

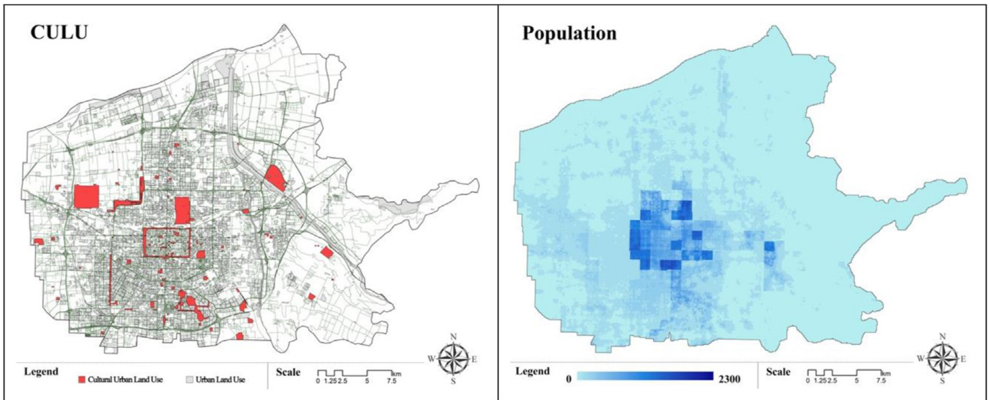
Based on WorldPop data, the study area is divided into 114,871 spatial units, and each of the space points has an accessibility value by using the improved method. The result reflects the spatial accessibility of Xi'an in detail. To have a more scientific cognition, we use statistical methods to analyze the data, which include primary statistical index maximum, average and standard deviations. Beyond the primary index, we have an index of standard deviation coefficient (SDC), correlation coefficient (CC), and valid data (VD). SDC is the ratio between standard deviations and average, which shows the absolute difference in a set of data. CC is the correlation between array 'population' and array 'accessibility value', which reflects the linear correlation between population and accessibility. And VD shows the ratio of non-zero data. Besides, we define total accessibility as the potential opportunities for people to reach CULU by using all the public ways. Thus, it can be considered the sum of walk, bus, and subway accessibility. Total accessibility can genuinely represent the real opportunity for people acquiring CULU.

3.1. Accessibility evaluation

The CULU accessibility analysis shows the characteristics of imbalance distribution in all three travel modes. The difference is due to the change of search radius under different travel modes. The search radius of walking is Euclidean distance, which reflects primitive accessibility features. And various indicators of accessibility have changed while adding public transport variables. We can observe the spatial distribution

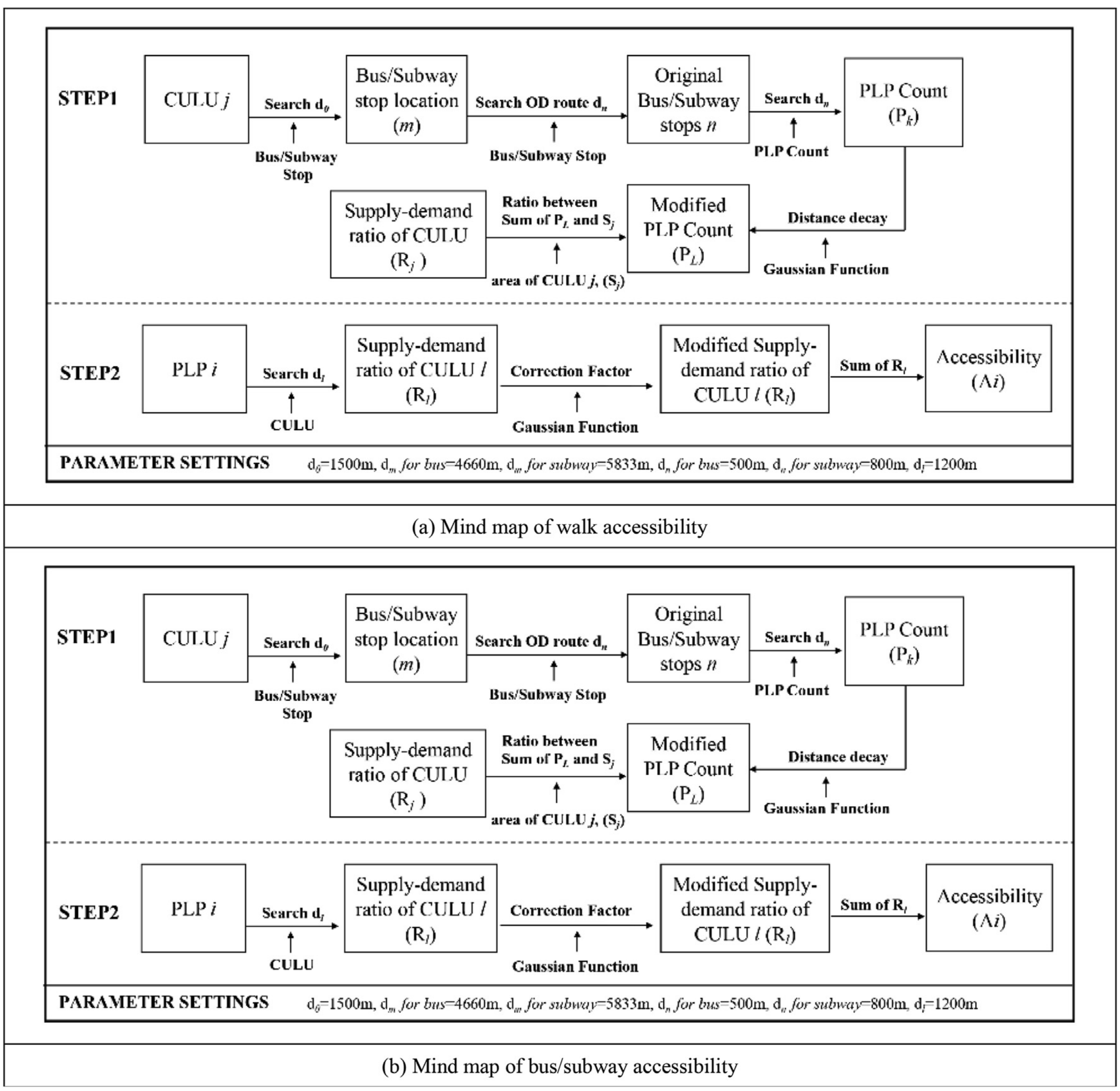
Table 2. Statistical analysis of CULU accessibility in different travel modes.

Mode	Maximum accessibility value	Average accessibility value	Median accessibility value	Standard Deviation	Valid Data	Correlation Coefficient	Standard Deviation Coefficient
Walk	228.81	7.90	0	28.91	43.47%	-0.05	3.66
Bus	107.77	4.03	0	16.31	41.49%	-0.06	4.04
Subway	234.92	2.92	0	22.81	11.97%	-0.03	7.80
Total	544.06	14.86	0	61.83	43.47%	-0.05	4.16



(a) Distribution of CULU in Xi'an (b) Distribution of population in Xi'an

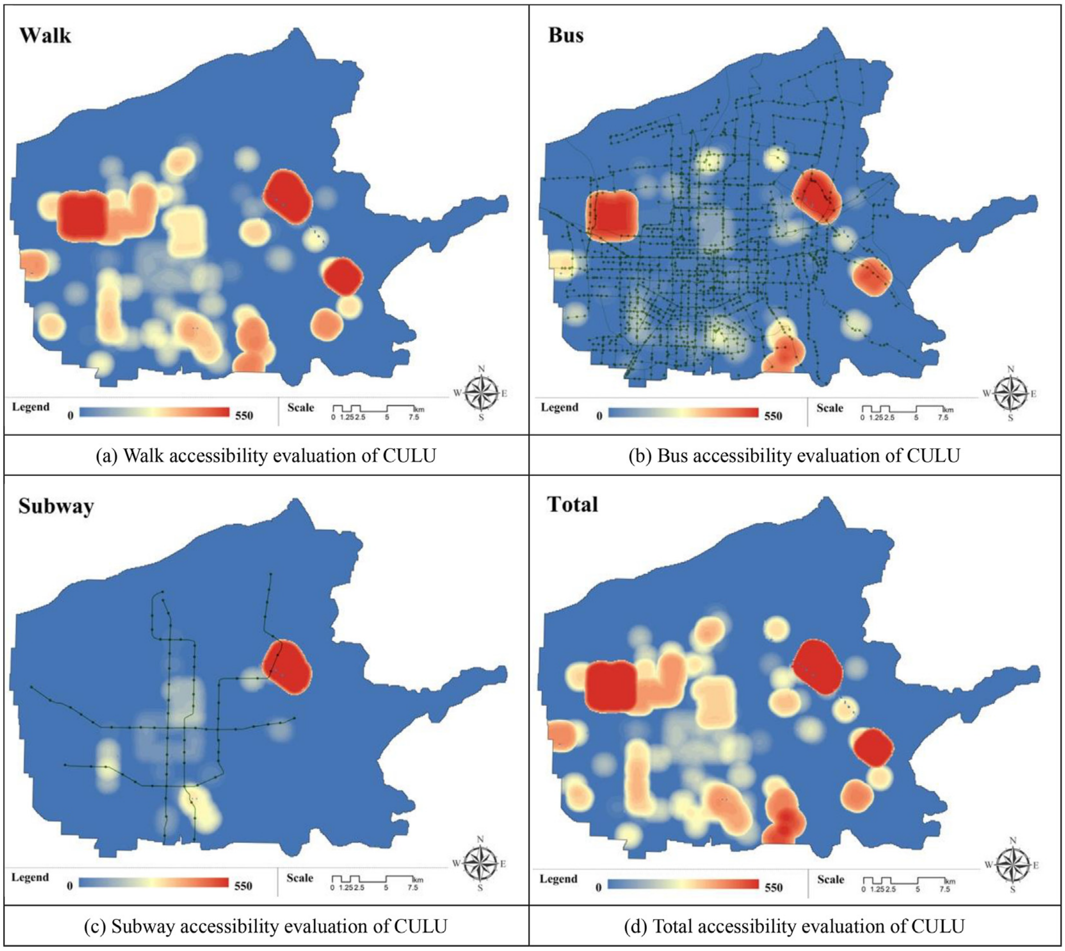
Figure 2. Distribution of CULU and population in Xi'an.



(a) Mind map of walk accessibility

(b) Mind map of bus/subway accessibility

Figure 3. Mind map of accessibility process.



(a) Walk accessibility evaluation of CULU

(b) Bus accessibility evaluation of CULU

(c) Subway accessibility evaluation of CULU

(d) Total accessibility evaluation of CULU

Figure 4. Accessibility evaluation of CULU in different travel modes.

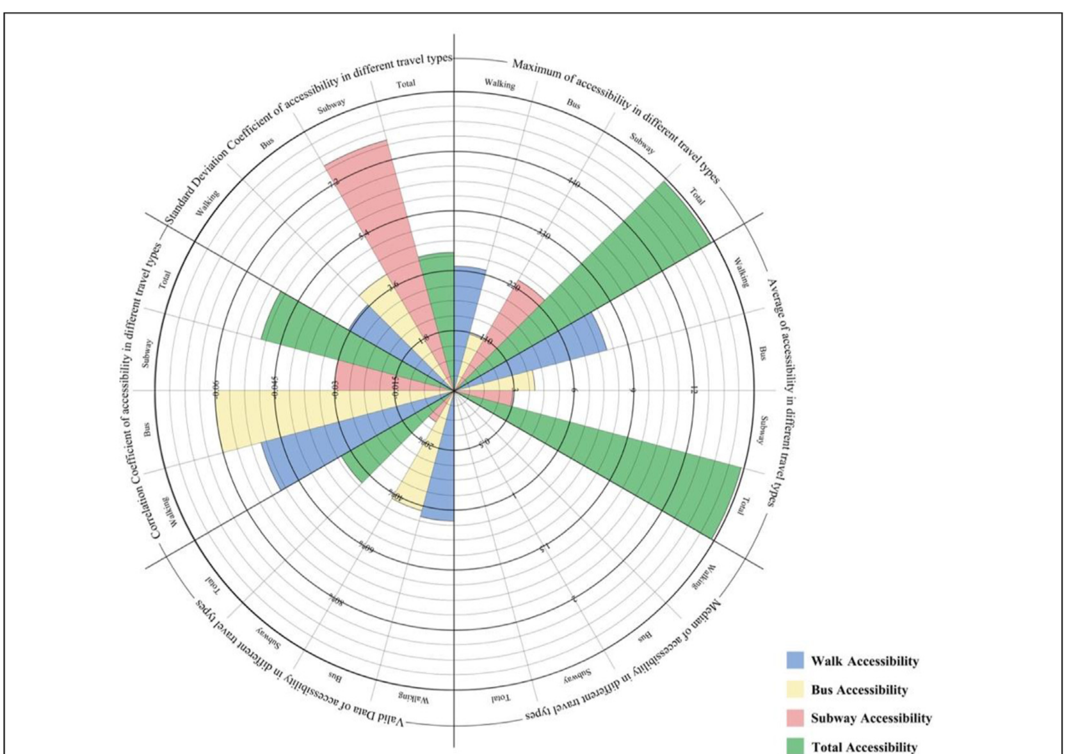


Figure 5. Statistical analysis of CULU accessibility in different travel modes.

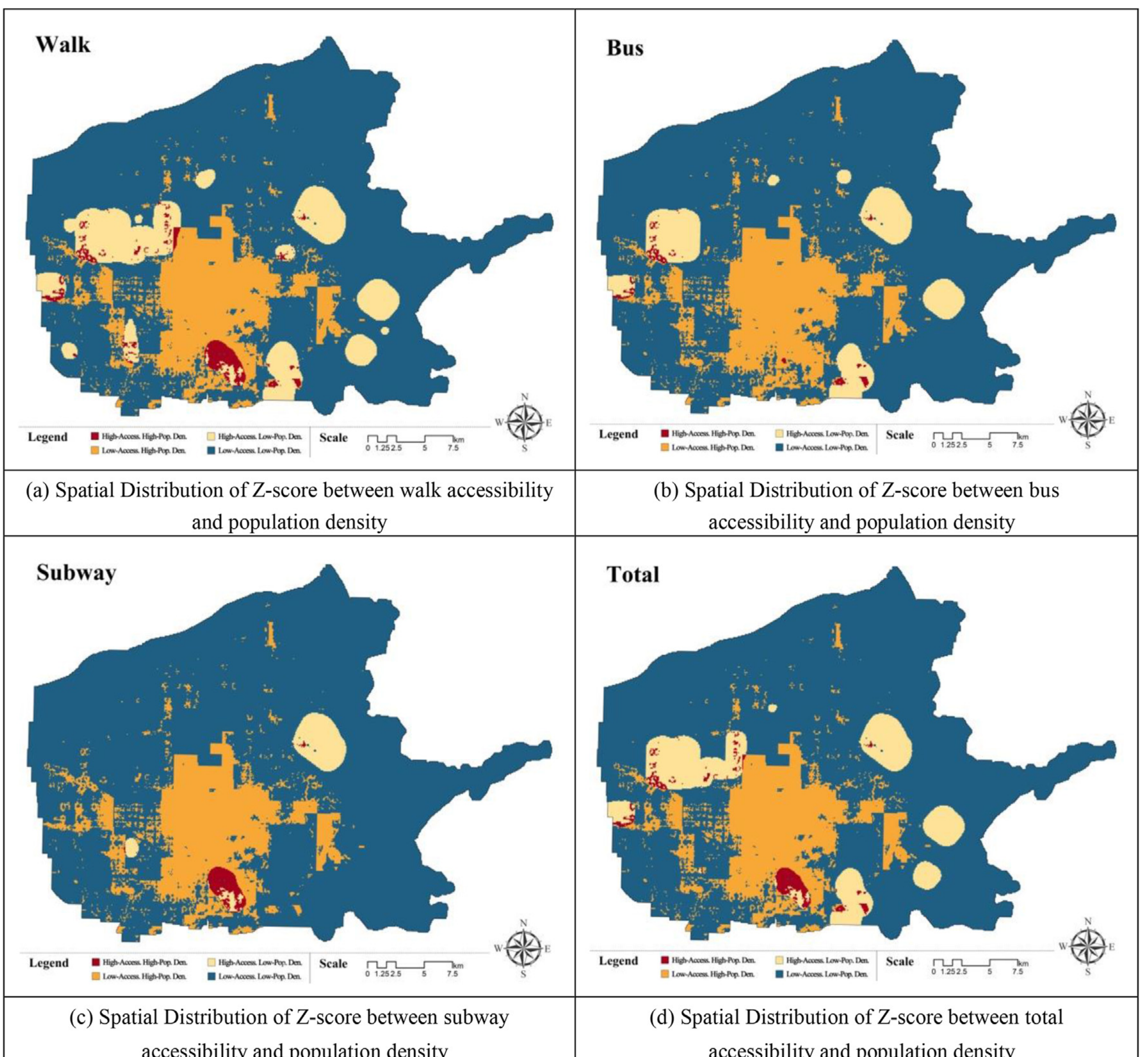
characteristics of accessibility value in Figure 4, and the result of the statistical analysis in Table 2 and Figure 5.

For the situation of the bus, it has no significant difference in spatial distribution compared with the walk from the perspective. The VD (41.49% vs. 43.47%) and SDC (4.04 vs. 3.66) values of bus and walk are close, which illustrates that Xi'an has done well in the distribution of bus stops setting. The main difference between the bus and the walk is the average (4.04 vs. 7.90) and maximum value (107.77 vs. 228.81), which indicates that the introduction of the bus will radiate more people under the premise of little difference in spatial distribution. It shows that CULU has more potential in construction. In terms of the subway, the situation is different from that of the bus. First of all, in terms of spatial distribution, the VD value of the subway is significantly small (11.97% vs. 43.47%), which shows that the subway facilities of Xi'an are insufficient. Secondly, the high SDC value (7.80 vs. 3.66) of the subway illustrates that the spatial distribution is unbalanced. Thirdly, the subway has a slight improvement in CC (−0.03 vs. -0.05), which indicates that the subway can help improve the correlation between population and accessibility. In terms of total accessibility, the increase of various indicators by the weighting of the three modes reflects the opportunities are increasing from the diversified choice of travel modes for citizens. The values of CC and SDC reflect the fundamental spatial distribution characteristics of accessibility in the city.

3.2. CULU distribution balance

For the distribution balance between accessibility and population, Z-score is calculated separately to determine the match level between accessibility value and population density. Figure 6 shows the Z-score between accessibility and population density in different modes, and Table 3 reflects the percent of four different types.

According to Z-score, we can observe the matching level of accessibility and population. It has four different types: high-accessibility with high-population density (HH), high accessibility with low-population density (HL), low accessibility with high-population density (LH), and low accessibility with low-population density (LL). From the perspective of spatial distribution, common features exist among different travel modes. LH is mainly distributed in the center of the city, and HL is primarily located in the city's suburbs. HH is rare in the city and is only distributed in certain areas. One of the areas is called



(a) Spatial Distribution of Z-score between walk accessibility and population density

(b) Spatial Distribution of Z-score between bus accessibility and population density

(c) Spatial Distribution of Z-score between subway accessibility and population density

(d) Spatial Distribution of Z-score between total accessibility and population density

Figure 6. Spatial Distribution of Z-score between accessibility and population density in different travel modes.

Table 3. Percentage of different Z-score types.

Mode	High-A_i. High-Pop.D_i.		Low-A_i.High-Pop.D_i.		High-A_i.Low-Pop.D_i.		Low-A_i.Low-Pop.D_i.	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Walk	1733	1.51%	18917	16.47%	12423	10.81%	81798	71.21%
Bus	489	0.43%	20161	17.55%	8205	7.14%	86016	74.88%
Subway	878	0.77%	19772	17.21%	2551	2.22%	91670	79.80%
Total	1295	1.13%	19355	16.85%	10312	8.98%	83909	73.04%

Qujiang, which is s a new site built based on historical and cultural resources.

The result of the statistical analysis shows in Table 3 and Figure 7 to analyze accessibility and population separately. Low accessibility and low-population density have a high proportion (over 70%) in all travel modes. It indicates that accessibility value and population have an imbalance distribution. Furthermore, the distribution of accessibility value is more imbalanced than population given that low accessibility has a higher proportion than low population.

For accessibility value, the proportion of high accessibility reflects the equity of distribution considering the formula of Z-score. Walk accessibility has the most balance distribution compared with other travel modes because it has the highest high-accessibility proportion. Contrarily, subway accessibility has the most imbalanced distribution, which fits the result in Figure 4.

It has some exciting changes while we add the Z-score of the population. Subway has the highest proportion of HH, although it has the most imbalance distribution, which is the highest among several modes. It shows that the site selection of a subway station in Xi'an encourages people to reach CULU. Contrastingly, the bus has the lowest proportion of HH, indicating that the distribution of bus stops in Xi'an does not fully consider the distribution of CULU and population.

3.3. Comparative analysis of the two categories of CULU

Considering the characteristics of Xi'an, we divide CULU into two categories to explore more detailed features. For the one that takes historical information, we call it 'historical CULU'. It is built on the basis of historical resources comprising historical sites, parks and buildings. Another kind of CULU, we call 'construction CULU', which means that the CULU is built based on the cultural requirement of the city. Cultural facilities, cultural theme parks, and squares belong to this category. For a city, the proportion of the 'historical CULU' area reflects the city's history and the utilization condition of the historical resources. It is a helpful index for comparing the utilization condition of historical resources among

Figure 7. Percentage of different Z-score types.

ancient cities. We calculate the proportion of ‘historical CULU’ area in Xi'an, which is 60%. The Spatial distribution map shows in Figure 8 (a).

The proportion of historical CULU accessibility and construction CULU shows the different types of opportunities that citizens can take. Historical CUCU represents the genetic information left by the development history of the city. And construction CULU means a cultural activity place that does not carry historical details but is built due to the needs of citizens today. It is a helpful index while comparing characteristics in CULU accessibility of different cities. We calculate the accessibility value separately through the same method before and then compute their percentage. Figure 8 (b), (c), and (d) show the ratio of the two categories of CULU in walk, bus, and subway. For all travel modes, accessibility historical CULU accounts for nearly 60% (walk 59.03%, bus 61.93% and subway 61.74%). It reflects the characteristics of the ancient city.

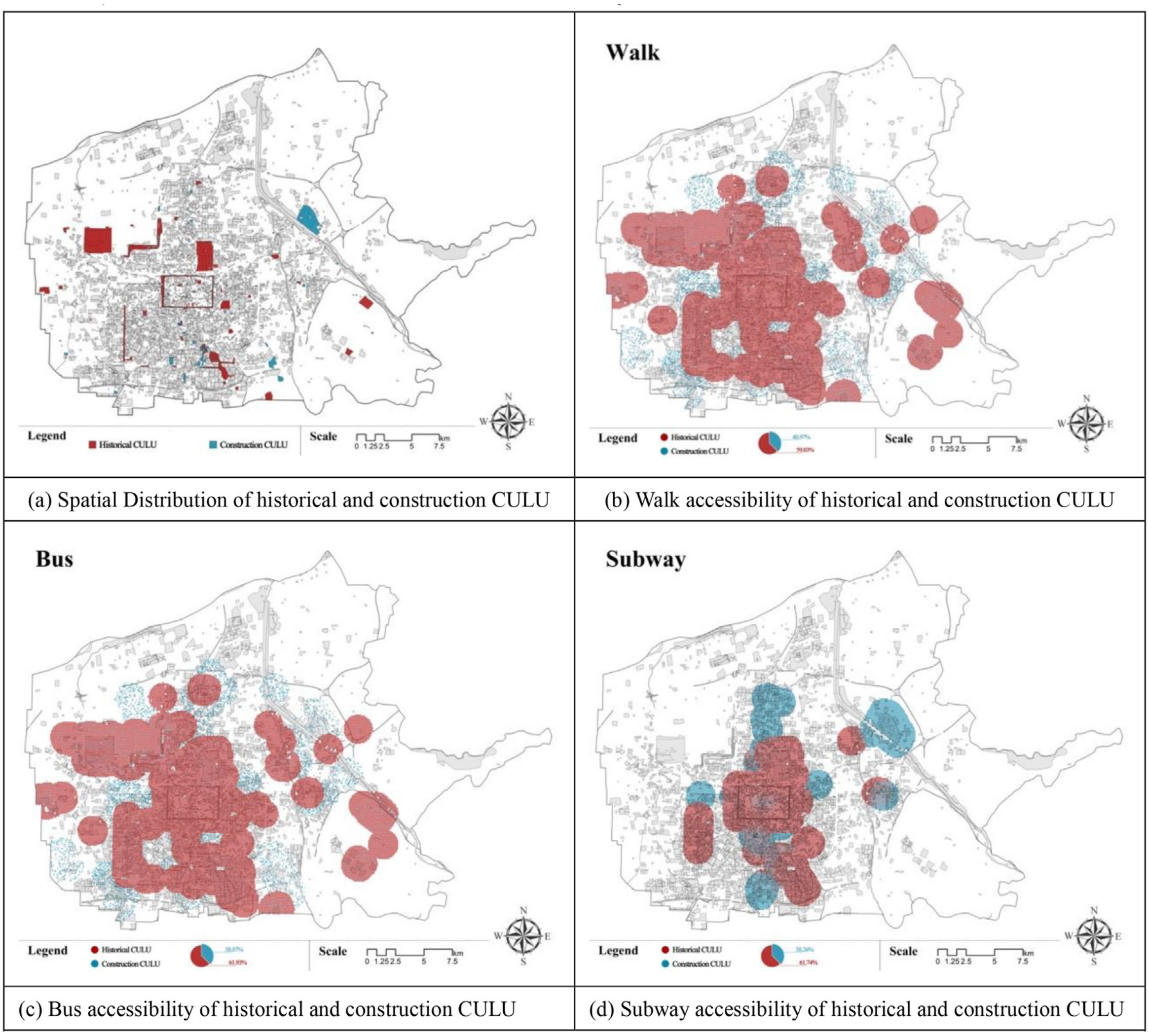
3.4. Accessibility evaluation in Xi'an city wall area

Xi'an City Wall area is a historical urban area enclosed by the Xi'an city wall, which has over 600 years of history (Wang, 2004; Jiang et al., 2014). It is the cultural center of Xi'an, but also the economic center until the 1990s (Y. Liu et al., 2016). Thus, the CULU accessibility in the area has unique characteristics. The location of the Xi'an City Wall area is displays in Figure 9. We analyze the accessibility of this area, and the result can be found in Table 4 and Figure 10.

Table 4 shows the characteristic of accessibility, and Figure 10 reflects the comparison accessibility results between the Xi'an city wall area and the study area. Firstly, lower maximum, average, median, and CC value demonstrates the feature of accessibility in the HH area. Then, the significantly higher VD and lower SDC values indicate an extremely balanced CULU construction, which is much better than the general situation in the city. Moreover, different from the entire Xi'an downtown area, subway accessibility has higher maximum, average, median, and lower SDC values compared with bus accessibility. It illustrates a suitable distribution and construction of the subway in the area.

4. Discussion

In this article, we expand the method of 2SFCA by estimating the travel time and calculating the accessibility value based on three modes of public transportation: walk, bus, and subway. Traditional 2SFCA can be used for calculating walk accessibility, but it cannot solve the travel mode that has more complex steps. Our research abstracts the travel mode of bus and subway, and utilizes the flexibility of the 2SFCA to explore the application expansion of 2SFCA method. We calculate the result of bus accessibility and subway accessibility by improved method, and find the difference



(a) Spatial Distribution of historical and construction CULU
(b) Walk accessibility of historical and construction CULU
(c) Bus accessibility of historical and construction CULU
(d) Subway accessibility of historical and construction CULU

Figure 8. Distribution and accessibility of historical and construction CULU in different travel modes.

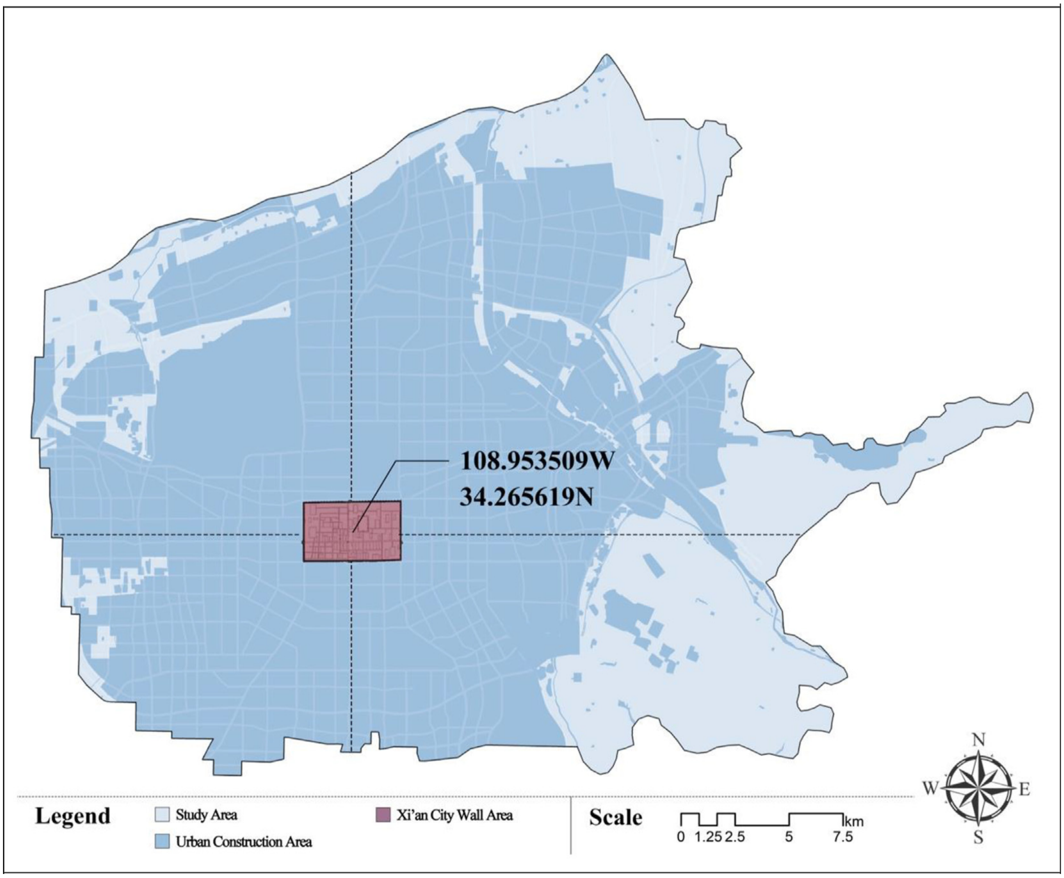


Figure 9. Location of Xi'an City Wall area.

Table 4. Statistical analysis of CULU accessibility in different travel modes in Xi'an City Wall area.

Mode	Maximum accessibility value	Average accessibility value	Median accessibility value	Standard Deviation	Valid Data	Correlation Coefficient	Standard Deviation Coefficient
Walk	6.67	1.72	1.31	1.16	100%	-0.27	0.67
Bus	1.03	0.21	0.15	0.19	100%	-0.27	0.90
Subway	1.94	0.62	0.59	0.34	100%	-0.01	0.55
Total	9.64	2.55	2.06	1.66	100%	-0.22	0.65

among different travel modes. Compared with walk, bus and subway radiate more people, so the accessibility value by the 2SFCA method is lower. However, accessibility value is affected by other factors, such as traffic lines, and bus stops (subway stations), which cause the different result between bus and subway. It indicates that the improved methods can genuinely reflect the characteristics of different travel modes.

The results show that all the travel modes have different degrees of imbalance. By comparing the accessibility amongst different travel modes, we can obtain some detailed information, such as the accessibility of the bus and subway has a close relationship with public transportation resources. For example, the limited help of the subway causes an extreme imbalance. Contrarily, bus accessibility has better performance, demonstrating an abundant resources of the bus.

Then, we obtain a comprehensive and detailed accessibility distribution map for Xi'an. The result of the accessibility evaluation shows that the distribution of CULU has a distinct feature. High-density and small-area CULU are located in center of the city, large area CULU are distributed in the suburbs, and zero-value of accessibility is mainly distributed on the edge of the city. As the historical urban area and old city center of the city, the Xi'an City Wall area presents a typical characteristic. Ultimately, for the content of CULU, Xi'an shows a representative feature of the ancient city. Comparative analysis indicates that about 60% of accessibility is based on historical resource.

Furthermore, through the analysis of the Z-score, we obtain four types of spatial units that are based on two variables: accessibility and density of population, and each of them should have a unique strategy for further management and development. HH performs exceptionally during high-density population, which summarizes the successful experience. HL mainly faces the problem of mismatch between people and CULU, which could have a residential construction planning in the future. LH has the difficulty of insufficient CULU. Hence, decision-makers should focus on CULU construction. LL may not face such a problem at the time but must prepare in advance because of the rapid urbanization and growing population.

Beyond the accessibility analysis, there exists an opportunity to build CULU's evaluation system for cities by using 2SFCA methods. The first step is calculating the accessibility in different travel modes, and it should have a recommended value for average accessibility, SDC, and VD. The second step is to analyze the historical urban areas and should have a recommended value for the average accessibility, SDC and VD. The third step is calculating the percentages of 'historical CULU' and 'construction CULU'. The portions could be a weight coefficient for the

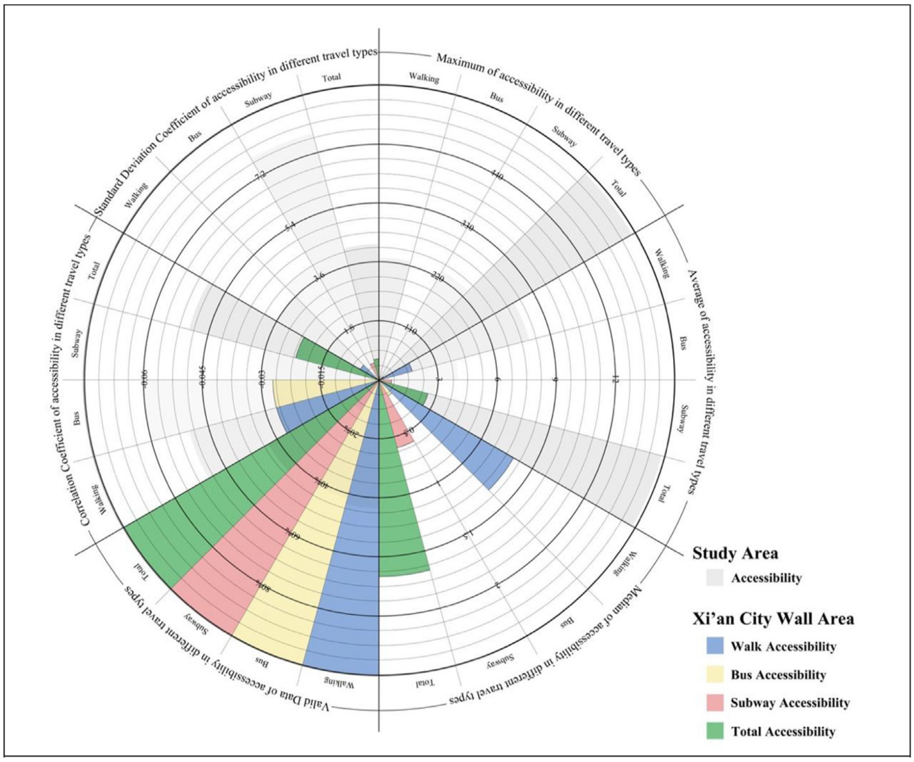


Figure 10. Comparation of statistical analysis between Study Area and Xi'an City Wall area.

evaluation of CULU. The fourth step is to compute Z-score to obtain four types of spatial units and provide relative strategies. Future studies should expand our research and focus on the evaluation system of CULU accessibility.

5. Conclusion

In this paper, we use the improved 2SFCA method to calculate the CULU accessibility value of the Xi'an downtown area and deeply analyze the result through statistics, Z-score, comparison of classification, and comparison of the particular area. Similar to green space, CULU is a necessary urban space in the city's daily life. However, studies on CULU remain limited. Our research is the first attempt at building a quantitative evaluation for CULU by using the concept of accessibility and the 2SFCA method. By calculating CULU in Xi'an as a representative ancient city, we obtain every accessibility value of 114,871 spatial units. Furthermore, we analyze the data through the methods above, which are helpful for decision-makers. The result of Xi'an inspires us to perceive the possibility of building CULU's evaluation system. Ultimately, we discuss the potential framework of the evaluation system. In future research, attempting to improve the evaluation system by calculating more samples is necessary.

Declarations

Author contribution statement

Shusheng Wang: Conceived and designed the experiments.
Ziliang Zhao: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.
Siran Yang: Performed the experiments.
Yuqian Xu: Contributed reagents, materials, analysis tools or data.
Xiaolong Li: Analyzed and interpreted the data; Wrote the paper.
Yuan Jiang: Analyzed and interpreted the data.

Funding statement

Shusheng Wang was supported by National Key R&D Program of China [Grant No. 2019YFD1100902].

Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The study was supported by National Key R&D Program of China (Grant No. 2019YFD1100902). We thank Prof. LU PengFei from Beijing University of Posts and Telecommunications for his kind suggestions.

References

Batty, M., 2007. Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals. The MIT press.
Cheng, Y., Wang, J., Rosenberg, M.W., 2012. Spatial access to residential care resources in Beijing, China. Int. J. Health Geogr. 11 (1), 32.
Dai, D., 2010. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. Health Place 16 (5), 1038–1052.
Dai, D., 2011. Racial/ethnic and socioeconomic disparities in urban green space accessibility: where to intervene? Landsc. Urban Plann. 102 (4), 234–244.
Dony, C.C., Delmelle, E.M., Delmelle, E.C., 2015. Re-conceptualizing accessibility to parks in multi-modal cities: a Variable-width Floating Catchment Area (VFCA) method. Landsc. Urban Plann. 143, 90–99.

Fransen, K., Neutens, T., De Maeyer, P., Deruyter, G., 2015. A commuter-based two-step floating catchment area method for measuring spatial accessibility of daycare centers. Health Place 32, 65–73.
Geurs, K.T., Ritsema van Eck, J.R., 2001. Accessibility Measures: Review and Applications. Evaluation of Accessibility Impacts of Land-Use Transportation Scenarios, and Related Social and Economic Impact. RIVM rapport 408505006.
Geurs, K.T., Van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. J. Transport Geogr. 12 (2), 127–140.
Halden, D., Mcguigan, D., Nisbet, A., Mckinnon, A., 2000. Accessibility: Review of Measuring Techniques and Their Application. Scottish Executive, Central Research Unit, Great Britain.
Handy, S.L., Niemeier, D.A., 1997. Measuring accessibility: an exploration of issues and alternatives. Environ. Plann. 29 (7), 1175–1194.
Hansen, W.G., 1959. How accessibility shapes land use. J. Am. Inst. Plan. 25 (2), 73–76.
Harris, B., 2001. Accessibility: concepts and applications. J. Transport. Stat. 4 (2/3), 15–30.
Horner, M.W., 2004. Exploring metropolitan accessibility and urban structure. Urban Geogr. 25 (3), 264–284.
Hu, N., Legara, E.F., Lee, K.K., Hung, G.G., Monterola, C., 2016. Impacts of land use and amenities on public transport use, urban planning and design. Land Use Pol. 57, 356–367.
Ingram, D.R., 1971. The concept of accessibility: a search for an operational form. Reg. Stud. 5 (2), 101–107.
Jiang, Y., Cui, L.P., Yan, S.F., 2014. A study of the history of protecting the Xi'an city wall in modern times. Arch. Cult. (2), 16.
Keeble, D., Owens, P.L., Thompson, C., 1982. Regional accessibility and economic potential in the European Community. Reg. Stud. 16 (6), 419–432.
Kelobonye, K., McCarney, G., Xia, J.C., Swapan, M.S.H., Mao, F., Zhou, H., 2019. Relative accessibility analysis for key land uses: a spatial equity perspective. J. Transport Geogr. 75, 82–93.
Kong, X., Liu, Y., Wang, Y., Tong, D., Zhang, J., 2017. Investigating public facility characteristics from a spatial interaction perspective: a case study of Beijing hospitals using taxi data. ISPRS Int. J. Geo-Inf. 6 (2), 38.
Kwan, M.P., 1998. Space-time and integral measures of individual accessibility: a comparative analysis using a point-based framework. Geogr. Anal. 30 (3), 191–216.
Lee, W.K., Sohn, S.Y., Heo, J., 2018. Utilizing mobile phone-based floating population data to measure the spatial accessibility to public transit. Appl. Geogr. 92, 123–130.
Liu, S., Ren, Y., Ma, D., Tian, Y., 2016. Study on the method of the urban space development history stage: an example of Xi'an urban from the reform to the early 21st century. Modern Urban Res. (7), 21.
Liu, Y., Ye, Q., Li, J., Kong, X., Jiao, L., 2016. Suitability evaluation of rural settlements based on accessibility of production and living: a case study of Tingzu Town in Hubei Province of China. Chin. Geogr. Sci. 26 (4), 550–565.
Luo, J., Chen, G., Li, C., Xia, B., Sun, X., Chen, S., 2018. Use of an E2SFCA method to measure and analyse spatial accessibility to medical services for elderly people in Wuhan, China. Int. J. Environ. Res. Publ. Health 15 (7), 1503.
Luo, W., Qi, Y., 2009. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. Health Place 15 (4), 1100–1107.
Luo, W., Wang, F., 2003. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. Environ. Plann. Plann. Des. 30 (6), 865–884.
McGrail, M.R., 2012. Spatial accessibility of primary health care utilising the two step floating catchment area method: an assessment of recent improvements. Int. J. Health Geogr. 11 (1), 50.
O'Sullivan, D., Morrison, A., Shearer, J., 2000. Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach. Int. J. Geogr. Inf. Sci. 14 (1), 85–104.
Radke, J., Mu, L., 2000. Spatial decompositions, modeling and mapping service regions to predict access to social programs. Geograph. Inform. Sci. 6 (2), 105–112.
Tao, Z.L., Cheng, Y., 2016. Research progress of the two-step floating catchment area method and extensions. Prog. Geogr. 35 (5), 589–599.
Vale, D.D.S., 2009. Sustainable Urban Form, Accessibility and Travel: the Relationship between Polycentric Urban Development and Commuting in Lisbon. Doctoral dissertation, Newcastle University.
Vale, D.S., Saraiva, M., Pereira, M., 2016. Active accessibility: a review of operational measures of walking and cycling accessibility. J. Transp. Land Use 9 (1), 209–235.
Vickerman, R., Spiekermann, K., Wegener, M., 1999. Accessibility and economic development in Europe. Reg. Stud. 33 (1), 1–15.
Wang, H., Huang, J., Li, Y., Yan, X., Xu, W., 2013. Evaluating and mapping the walking accessibility, bus availability and car dependence in urban space: a case study of Xiamen, China. Acta Geograph. Sin. 68 (4), 477–490.
Wang, Q., Xiu, C.L., Wei, Y., Zhang, L.J., 2015. Evaluation of job accessibility of Shenyang using Gaussian based 2-step floating catchment area method. Hum. Geogr. 30 (2), 78–82.
Wang, S.S., 2004. Preliminary analysis of planning methods of Xi'an urban pattern in the beginning of ming dynasty. Urban Plan. Forum (5), 85–88, 96.
Wang, S.S., 2018. A study on cultural land system planning. City Plan. Rev. 42 (12), 76–82.
Wang, S.S., Yang, S.R., Xu, Y.Q., Zhao, Z.L., Jiang, Y., Li, X.L., 2021. J. Urban Plann. Dev. 147 (4), 04021045, 2021.
Wei, F., 2017. Greener urbanization? Changing accessibility to parks in China. Landsc. Urban Plann. 157, 542–552.
Wu, H., Liu, L., Yu, Y., Peng, Z., 2018. Evaluation and planning of urban green space distribution based on mobile phone data and two-step floating catchment area method. Sustainability 10 (1), 214.
Xiao, Y., Wang, Z., Li, Z., Tang, Z., 2017. An assessment of urban park access in Shanghai–Implications for the social equity in urban China. Landsc. Urban Plann. 157, 383–393.
Xing, L., Liu, Y., Liu, X., 2018. Measuring spatial disparity in accessibility with a multi-mode method based on park green spaces classification in Wuhan, China. Appl. Geogr. 94, 251–261.
Yin, C., He, Q., Liu, Y., Chen, W., Gao, Y., 2018. Inequality of public health and its role in spatial accessibility to medical facilities in China. Appl. Geogr. 92, 50–62.
Yu, D., Tan, H., Ruan, Y., 2012. An improved two-step floating catchment area method for supporting district building energy planning: a case study of Yongding County city, China. Appl. Energy 95, 156–163.
Yu, W., 2017. Assessing the implications of the recent community opening policy on the street centrality in China: a GIS-based method and case study. Appl. Geogr. 89, 61–76.
Zhu, X., Tong, Z., Liu, X., Li, X., Lin, P., Wang, T., 2018. An improved two-step floating catchment area method for evaluating spatial accessibility to urban emergency shelters. Sustainability 10 (7), 2180.