Gated university campus and its implications for socio-spatial inequality: Evidence from students' accessibility to local public transport

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Abstract

Rapid urbanization has led to a massive transformation of urban space in China, spatially and socially. Its higher education has been growing much faster than ever before, along with an explosive increase of university students' population. Different from the Western universities, a majority of Chinese university students are required to reside in gated campuses. Their accessibilities to public transport and subsequent spatial and social implications have been neglected in the literature. Taking Wuhan city as a case study, this paper aims to examine the public transport service to gated university campuses and its impacts on spatial and social inequalities. The spatial accessibility is measured by four methods: proximity-based, gravity-based, population-weighted average, and competition-based, using population data at residential building level. All the results have confirmed the presence of spatial and social inequalities in public transport accessibility for university campuses and students population. The study has also found that these inequalities are not contributed directly from the provision of public transport services but the closure of gated campus to the external public transport.

Keywords: inequality; accessibility; university campus; university student; public transport; Wuhan.

1 Introduction

Rapid urbanization has led to a massive transformation of urban space in China, spatially and socially. The spatial and social inequities in urban services, as a dimension of urban sustainability, have been of growing concern to both academics and policy makers (Feitelson, 2002). For example, previous decades have witnessed a remarkable shift from effective transport to equal access in the urban transport planning process, of which two of the most important aspects are transport equity and transport–related social exclusion (Kaplan et al. , 2014). It has been widely accepted that an important goal of sustainable urban transport is to provide equal access to necessary services to social groups that lack private transport (Holzer et al. , 2003, Ricciardi et al. , 2015). It is concluded that lack of access to any specific services will reduce their expected opportunities, and this will accordingly lead to deprivation, social exclusion, and a decreasing quality of life (El-Geneidy et al. , 2015, Jin et al. , 2015, Lucas, 2012, Wan and Su, 2017). However, due to the unavailability of high-resolution data, few studies have been conducted that explore specific groups' travel needs in Chinese cities, where a dramatic rate of urbanization is precipitating challenges of sustainability about transport-induced equity issues.

Meanwhile, higher education in China has been growing much faster than ever before, along with an explosive increase of university students' population. The total population of university students (undergraduate and post-graduate) has increased by 840% from 1997 to 2016. For example, there are 26,252,968 undergraduate students and 1,911,406 postgraduate students in total who enrolled with about 2,560 Chinese universities in 2016 (MOE, 2016a, b). But, these figures in 1997 were only 3,174,326 and 176,353 for undergraduate and postgraduate students respectively (MOE, 2005a, b, c). The lifestyles and travel demand of these university students have shown remarkable disparities with those in Western countries. In China, a majority of students are required to reside within university campuses (Zhong et al. , 2018), which are walled as a non-production work unit and gated community inherited from the Soviet tradition (He, 2013).

Public transport is essential for citizens' daily activities, and university students do need public transport services as well. Unlike other social groups and university students in Western countries, Chinese university students, as a unique social group, only rely on public transport systems due to limited incomes and transport choices. This paper aims to explore the social and spatial inequalities in relation to university students' access to public transport and analyze its implications for gated university campuses' planning and governance by using high-resolution spatial data and GIS (Geographical Information System) methods. Wuhan in Central China, which has the third largest group of university students in China, is taken as our case study. The remainder of this paper is organized into six sections. Section Two reviews relevant literature on social and spatial inequalities in public transport accessibility and studies about gated university campuses. Section Three introduces the study area, its student population and data collection briefly. Section Four explains the methodology of measuring spatial accessibility to public transport services used for this case study. Section Five presents the analytical results and explores the disparities in accessibility to public transport and evaluates its findings. Further discussions, implications and possible further research are recommended in addition to general conclusions in Section Six.

2 Literature review: socio-spatial inequality in public transport accessibility and university campus

2.1 Public transport accessibility and socio-spatial inequality

Accessibility can be defined as the ease to reach the destinations from a given location (Farrington, 2007), and it was defined as the "transport good" (Martens, 2012). Accessibility is a fundamental concept associated with social equity in geographical and urban studies (Di Ciommo and Shiftan, 2017). While transport "goods and bads" are often unevenly distributed, which means some social groups are more disadvantaged than others are (Lucas and Jones, 2012), the even distribution of public transport resources and its socio-spatial effects have been one of the key concerns in the field of public transport planning. According to Litman (2002), there are two kinds of equity in public transport, that is, horizontal and vertical equity. By this framework, the horizontal equity means providing public transport services to individuals or groups without considering their ability, while the vertical equity considers the abilities and needs of specific groups when distributing public transport services. Recent studies have paid more attention to vertical equity because the "social transit" perspective based on the latter, rather than the "mass transit" perspective based on the former, considers various population destinies in a city (Foth et al. , 2013) and prioritizes the special needs of those groups without private transport (Delbosc and

Currie, 2011). However, a specific definition of equity is hard to determine and may lead to vague goals (Martens et al. , 2012). Thereby, one solution is to minimize the creation of inequity and inequality of opportunity (Dawkins, 2016, Ogryczak, 2007).

For the elderly people in North America and Europe, car driving has been one of their most important travel modes (Szeto et al. , 2017). However, the travel mode choice of elderly people in China is quite different from these countries. The study on the elderly people's accessibility has been well publicized for their unavailable access to services by car (Wong et al. , 2018). A travel behavior survey conducted by Hu et al. (2013) reveals that 48.52% of the elder people travel as pedestrians and 43.38% as public transport users, while only 0.99% choose car driving. This is mainly the result of the limited ownership of car driving licenses among the elderly population in China. The age limit for car driving license application is 70, and the car driving license owner at the age of 70 and above is also required to submit a health report annually (MPS, 2016). Alternatively, public transport provides them with a reliable mean of daily trips (Ikram et al. , 2015). Traditionally, as a non-car group that always suffers from transport-related social exclusion, the elderly people's residential locales are also described as "transport disadvantaged" (Engels and Liu, 2011, Ricciardi, Xia, 2015). In many aspects, the university students in China share a similar position of their accessibility concern as elderly people. Most students, as unemployed even partially, have no sufficient income to buy, maintain and own a private car or frequently travel by taxi. As with elderly people, the student group has to rely on public transport systems for regular off-campus activities (Cao, 2008, Qi and Lu, 2016). Thereby, the access to public transport is crucial for all non-car drivers, both elderly people and university students. To analyze social inequality, elderly people's accessibility is used as an appropriate benchmark to compare them with university students.

2.2 Students' life in gated university campus

The "Soviet Model" university system was formed in the middle of 1950s (Liu, 2017b) when a number of university campuses were built with walls and gates, and spatially segregated from urban public space as a kind of non-production work units (Tang et al. , 2011). The "Soviet Model" reflects a traditional combination of the gated community and the work unit in Chinese campuses, where accommodation and other resources in the campus were mostly provided as a kind of welfare for university students. In contrast to the commercialization process of “studentification” in the UK (Smith, 2009), Chinese universities still keep running the model after the housing policy’s marketization reform in the 1990s (Logan et al. , 2010) by providing accommodation to their students at a much lower price than renting a room from the market as rural migrants are doing. The central or provincial governments, who fund all of these public universities, play a vital role in their operation and internal governance (Liu, 2017b). In addition to public universities, provincial governments also govern private colleges although they have been given greater autonomy than the public universities (MOE, 2007). In this context, the conception of governing means that universities and colleges in China are spatially independent of other organizations. Other types of gated community in China have led to the spatial segregation between the inside and the society outside (Deng, 2017, Wu et al. , 2014), however, the relevant work on gated campus still lacks quantitative evidence regarding its spatial and social effects.

Although such gated university campuses, as non-production work units, remain existing spatially with housing provision as well as walls and gates (Qian, 2014, Xu and Yang, 2009), a dramatic transformation in the era of post-reform is undergoing in two ways. Firstly, the daily activities and social lives of the residents are not directly controlled and separated from the outer urban area. Many services formerly offered by the work unit are now provided through services from increasingly growing commercial markets (He, 2013). Those services are located across the whole city and beyond the capacities and scales of those work units, especially in the era of globalization. Secondly, the relationship and interactions between the university and the city are also changing globally and locally. Universities are increasingly engaged with urban and community development (Liu, 2017a), particularly in the aspects of creative city and innovation as the basis of scientific research and higher education and professional training (Smith, 2016). They are not only ‘in’ the city but also ‘of’ the city (Bender, 1998). There are several dimensions of roles and effects for universities to engage in the city (Fernández-Esquinas and Pinto, 2014): universities are not only amenities and attractions in urban life but also customers of local businesses. Considering that public transport is essential for citizens’ daily activities, students need public transport services for accessing those activities which are not located in their gated campuses, or when the services in the campus could not meet their demand and satisfaction. Yet gated campuses are deemed as self-organized communities, and previous works have mostly neglected two aspects:

firstly, students' accessibility to their destinations by traveling out from their residential location within a campus, and secondly, transport connection between those and outer urban areas.

Local urban planning cannot regulate the land allocation and spatial arrangement within a university campus, because these public universities are administered by either Ministry of Education or provincial governments, rather than municipal governments (Wang and Vallance, 2015). What all the local municipality and planning organizations can do is to provide public transport services around campuses, but it is still unknown whether such provision has sufficiently met students' needs. Therefore, it is necessary to examine the gated university campus and its socio-spatial implications from the aspect of public transport accessibility in the context of China.

3 Study area and data sets

3.1 Study area

Wuhan, as the capital of Hubei province, is situated in Central China and at the middle reaches of Yangtze River (Wuhan City Government, 2011) (Figure 1). The Yangtze River and its longest tributary, the Han River, flowing through the city, have divided it into three parts: Wuchang, Hankou, and Hanyang.

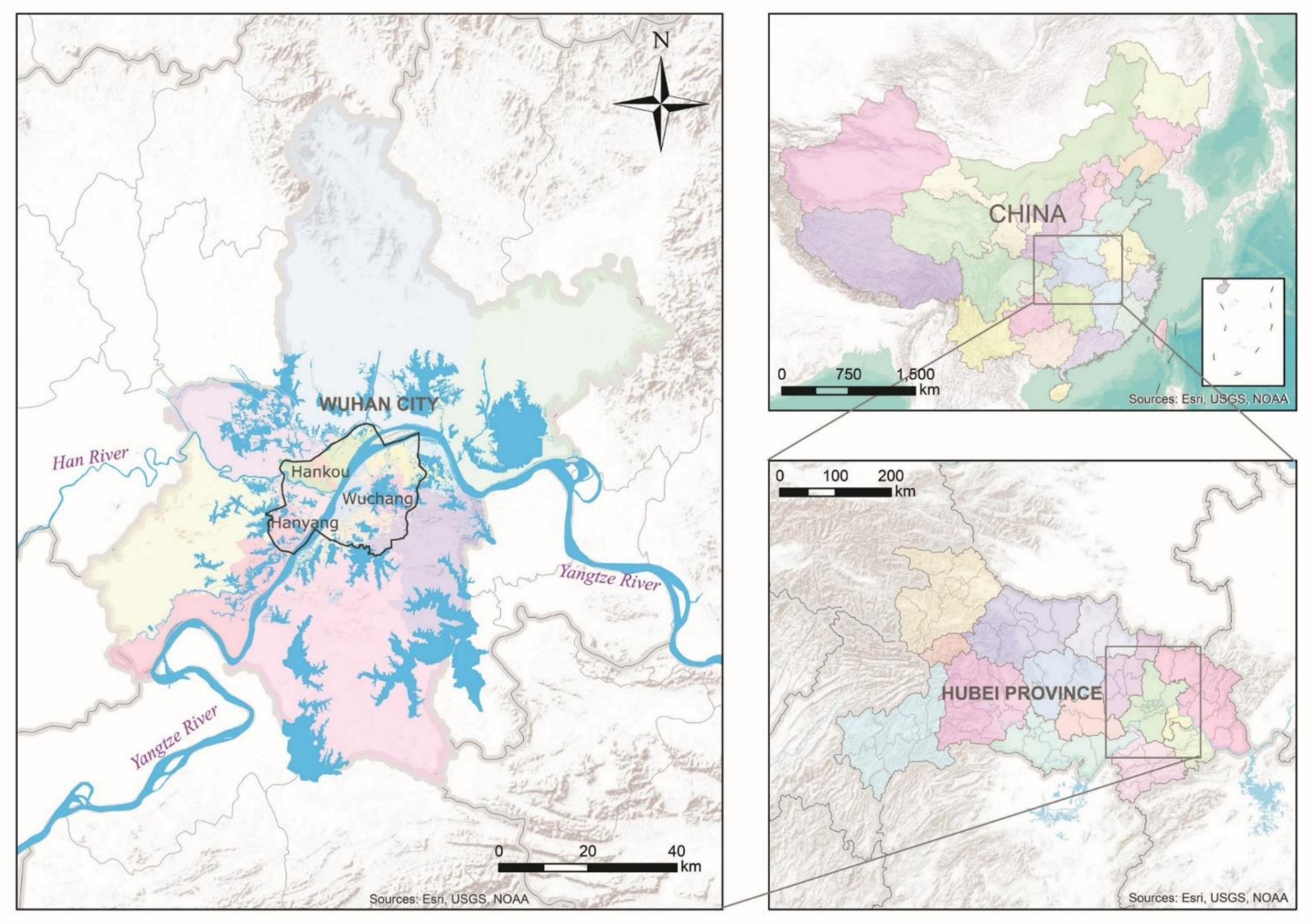

Figure 1. Location of the study area – Wuhan Municipality

The resident population of Wuhan Municipality is 10,607,700 in 2015 (WBS, 2016a), of which 956,705 are university students who are attending the higher education in 79 universities and colleges (WBS, 2016b). As the university students occupy 9.02% of its total population, Wuhan has had the highest proportion of university student population in China. Thereby, Wuhan is a representative of a university city.

All the higher-education institutions include 8 national universities administered by Ministry of Education, 14 provincial colleges and universities, 9 private colleges, 15 independent private colleges, and 33 higher vocational colleges administered by the provincial government. All the military colleges are excluded from this study, due to different regulations and governing system. The built-up area of Wuhan city is 76,300 hectares in 2015 (WLRPB and WIPD, 2016), but all the 79 universities or 103 campuses with a total area of 4,548.09 hectares, occupy 5.96% of the city built-up area, with 44.16

hectares per campus on average.

As most colleges and universities are primarily concentrated in Wuchang, and nearly half of the campuses are located around Hongshan, South Lake, and Optics Valley, a central part of the city (Figure 2) is chosen as the study area for quantitative analysis.

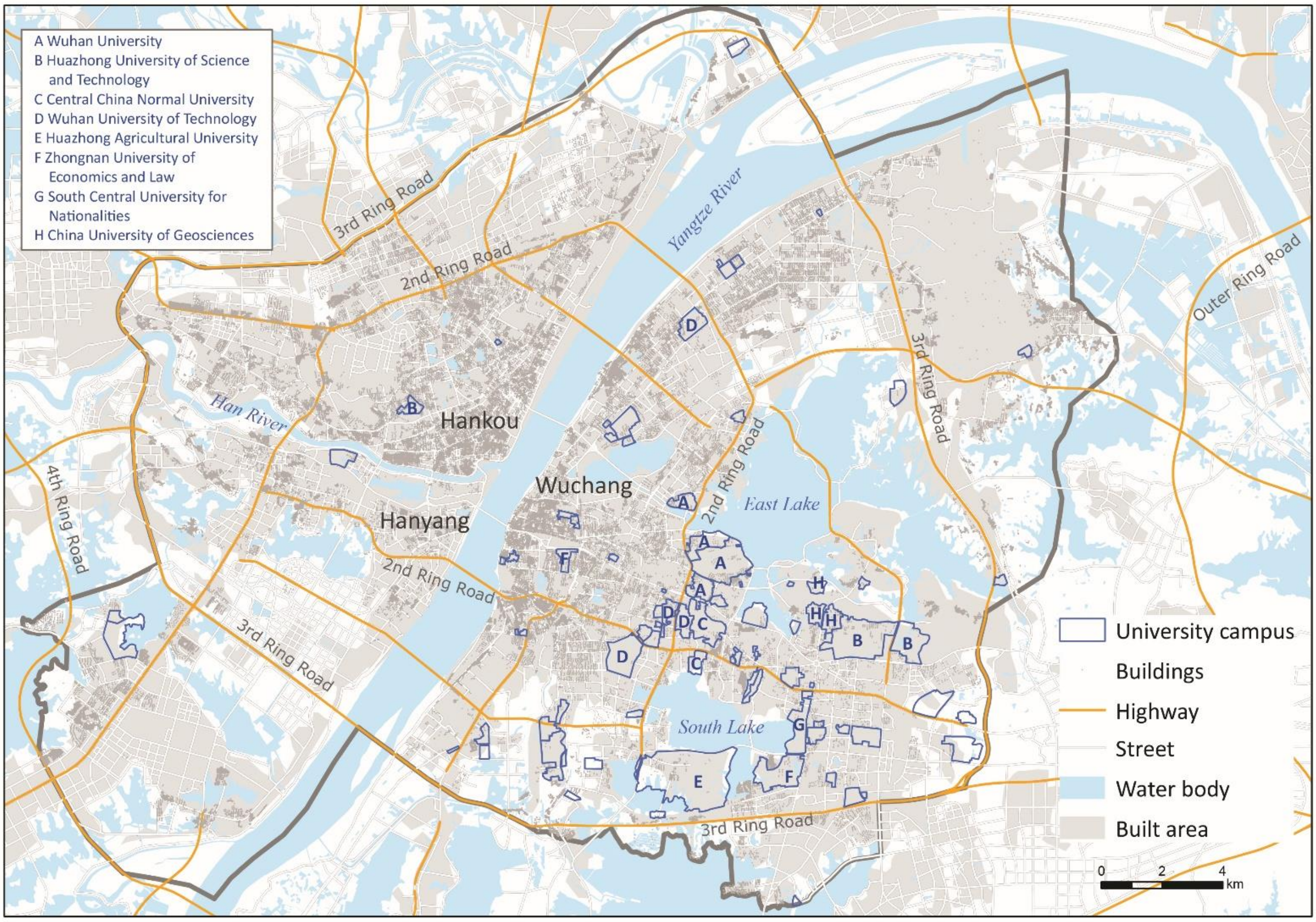

Figure 2. The study area and distribution of residential buildings and university campuses in the central Wuhan city (built-up area in the map)

Wuhan's public transport system consists of buses, metros, trams, and ferries. Until December 2016, there have been 376 public transit lines (356 bus lines, 4 trolleybus lines, 4 metro lines, and 12 ferry lines), 2653 stations (2545 bus stops and stations, 96 metro stations, and 12 ferry terminals) in total across the municipality. Wuhan bus company has a long-standing reputation in China for its large capacity and good coverage and service (Cheng and Zhou, 2014).

3.2 Data collection and processing

The data sets required for this study includes bus stops, demography at building level, road networks, and university campus land-use (Table 1). Bus stops were collated from the Wuhan Transportation Committee website (Figure 4). Only bus stops, rather than metro stations, are taken into account for public transport, because the incomplete metro system in Wuhan, with several lines still under construction, only undertook 30% passengers in public transport (Zhang, 2017). On the contrary, the bus service has been used as the primary public transport mode in Wuhan since 1929.

Table 1. Datasets and sources for this study

Datasets	Description	Sample	Source	Year
Public transport	Bus stops	1,919	Wuhan Transportation Committee (WTC)	2016
	Bus lines and routes	368	WTC	2016
Land-use	Residential buildings	91,967	Processed by a company	2015
	Campus boundaries	77	Remote Sensing (RS) Imagery	2015
	Campus gates	183	RS Imagery	2015
Walking network	Road network	14,010	RS Imagery	2016

The demographic data at building level was provided by a company, who has processed this by integrating primary and secondary data from diverse sources and using spatial statistical methods. This set of data includes the building's location (point), the total number of residents, gender groups and three age groups (1-17, 18-59, and above 60) (Figure 3). To our best knowledge, this has been the highest-resolution spatial data of population for Chinese urban studies as the majority of studies in the published literature only have access to national census data at community (Wu, Cheng, 2014) or sub-district level. The group aged over 60 is defined as the elderly population in this study, as it is the legal age for retirement in China. It is relatively easy and accurate to recognize the students' residential buildings within the campuses by using universities' official campus maps and other online maps and images. This recognition was further validated if the number of people in the age groups less than 18 and above 60 is zero. It is clear that most university undergraduate students are aged between 18 and 22 as the Chinese education system includes the entry into school at 6 years old, 6-year primary school, 3-year junior secondary school, 3-year senior secondary school or high school, and 3-4 years college or university. The age group between 18-59 enables us to identify those students living in university campuses as the students' dormitory is entirely occupied by students. This rule helps us easily detect the students' residential buildings within university campuses.

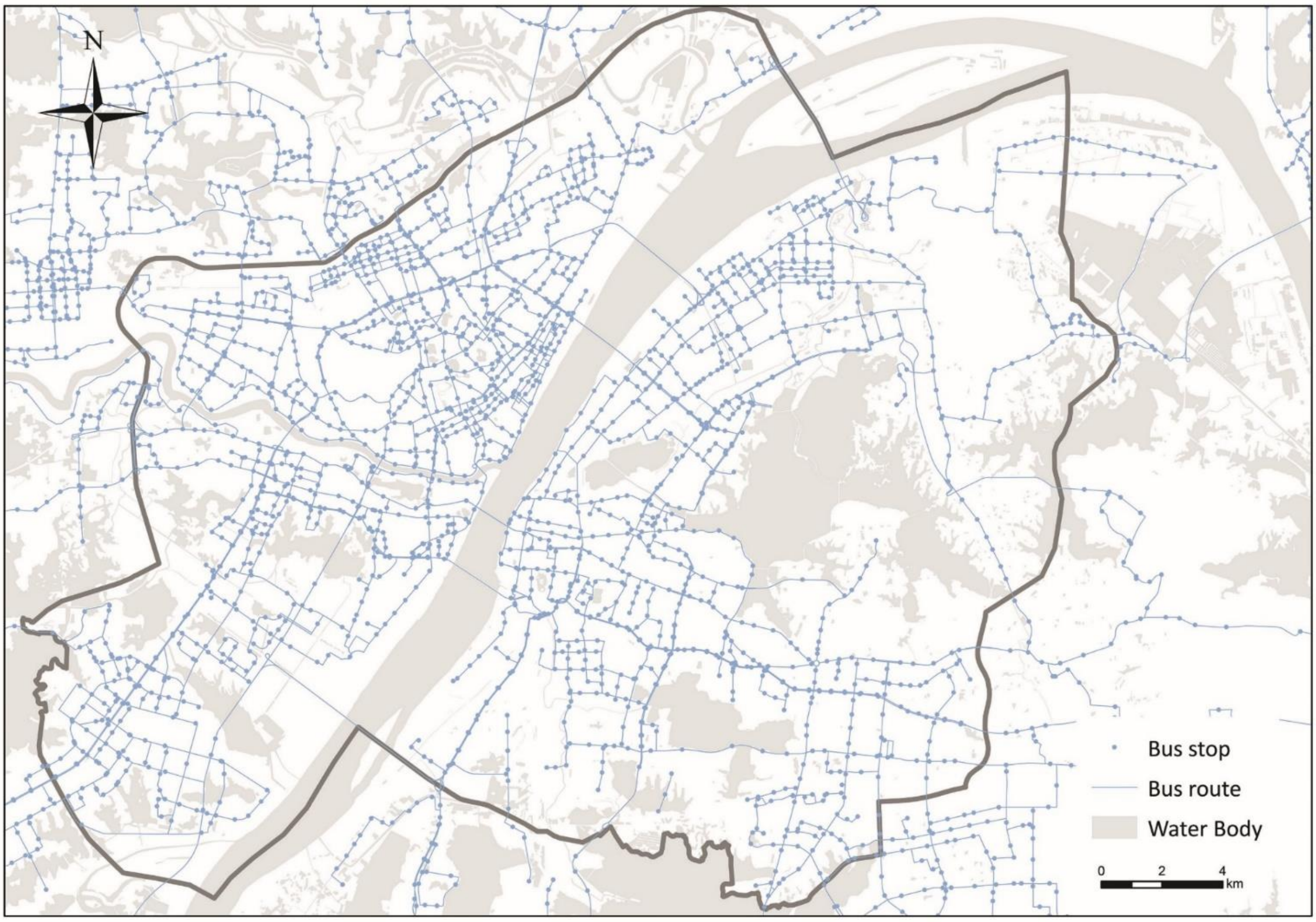

Figure 3. Distribution of bus services across the study area

The road network data were interpreted visually from online satellite images and secondary maps such as Autonavi Maps, Google Maps, and Bing Maps. To analyze the accessibility of university students to bus stops, a walking network dataset is created by using ArcGIS 10.5 – Network Analyst and the road network data (Figure 5). First, the pedestrians and walkable paths are extracted from the road network by excluding motorways, viaducts, and other features where pedestrians are banned from walking (from a to c in Figure 4). Second, the walking speed was set at 4.5 km/h, which has been validated in another previous study (Li, 2008).

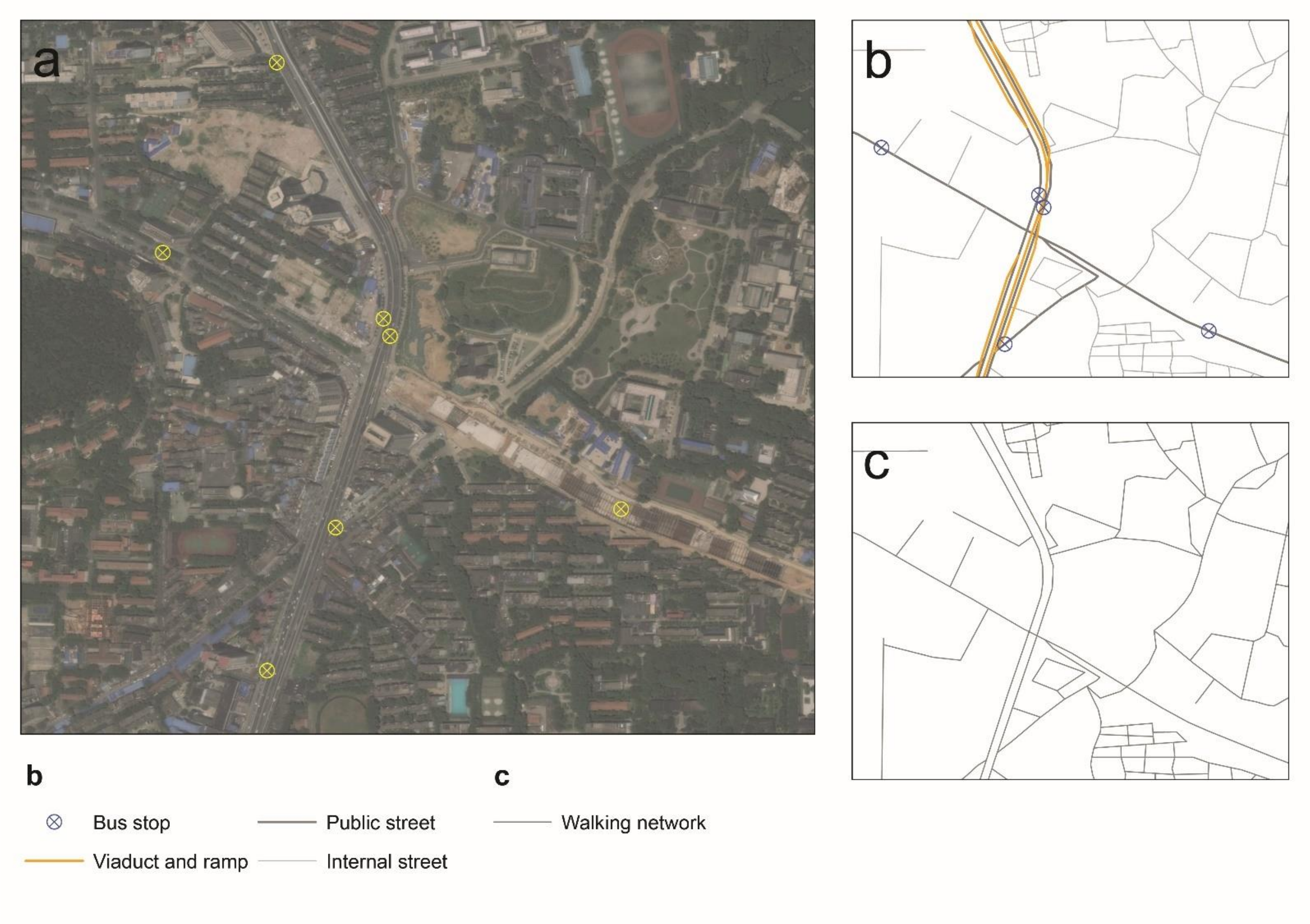

Figure 4. Data processing from satellite images to walking network

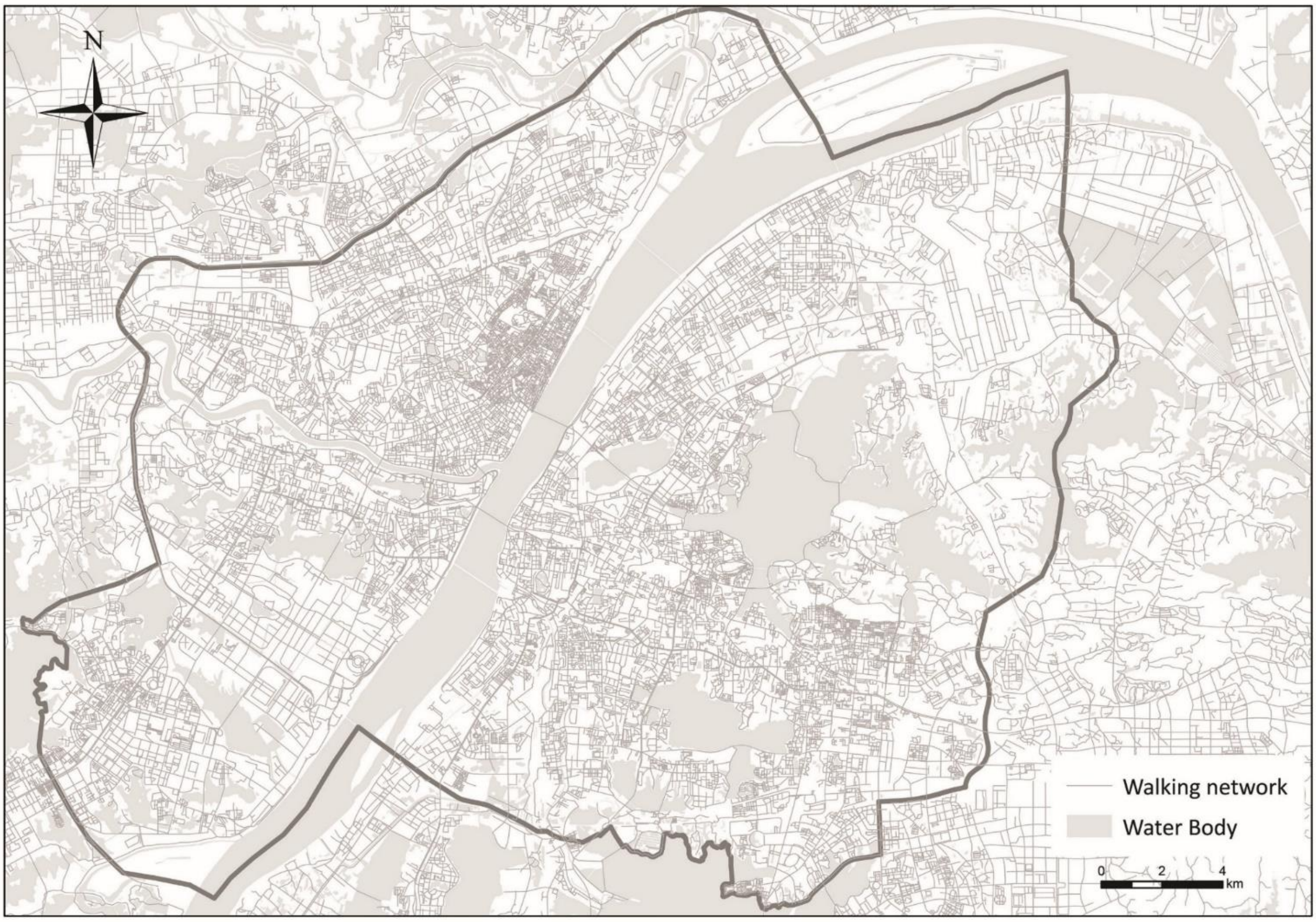

Figure 5. Walking network in the study area

Land-use data of university campus were derived from multi-source satellite images and websites, including Google Maps, Bing Maps, and Tianditu Wuhan, that is, an online map service published by Wuhan Land Resources and Planning Bureau (Figure 3), e.g. Wuhan University and Huazhong University of Science and Technology (see A and B in Figure 3). The university official maps were georeferenced, and a visual interpretation was conducted to verify the land-use polygons based on campus boundary from those satellite images and OpenStreetMap. The same method is used to create the point data of university campus gates.

All data were processed into a geodatabase by ArcGIS 10.5, based on the Gauss Kruger 38N projected coordinate system. To verify the data sets, several fieldworks were conducted from 2014 to 2016 to assess its accuracy. In total, 77 (out of 103) campuses located in the study area and with an average gated area of 40.11 hectares per campus are analyzed, including all of the national universities (administrated by Ministry of Education) in the study area (see A to H in Figure 2).

4 Spatial methods

Public transport is an important factor contributing to not only environmental but also social sustainability. A variety of efforts have been made to measure public transport accessibility in the published literature. There are four types of indicator to measure it (Fransen et al. , 2015): the proximity to transport stops, the positioning of transport stops on the overall network, costs considering destinations, and accessibility accounting for temporal variability. The public transport access measurements can be classified into three categories (Mavoa et al. , 2012): access to public transport stops, public transport duration, and access to destinations via public transport. Accessibility is also an indicator to coordinate supply and demand, which can be divided into two types in transport studies: “to transit” and “by transit” (Xu et al. , 2015). There are two ways to measure public transport accessibility in the previous studies: “access to” and “access by.” “Access to” is crucial because the first thing to get into a public transport system for an individual is to access to a public transport stop, including bus stops, metro stations, ferry docks, and so forth. Also, considering the difference between equity of opportunity and equity of outcome (Litman, 2002), “access to” is more suitable than “access by” for analyzing public transport inequity issues.

Hereby, the spatial accessibility to public transport at the building level and for different social groups are the focus of this study. Its spatial accessibility is considered as “access to transit” and measured by two methods: proximity-based and gravity-based accessibility. It is then weighted by the population of social groups.

4.1 Measuring proximity-based public transport accessibility

To be easily understood and communicated, the public transport accessibility is first measured by a proximity method, described by Gutiérrez and García-Palomares (2008), which utilizes the coverage area of bus stop service based on network distance. Previous studies have measured the proximity to a transit stop from an administrative or census unit centroid, but this may lead to errors due to low spatial resolution. A more accurate way is the direct use of dwelling units instead of census units (Biba et al. , 2010). It is clear that network distance is more accurate to measure proximity than Euclidean buffers (El-Geneidy et al. , 2009). The first measurement of public transport accessibility is defined as the proximity from one dwelling unit to the nearest bus stop within a threshold travel time (equation 1). The travel time was estimated as walking minutes based on pedestrians' distance calculated from the constructed walking network dataset.

$$A_i^M = \min(t_{ij}) \quad (1)$$

where A_i^M is an accessibility index represented as the minimum time, i is the origin place (building), j is the destination (bus stop), min is a function to find the minimum value, and t_{ij} is the walking time between i and j over a walking network.

4.2 Measuring gravity-based public transport accessibility

The proximity-based measurement is easy for understanding and interpretation, but a noticeable limitation is that it assumes that people always choose and access to the nearest bus stop within a subjective traveling time threshold, which may vary with passengers. Another methodological limitation is ignorance of distance decay effect. Considering these limitations, a gravity-based model is adopted as follows, which is another popular method to measure accessibility (Curtis and Scheurer, 2010).

$$A_i^G = \sum_{j=1}^{n} S_j f(c_{ij}) \quad (2)$$

$$f(c_{ij}) = D_{ij}^{-\beta} \quad (3)$$

where A_i^G is the accessibility index measured by the gravity model, i is the origin place (building), j is the destination (bus stop), S_j is the supply of bus services and specifically the number of bus routes through the stop j in this case. The distance that people walk to a bus stop defines the spatial barriers between its origin and destinations. D_{ij} is the network distance between building i and bus stop j. $f(c_{ij})$ is a distance decay function. There are five common forms of the distance decay function (Gharani et al. , 2015): power, exponential, exponential-normal, exponential-square, and log-normal. The previous works on the public transport in China have confirmed the suitability of power function for urban mobility (e.g. (Chen et al. , 2014, Jin et al. , 2017, Xu, Ding, 2015)). β is a distance friction parameter, whose selection is based on many calibrated case studies of Chinese cities.

The investigation conducted by Burke and Brown (2007) shows that the walking distances to a variety of services are always much greater than the standard theoretical ones commonly used by planners. So, referring to Passenger Transport Services for Bus/Trolleybus (China GB standard, GB/T 22484-2008), the threshold value was set at 1,000 meters, doubling the longest walking network distance to bus stops according to the standard.

4.3 Measuring population weighted average accessibility

Population-weighted average accessibility is a popular method in equity analyses used to assess and compare accessibilities between various social groups (Golub and Martens, 2014, Langford et al. , 2012). In the previous studies, the accessibility is calculated based on Traffic Analysis Zone (TAZ) or census centroids, but it has been improved by measuring it at building level (equation 4).

$$A_g = \frac{\sum_{i=1}^{n} P_i A_i}{P_g} \quad (4)$$

where A_g is the group g's average accessibility, P_i is the population of the group g in the building i, A_i is the spatial accessibility index at the building i, and P_g is the total population of the group g.

In this study, the group of university students is compared with the group of elderly people for the following reasons. The elderly people are defined as those aged above 60, which is the legal retirement age in China currently, and Hubei province where Wuhan locates is also a main ageing population society in China (Yang, 2016). First, both groups use public transport services temporally more flexibly than those commuters who travel on peak-time. Second, both groups have low income due to unemployment and retirement. Students' subsistence is always fully funded by their parents in China. Comparatively, the senior people rely on their retirement pensions. Both groups travel by public transport because of the low-cost fare. Therefore, university students and the elderly people are disadvantaged groups lacking access to private transport. The accessibility of public transport affects their quality of life, so both demand more services than other groups who have more choices of transport mode.

4.4 Measuring competition-based accessibility at bus stops

Due to high population density, there has always been a shortage of bus supplies and intense competition among bus passengers in Chinese megacities. People have to wait for a long time to get on an overcrowded bus, especially during peak hours. Therefore, the passenger congestion at a bus stop, which relates to temporal factors (e.g., waiting time), supply factors (e.g., service frequency), and demand factors (e.g., public transport passengers), is also an essential element in our accessibility study.

Taking the account of public transport frequency and potential demand, the first step in the Enhanced 2-Step Floating Catchment Area method (E2SFCA) (Langford, Higgs, 2012) is adopted to measure the competition-based accessibility at a bus stop as follows (equation 5).

$$R_j = \frac{S_j}{\sum_{i=1}^{n} P_i f(c_{ij})} = \frac{S_j}{\sum_{i=1}^{n} P_i D_{ij}^{-\beta}} \quad (5)$$

where S_j is the number of bus routes via the stop j. This value represents the supply and the frequency of bus services for two reasons. First, the bus timetable data is not available in this study. Second, the frequency of each bus service is relatively similar between these routes at the same time, although there is temporal variation in a day. P_i is the population at building i, which is located within the longest catchment distance from a bus stop (e.g. 1,000 meters). $f(c_{ij})$ is the distance decay function as used in the gravity-based accessibility (equation 3). Therefore, this measure indicates the waiting time for public transport by considering the competition on the demand side between potential bus passengers. The lower value the R_j has, the higher level of congestion at the bus stop has.

5 Results

5.1 Spatial inequality in accessibility to public transport

The result of spatial accessibility to bus stops by proximity analysis (equation 1) is shown in Figure 6, which is divided into five classes by quantile classification. It means the range of classes was determined by ranks, and huge different values would be classified into one category. Compared with natural breaks, equal interval, standard deviation, or other classification methods, quantile method can clearly visualize the disparities in public transport proximity between dwelling units, especially for the data distribution with a long tail. The maximum time to the nearest bus stop is 41.86 minutes by walking, while the median time is only 4.23 minutes. 80% of the residential buildings in our study area has achieved a walking time less than 7.39 minutes. Calculated by the walking speed of 4.5 km/h, the majority of the residential buildings across Wuhan central city area have less than 554.25 meters proximity to the nearest bus stop. Obviously, the closer to a bus stop a residential building is, the higher-level accessibility it gains.

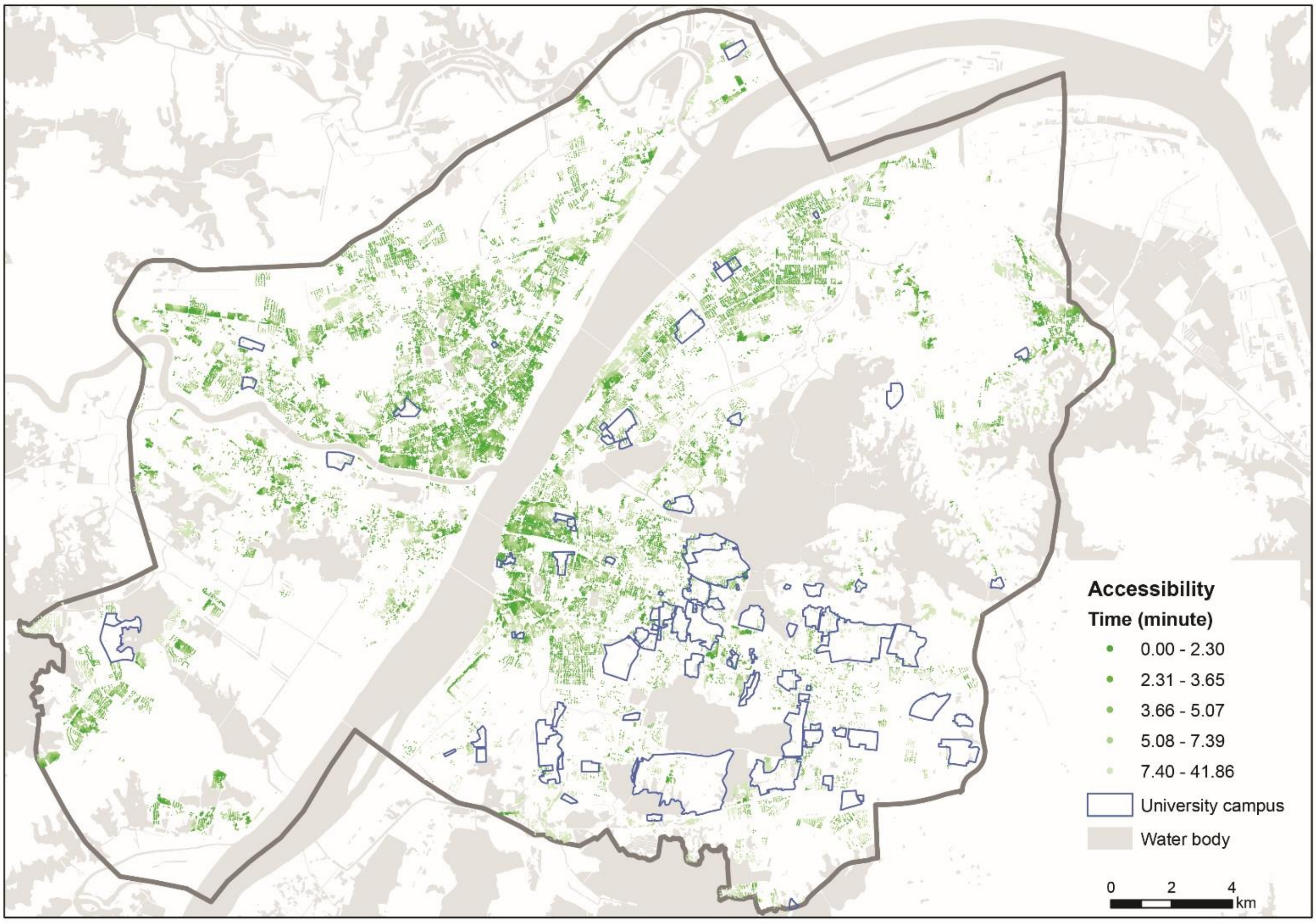

Figure 6. Spatial proximity to bus stop at residential building level

The median of walking time to the nearest bus stop from the residential buildings within university campuses is 5.61 minutes. It is higher than the median of walking time of those residential buildings outside the gated campuses, which is 4.24 minutes, while only 33.23% of the residential buildings outside the campus must walk higher than 5.61 minutes. Thereby, from the perspective of proximity, the students' residence buildings have a lower level of accessibility to bus stops than any other living areas, which demonstrates the spatial inequality in bus stop access between university campuses and all the rest residential areas.

As mentioned before, campuses within the study area are dominated by large gated blocks with a mean area of 40.11 hectares and a large number of students. Thereby, university campuses have become important sites for transport attractions. To explore the roles of land-use within campus shaping the inequality, the accessibility to bus stops between campus gates and campus buildings are compared.

The accessibility from campus gates to bus stops illustrated in Figure 7, which is divided into five classes by quintile as well. The maximum walking time from a university campus gate to the nearest bus stop is 22.29 minutes, and the median time is 2.71 minutes. Comparatively, it is much shorter than not only the median time from the residential buildings within the campus but also the median time from those residential buildings outside the campus. Walking from 80% university campus gates to a bus stop is less than 5.77 minutes, which is equal to 430 meters.

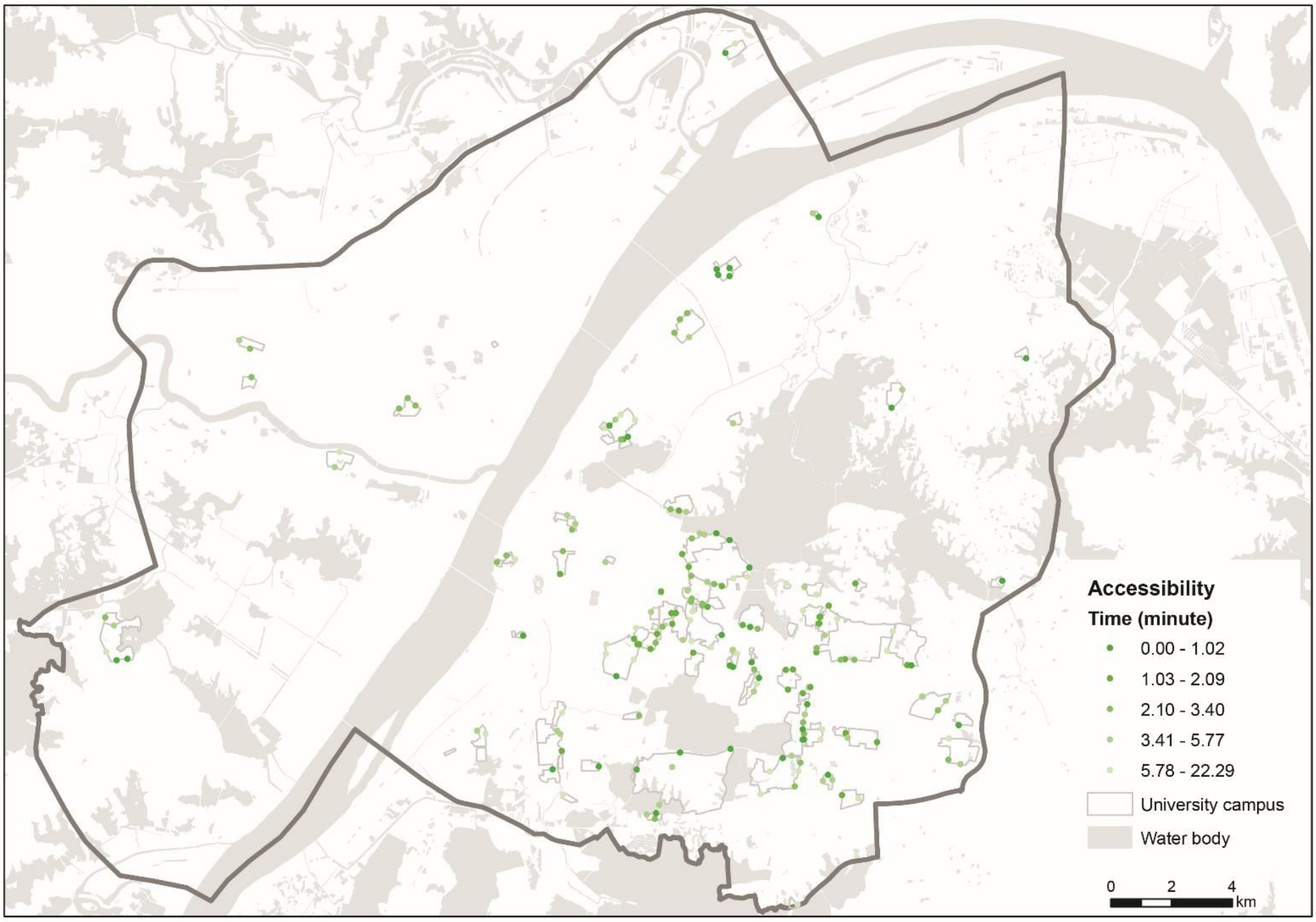

Figure 7. Spatial proximity to bus stop at university campus gate level

This result indicates that the university campus, as a unique spatial unit, has received good service of public transport. It also means the urban and transport planning at city level have considered the travel demand of universities. However, when comparing the results from Figures 6 and 7, it is clear that students have a poor level of accessibility to university campus gates, which has led to the spatial inequality mentioned above. This has reflected that the transport and land-use interaction within university campuses, which includes the connection between campus and its outside, transport within campuses and the spatial distribution of students' residence buildings, have been neglected in the current China's urban study. The public transport planning has already considered university campuses as transport attractions and the travel demand from university students because bus stops have been allocated nearer to campus gates than other areas. However, the spatial governance of university campus is complicated by the administrative relationships between Ministry of Education, provincical and municipal governments. The land-use and transport planning within a university campus is not integrated into the processes of urban and transport planning at city level as there is no bus stop within the campus and no transport connection with outside.

Therefore, urban students have to walk a long distance from their residence buildings to a university campus gate first. When calculating the gravity-based accessibility (equations 2 and 3), it is very crucial to justify the selection of its friction coefficient for a specific case study. Many studies of Chinese cities have calibrated the coefficient. For example, the β value of 1.18 was used in the study by Xu, Ding (2015), and the range from 0.9 to 2.29 was adopted in other studies (Tao et al. , 2015). A β value of 1.2, which is close to those in the two studies (Tao, Cheng, 2015, Xu, Ding, 2015), is selected for calculating the accessibilities in this case study.

The resulting spatial distribution of the gravity-based accessibility to bus stops across the study area is shown in Figure 8 with five classes categorized by the quantile classification. The median value of such accessibility for the residential buildings in gated campuses is 0.30, which is much smaller than 0.57, the mean value of accessibility for the rest residence buildings located outside. Gravity-based measurement of accessibility is assumed to be more accurate due to the consideration of distance decay (Cheng and Bertolini, 2013) and bus services (e.g., number of bus routes). The result has further confirmed the spatial inequality in accessibility to bus stops between residential buildings within and outside university campuses.

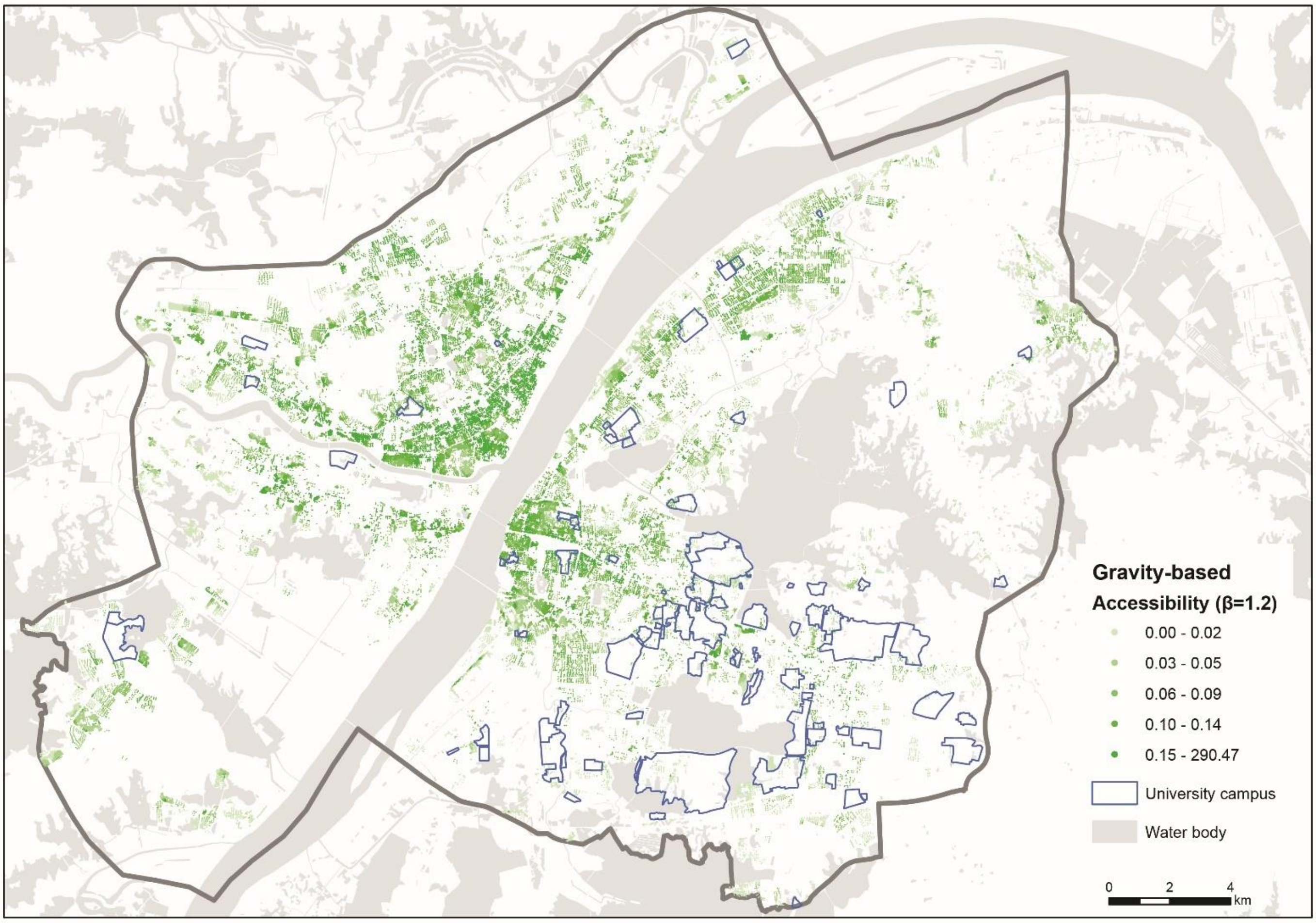

Figure 8. Gravity-based accessibility at residential building level

In addition to the vertical equality issues, the horizontal equality has been explored in this case study as well, which is indicated by the spatial disparities in gravity-based accessibility between all the selected university campuses. The results shown in Figure 9 imply such spatial inequality. Taking Wuhan University (see A in Figure 3) as an example, which owns four campuses in total, the mean accessibility values between all the four campuses is 0.04. However, the accessibility values vary with campuses. 0.02 for the Art and Science Campus, 0.03 for the Engineering Campus, 0.07 for the Informatics Campus, and 0.09 for the Physic Campus. It means that all the students living in the Physic Campus have more opportunities of shopping, entertainment and visiting than the rest due to higher accessibility to bus services.

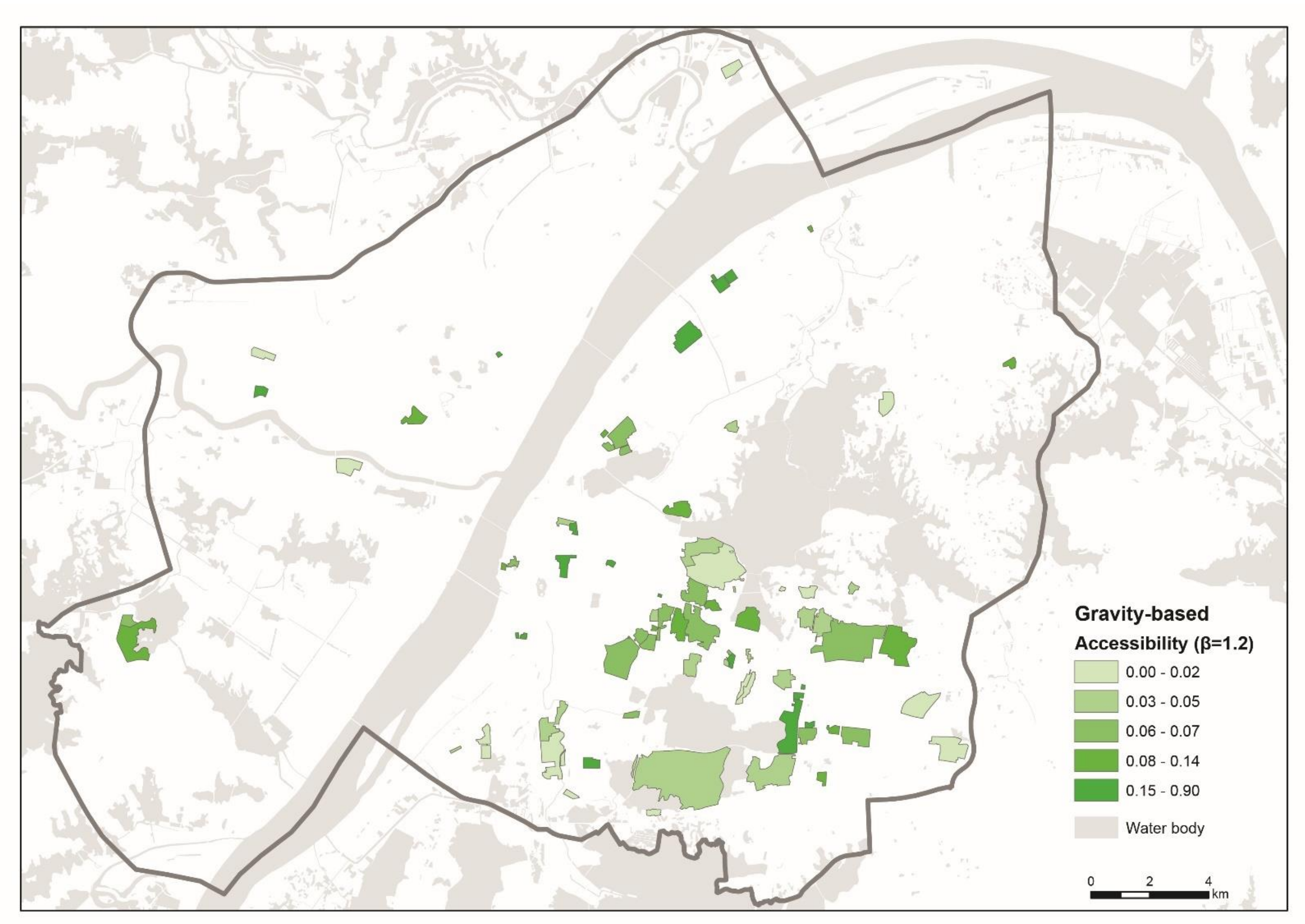

Figure 9. Gravity-based spatial accessibility at campus level

All the results showed a highly skewed distribution, and the long tail in the last category from each accessibility measurement implies that some sites have extremely high (by the gravity method, or low by the proximity method) level of accessibility than other sites. We have checked those sites with very high values and found that this is mainly caused by the very short distance and a flourishing public transport support with an inverse power used for the measurement.

5.2 Social inequality in public transport accessibility

The elderly people and university students are all disadvantaged groups in transport accessibility as they are unable to drive private cars. It is interesting to compare the public transport accessibility between these two groups. In terms of proximity (equations 1 and 4), university students' average time to the nearest bus stop is 8.88 minutes, contrasting with elderly group's average time, 4.10 minutes.

The gravity-based accessibility (equations 2 and 4) further enhanced the statement as the average accessibility weighted by the population of students is 0.03, against 0.53, which is the average accessibility weighted by the elderly population.

The results above indicate the remarkable disparity in public transport accessibility between two social groups, which demonstrates the social inequality in the public transport services.

5.3 Public transport competition at bus stops

Public transport service is very much affected by the number of routes through each bus stops as shown in Figure 10. It is clear to see that the high-density bus routes are more concentrated in the university streets such as Hongshan, South Lake and Optics Valley than other areas. It is also easy to find that bus routes are evenly distributed between the university campuses in Wuchang. The campus spaces are segregated from the urban public space, and a bus cannot drive through a university campus because of the closure of gated campuses.

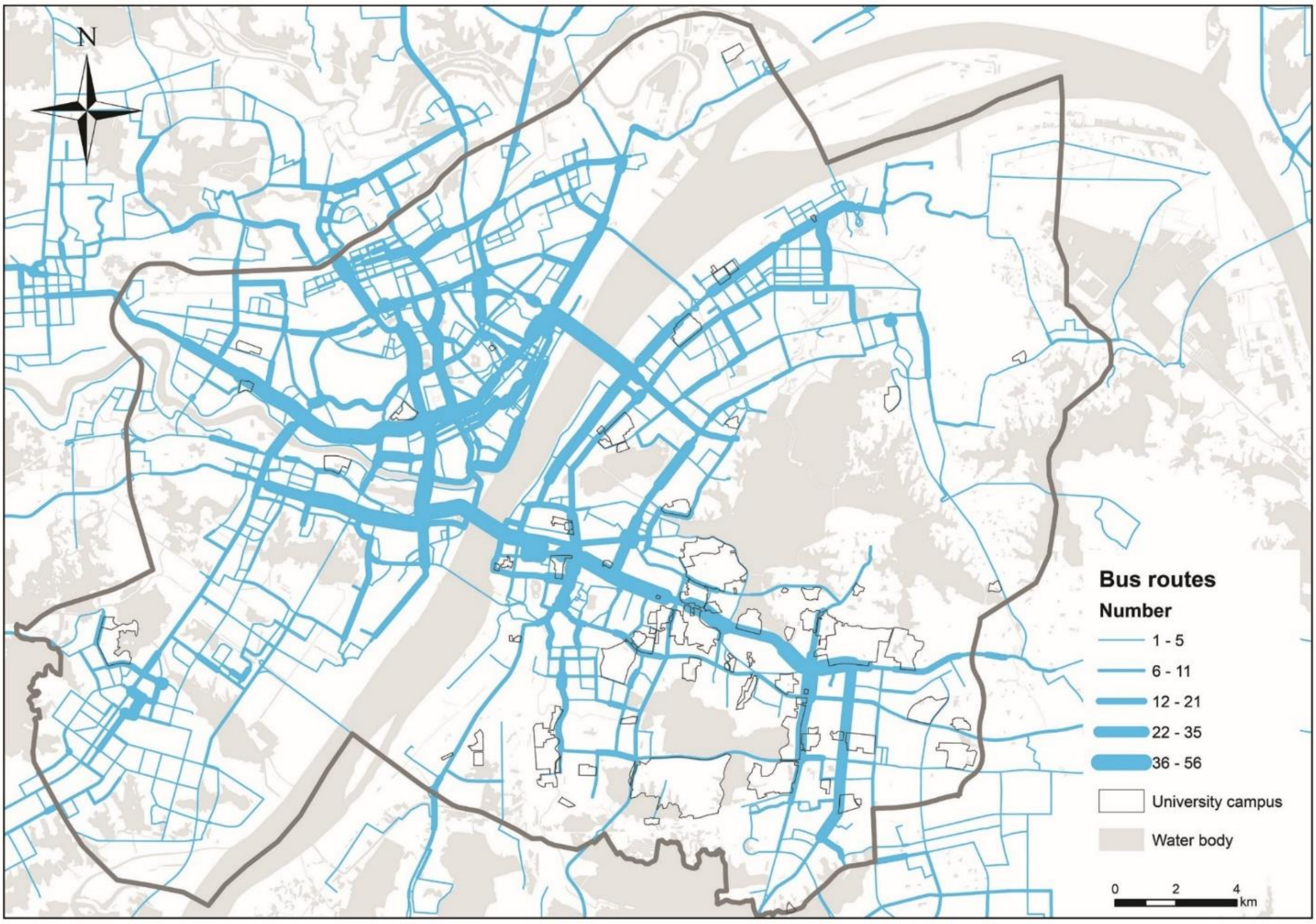

Figure 10. Distribution of bus routes

To estimate the passengers' waiting time at a bus stop, the passenger congestion level at a bus stop was calculated by equation 5, shown in Figure 11, which reflects the competition between bus passengers.

As with the results of accessibility measurements, the bus stop competition level also showed a highly skewed distribution, which implies that some bus stops have an extremely high level of passenger competition compared to other sites. This is mainly the result of a limited number of bus routes and huge demand from the accessible population. It is clear to see that high-level competition is concentrated around the university street (see examples in Appendix 1 and 2). In other words, university students have to wait a longer time to get on a bus than others do. This indicates the bus service is insufficient for the area with a high concentration of students. The metro service or other high-volume transit systems might be a better solution.

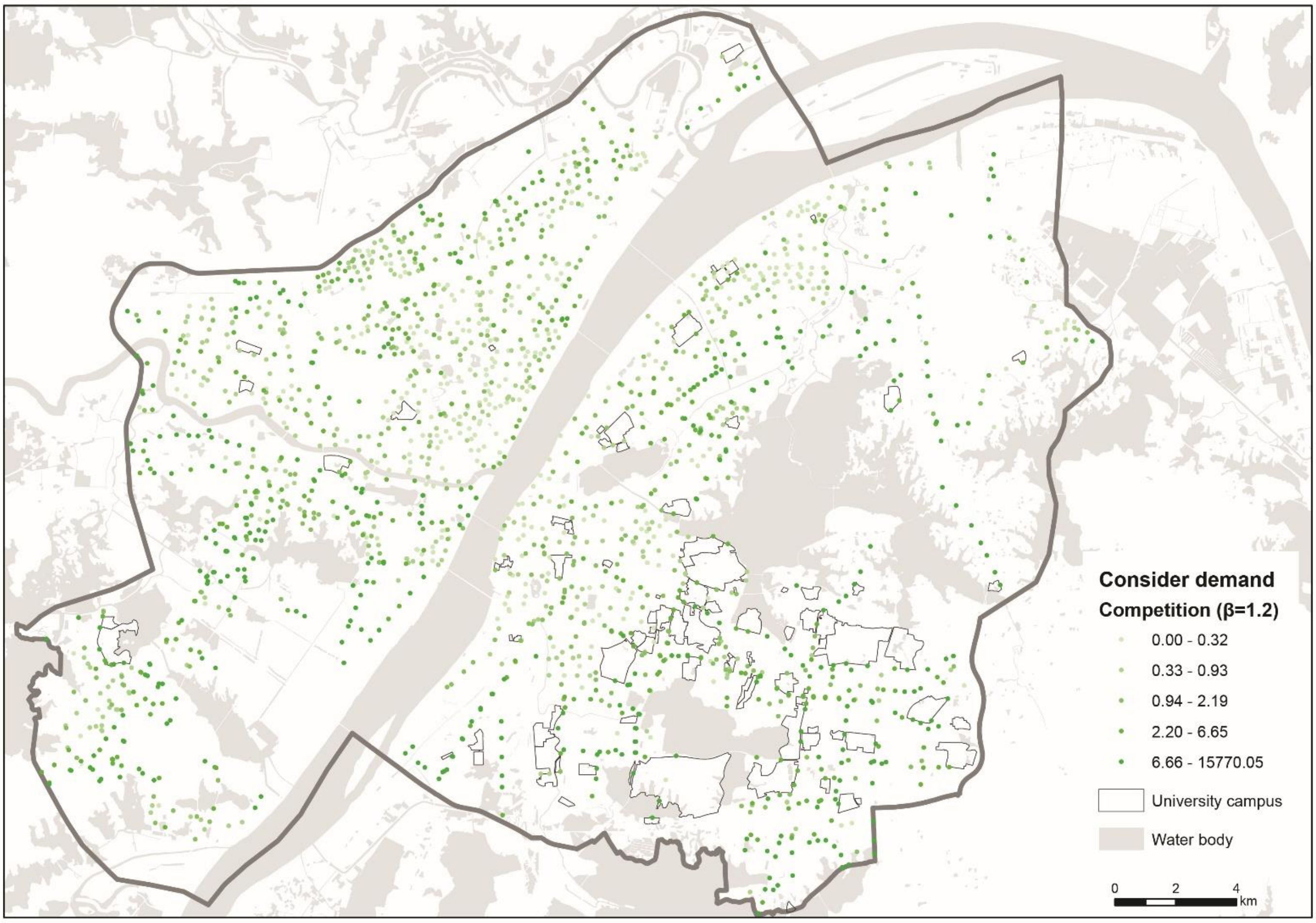

Figure 11. The bus stop competition level by considering potential demand

6 Discussion and conclusions

As enduring bodies of walled non-production work units, gated university campuses are quite unique in post-reform Chinese cities. This study has provided the first evidence regarding the socio-spatial impact of gated university campus from inequality perspectives. Using Wuhan city in Central China as a case study, where nearly 1 million university students are in higher education, the spatial accessibility to public transport service (bus services in this case) has been measured and assessed by using proximity, gravity-based and E2SFCA measurement methods. Further comparison analyses (e.g. accessibility weighted by population of different groups and measured by considering passenger competition on the demand side) have confirmed the presence of spatial and social inequalities in the public transport accessibility across the central city.

It is found that better access to public transport service as distributional 'transport good' concentrates near the gates of those walled campuses. Comparing the proximity and gravity-based accessibility between outer residential buildings and students' dormitories, those students who reside within gated campus at a distance far from those gates are less likely to have equal access to public transport service when traveling out. The spatial inequality is reflected by two aspects: longer walking distance within campuses than other areas or remarkable variation in accessing bus stops between these university campuses. Our study has found that the spatial inequalities are not contributed directly from the provision of public transport services because a university as a whole has been provided with more bus stops and routes near the university gates. However, the high volume of bus passengers from university campus has led to significant increase of waiting time at the bus stop, which makes the bus service less accessible temporarily. This implies that bus service is insufficient to meet the travel demand of university campus with a high concentration of massive student population. Metro and tram will be the alternative better modes of transport, whose impacts will be examined in the future as Wuhan city has not yet developed a metro system with full coverage. Other than spatial inequality, the social inequality is indicated by the different level of public transport accessibility between university students and the elderly group, and the former has much lower level than the latter. Consequently, it is argued that the university students residing in gated campuses may be more disadvantaged than the elderly people from the public transport access point of view. Compared with "studentification" as a process of gentrification in the UK (Smith, 2009), gated campuses where most university students in China are obliged to reside and concentrate are more likely to be "transport disadvantaged" places (Ricciardi, Xia, 2015).

Another important but easily neglected factor contributing to the inequalities mentioned above, is the land-use plan within a university campus, as there is a remarkable variety of proximity to a bus stop between these students' residential buildings. First, the campus is a quite large walled block with very few gates. Some residential buildings within the campus may have a short direct-line distance to a bus stop, but walking distance to the bus stop is very long due to the segregation between the buildings and the bus stops by the wall. Taking the Art and Science Campus in Wuhan University as an example (Figure 12), there are five residential zones from A to E in the campus, and all of which apart from D have a distance of 501-1000 meters to the nearest bus stop. Some buildings in B and C even have a distance of more than 1000 meters. Second, due to the traditional governance of gated university campus in China, the local public transport service is not allowed to enter into university campuses, which has led to the transport, spatial, and even social segregation. Bus stops can only be located on external roads outside the gated campus because campuses are an independent work-unit governed by the central or provincial government but not by the municipal government. The hierarchical administrative system related to the governance of university campuses have contributed to the spatial and social inequality in public transport accessibility, even though the university campus has been treated as a kind of welfare for university students (Tang, Tomba, 2011).

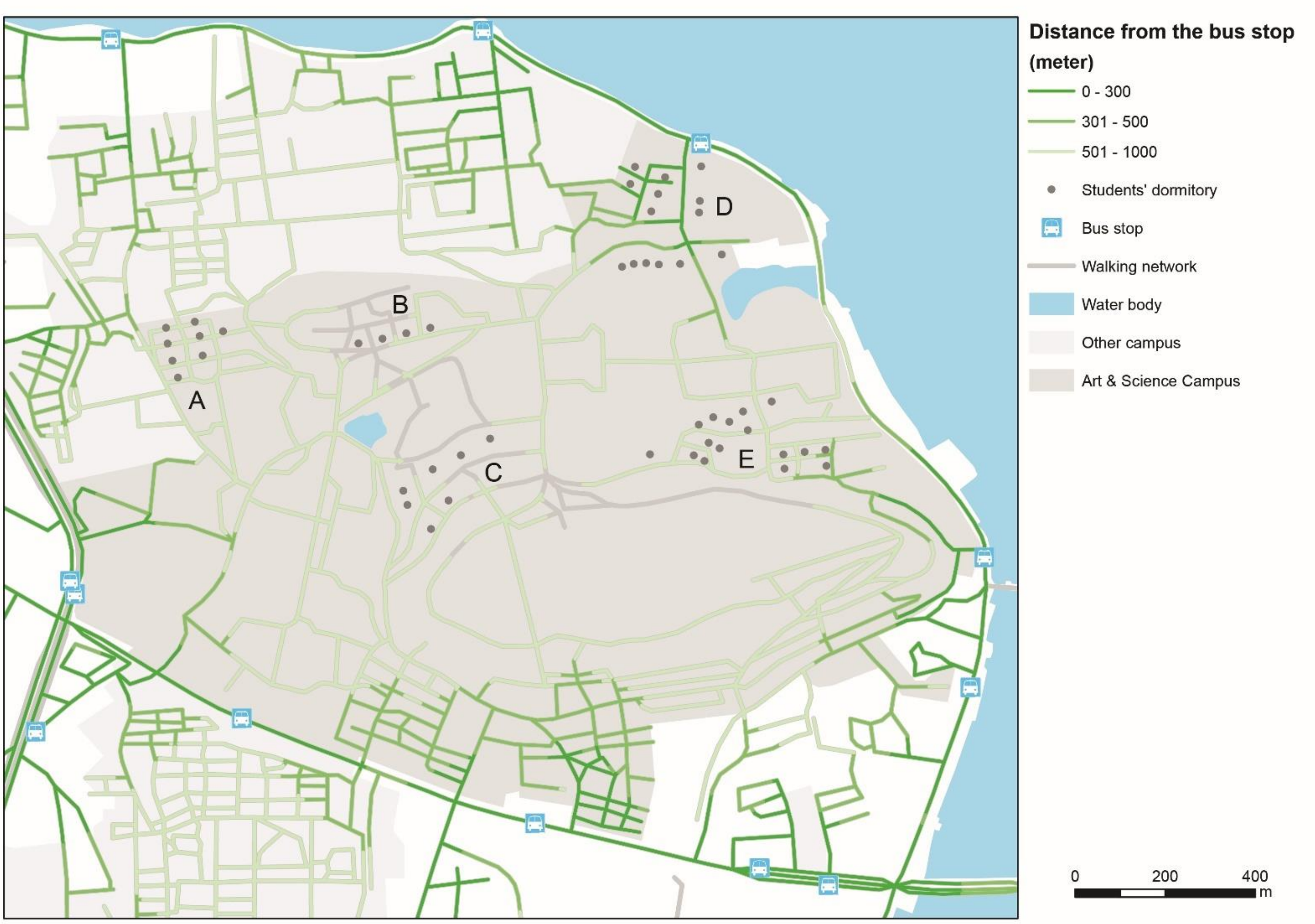

Figure 12. Disparity in distance to bus stop within a campus

In addition, our quantitative evidence has indicated that the segregation of university campus as a remaining non-production work unit and gated community has remarkably contributed to the spatial and social inequalities (see example in Appendix 3). Skewed distributions of proximity and gravity-based accessibility indexes indicate huge disparities and horizontal inequality among accessibility and potential needs. Apart from the horizontal disparity, the quantitative results also exhibit the spatial variation in public transport accessibility between universities and their local interactions derived from gated campuses. Students living within the walled campus have to walk out a long distance to participate in local urban activities, and this may lead to a new type of transport-induced social exclusion, which is not witnessed in western countries (Fernández-Esquinas and Pinto, 2014). Moreover, the segregation is a dual process across the city. Universities are developing a new mission to serve local economic and social development, while the gated campus segregates local citizens from accessing the university's public services. Therefore, in the context of China, the spatial governance of university campuses, as a unique spatial unit, should be extensively studied in the future.

As a first attempt to explore university campus as a gated community, this study is still very limited in its depth and breadth, and more positive and negative evidence should be created for further discussion. The university campus, as a unique community that has many internal services for daily living including schools, hospitals or medical centers, open markets, banks, and shops, functions as a small town. There is a saying in Chinese culture that staff members residing within the campus can live there for a lifetime without walking out of the campus. Such community structure may help to reduce the travel demand of students to some extent and accordingly enables the mitigation of traffic congestion at local level. Consequently, there is an interesting question: how much can the gated campus contribute to the reduction of travel demand for external public transport? Such impact of the built environment within campuses on the travel behavior of students should be examined in the future. In addition, an obvious solution to exploring such inequality problems is to open the gated campuses to society. Most of the universities in the world such as Harvard University have no walls and no gates at all. The University of Manchester is located along the two sides of Oxford Road (see appendix 4), where the busiest bus routes in the whole of Europe transport a high-density student population. But, there might be another voice to object the openness of university campus, e.g. increasing crime incidences caused. Another debate related to opening the university campus to the city is the relocation of students' residential buildings from the campus to the market, which may stimulate the process of "studentification" (Smith, 2009), a popular social space in the Western cities. All the debates need further elaboration, including but not limited to crime rate, environmental quality, students' satisfaction, transport impacts, and optimal distribution of public transport stops, within the university campus. The further study of spatial governance may contribute to these debates as well as urban governance in Chinese cities.

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Appendices

Appendix 1. Passenger congestion at a bus stop in Optics Valley area (taken on March 2, 2008)

Appendix 2. Example of an overloaded bus with students from the campuses (taken on December 12, 2008)

Appendix 3. An example campus gate in Hubei University of Economics (taken on July 24, 2010)

Appendix 4. The bus service through the University of Manchester campus (taken on July 12, 2017)