Accessibility-Based Equity of Public Facilities: a Case Study in Xiamen, China

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Abstract

China's rapid economic development has led to inequality in terms of property, education, and health. Equal access to basic public facilities has become a key concern of inclusive development policies. However, previous studies have paid little attention to the effects of different travel modes on the accessibility of basic public facilities. The present research fills this gap. Taking Xiamen city as a case study, it explores the degrees of horizontal and vertical equity by examining the accessibility of various basic public facilities, paying attention to different travel modes and travel times. The results for Xiamen city show that disadvantaged groups experience a greater level of inequity. By taking these aspects into account, one is better equipped to identify areas in the city where access to basic public facilities is in need of substantial improvement.

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Introduction

There has been a growing scholarly interest in the accessibility of public facilities in the past few decades (Kirby et al., 1983; Talen & Anselin, 1998; Grubesic & Durbin, 2017). Good accessibility allows residents to access vital public facilities like schools and hospitals and participate in services and social interaction, while poor accessibility can lead to, or exacerbate, poor socioeconomic effects and inequality (Kelobonye et al., 2019; Lee & Miller, 2018). Therefore, examining the accessibility of urban public facilities is essential for arriving at equality in sustainable urban development and high quality of life. However, most existing studies have tended to focus on one particular facility (Apparicio et al., 2008; Fasihi & Parizadi, 2020; Grubesic & Durbin, 2017). The big advantage of this focus on one particular facility is that it can identify areas that are underserved in a certain sense and are in need of improvement in facility allocation, in other words, it can help in setting up a reasonable public facility allocation strategy. On the contrary, Tsou et al. (2005) argue that only focusing on one type of urban public facility and ignoring the relationship between public service facilities will weaken the substitution effect between public service facilities, and therefore failing to effectively measure the impact of the overall public service facilities on residents. Ashik et al. (2020) also point out that the lower accessibility of a particular urban public facility can be compensated for by the higher accessibility of another one. Therefore, it is not only necessary to allocate specific types of public facilities by disintegrated accessibility measures, but also to conduct integrated measures of accessibility that include different urban public facilities, so as to systematically identify the areas with the biggest overall shortage of services. Up till now, relatively few studies have considered a systematic approach to examining the level of accessibility of various urban public facilities (Ashik et al., 2020; Taleai et al., 2014; Tsou et al., 2005). Although these studies have provided a good starting point for measuring the integrated accessibility of various public facilities, several improvements are needed.

First, the modifiable areal unit problem (MAUP) should be considered in the spatial analysis. MAUP refers to the problem that the results of some spatial analyses (e.g., overlay analysis) depend on the choice of the areal units when point-based individual data are aggregated into areal units (Fotheringham & Wong, 1991; Kwan & Weber, 2008). Most studies on integrated accessibility use administrative or census units as the basic unit, which is quite often too large to produce accurate results. A solution can be to use smaller spatial units in order to produce more accurate results through less aggregation.

Second, studies on the integrated accessibility of public facilities have paid little attention to travel modes (Ashik et al., 2020). Although the service radius provides the basis for setting the threshold, it cannot reflect the ease of reaching public facilities. People rely on transportation when accessing public facilities, and the ease of reaching public services within the same threshold time or distance may differ under different traffic modes. Therefore, the accessibility of public facilities should consider different transport modes. In China, the number of private cars has increased in the past few decades, but public transportation is still the major motorized mode in

many cities, especially for vulnerable groups. According to the Yearbook of Xiamen Special Economic Zone, in 2015 only 22.9% of the population of Xiamen city owned a private car (Xiamen Municipal Statistical Bureau, 2016). Therefore, more attention should be paid to walking and public transportation in the study of accessibility of public facilities for disadvantaged groups.

Third, research has tended to use threshold travel distance rather than travel time. For instance, Taleai et al. (2014) set different threshold travel distances for each type of public facility: At the district level, the threshold travel distance ranges from 650 to 3000 m, and at the community level from 300 to 1000 m. According to China's "Standard for urban public service facilities planning," the service radius of district-level public facilities (e.g., public libraries, cultural centers, senior citizens activity centers, and public sports centers) ranges from 4000 to 7000 m for a city with a population of 3 million (Ministry of Housing and Urban–Rural Development of the People's Republic of China, 2018). In comparison to this broad range of service radius, travel time may better reflect the differences in time use.

Fourth, studies have mainly utilized the analytical hierarchy process (AHP) to estimate the weight for, and thus the importance of, certain urban facilities (Ashik et al., 2020; Taleai et al., 2014). Although the AHP can be used to determine the preferences for different types of public facilities from the perspective of planners and policymakers, it cannot determine the actual preferences of users for different facilities. Moreover, Iacono et al. (2008) found that for different travel modes and purposes, the coefficient of distance decay function is different. Therefore, actual travel behavior data are needed to calculate actual preferences for different types of public facilities as well as distance decay function parameters.

Lastly, little attention has been paid to vertical equity. The spatial distribution of urban facilities could be unequal due to the allocation priority to the disadvantaged or high-demand groups, leading to unequal opportunities but equal outcomes. In this regard, Rawls (1971) argues that public facilities should be distributed to favor the more disadvantaged people. Without consideration of non-spatial factors, it is impossible to assess vertical equity based on the constraints and needs of residents.

To fill the mentioned gaps, the present research investigated the disintegrated and integrated accessibility of various public facilities in Xiamen, China. We were particularly interested in the accessibility of community- and district-level public facilities and the resulting degree of horizontal and vertical equity. We therefore developed a methodology to detect areas where access to basic public facilities needs substantial improvement. The methodology entails combining open data and travel survey data to analyze the accessibility of public facilities for different social groups. Open and big datasets—namely POI data on basic public facilities, as well as travel time matrix data—were scraped from the online platform Gaode Map Web API by making use of the Python programming language. These data were then used to measure walking and public transportation catchment areas.

This article is structured as follows. Section 2 reviews the literature on accessibility measurements and the resulting horizontal and vertical equity. Section 3 introduces the research methodology, including the collection and analysis of several datasets. Sections 4 and 5 present the results and conclusions, respectively.

Literature Review

Equity in the Accessibility of Public Facilities

According to the service range, public facilities can be divided into several levels, such as city, district, subdistrict, community, and neighborhood levels (Taleai et al., 2014; Tsou et al., 2005). The service range of city-level facilities covers an entire city, whereas that of neighborhood-level facilities covers only a neighborhood. The travel costs associated with accessing these different levels of public service facilities also differ. When conducting a multicriteria analysis, Taleai et al. (2014) defined the divergent threshold distances for different levels and types of public facilities by consulting four local planners in Tehran (Iran). Since the travel distance influences the choice of travel mode, Li (2014) matched different levels of public facilities with different travel modes: 1) city and district levels correspond to public transportation; 2) subdistrict level corresponds to cycling; and 3) community and neighborhood levels correspond to walking. These differences in travel mode associated with the level of public facilities influence the accessibility of public facilities and thus the degree of equity.

There has been considerable debate about the relationship between equity and the accessibility of public facilities (Grengs, 2014). The provision of non-profit public facilities and services has a redistributive effect, that is, it "alleviate[s] to some degree the worst impacts of the wage system on the poorest groups in society" (Harvey, 1973, p. 274). Litman (2002) classifies equity into two general types, namely horizontal equity and vertical equity. The former is related to "the distribution of impacts between individuals and groups considered equal in ability and need" (Litman, 2002, p. 3). Equal groups should "receive equal shares of resources," meaning that "public policies should avoid favoring one individual or group over others" (Litman, 2002, p. 3). In contrast, vertical equity is related to "the distribution of impacts between individuals and groups that differ in abilities and needs," and transport policies are equitable "if they favor economically and socially disadvantaged groups, therefore compensating for overall inequities" (Litman, 2002, p. 3).

Vertical equity has been applied to reveal the level of accessibility in socially disadvantaged neighborhoods. The findings were diverse and even contradictory in different contexts. Lucas (2012) indicates that low-income and socially disadvantaged groups often faced barriers to accessing their desired destinations. Similarly, Ricciardi et al. (2015) point out that socially disadvantaged groups comprising elderly people, low-income households, and no-care households suffer from inequitable distribution of accessibility in Perth, Australia. However, Grengs (2014) argues that vulnerable social groups in Detroit enjoy better accessibility than more privileged groups for several trip purposes, such as childcare facilities and hospitals, while the situation is reversed when it comes to accessing stores and supermarkets. In the Chinese context, some scholars identify an unbalanced spatial development of public services such as elderly care facilities (e.g., Jia et al., 2018). Others argue that low-income migrants in cities mostly live

close to public facilities (Lin et al., 2011; Liu et al., 2018). These studies mainly paid attention to one specific public facility or social group, and there is a lack of research on the accessibility of various public facilities that take differences in mobility needs and abilities into account.

Accessibility Measurements

Over the past few decades, researchers have explored the accessibility of basic public facilities with a focus on the spatial equality or inequality caused by the distribution of these services (Del Casino & Jones, 2007; Kunzmann, 1998). Accessibility can be used as an evaluation tool to direct policies for spatial equity (Panagiotopoulos and Kaliampakos, 2019). The literature addresses three key issues regarding accessibility measurements.

The first issue is the approach used to measure accessibility (Handy & Niemeier, 1997; Stanley et al., 2016; Talen & Anselin, 1998; Tsou et al., 2005). In literature, there are several common approaches, such as the container, coverage, minimum distance, travel cost, gravity, and two-step floating catchment area (2SFCA) approaches (Luo & Wang, 2003; Emily Talen, 2003). The container and coverage approaches measure the number of facilities in a given spatial unit or within a given distance from the point of origin. The minimum distance and travel cost approach to measuring the degree of closeness of facilities. The gravity approach calculates the sum of all facilities (weighted by their size or other characteristics) divided by the functional effect of their distance from the point of origin. An objection to the minimum distance and travel cost approach is that even if people choose a facility based only upon the distance, they will not necessarily choose the facility closest to their homes if they want to undertake more than one activity. For instance, if people want to undertake two or more activities, they can choose to minimize the total travel distance and travel cost, instead of choosing the activity closest to their homes. Given that a person's daily travel is comprised not only of primary but also of secondary activities, service will become more accessible when there are more opportunities.

Thus, in comparison to the minimum distance or travel cost approach, the container and the coverage approaches may be more suitable for measuring overall accessibility. Nevertheless, they have some limitations too. For example, an individual can access the facilities in adjacent spatial units. To solve this problem, a network-constrained catchment area method has been proposed. In fact, this method can be classified as a coverage approach (Miyake et al., 2010). In addition to the container and the coverage approach, the 2SFCA has been proposed. This approach can model the supply factor and the population demand factor (Luo & Wang, 2003). It estimates the supply-to-demand ratio for each public facility within a certain catchment area in the first step and sums up all supply-to-demand ratios for each population point within a certain catchment area in the second step. However, the original 2SFCA method failed to address the travel impedance factor. Therefore, an enhanced 2SFCA method—which assigns travel impedance factors using distance decay functions–was developed (Guo et al., 2019; Hu et al., 2019; Luo & Whippo, 2012; J. Wang et al., 2020; Xu, 2016).

The second issue relates to the accessibility measurement by travel modes. Although extensive research on the accessibility of a certain facility has considered the effect of travel modes (Arranz-López et al., 2019; Owen & Levinson, 2015), only a few empirical studies have focused on the integrated accessibility of different public facilities by different travel modes. In a city like Xiamen, the accessibility of public facilities by public transportation instead of private cars should be considered. Here, measurements by public transportation can be broadly divided into two types. Some studies measure the travel time by public transportation as the value of accessibility; they make use of public transportation routes, stops, and schedule information, and estimate travel times with the standard suite of ArcGIS Network Analyst tools (Lei & Church, 2010; Widener et al., 2015). In contrast, other studies measure accessibility by public transportation by calculating the number of public facilities within catchment areas (Grengs, 2012; Mao & Nekorchuk, 2013). In that case, they simplify the public transportation system by allowing buses to travel along the same routes as private cars, although at a slower speed. However, public transportation routes are quite often different from car routes. In addition, a public transportation passenger can only get on and off at designated stops rather than at any point along the route. In this regard, Google/Baidu/Gaode maps API can provide an origin/destination (OD) travel time matrix based on actual routes and traffic conditions for different travel modes, which is more useful than the information provided by the commonly used ArcGIS Network Analyst (Wang & Xu, 2011).

The third issue concerns the differences in preference and demand for different types of public facilities. For instance, Taleai et al. (2014) use different threshold distances for different types of public facilities based on their travel costs. In addition to the threshold time/distance, a differential weight for each public facility can be considered. Li (2014) conducted a questionnaire survey, based on which she ranked (from 1 to 7) different types of public facilities by travel frequency and importance, and then determined a weight for each type of public facility using the analytic hierarchy process (AHP method). Such approaches, however, fail to address the actual number of trips to different facilities. Another factor is the distance decay function parameter. Research by Iacono et al. (2008) shows that the coefficients of distance decay functions for walking trips are -0.094, -0.106, -0.093, and -0.100 for shopping, school, restaurant, and recreation, respectively. In terms of public transportation, they measured only the parameter of shopping trips (0.029). Their research implies that diverse decay function parameters should be measured for each trip purpose and each travel mode.

In sum, in comparison to other accessibility measurements, the enhanced 2SFCA method is considered an appropriate method for conducting integrated accessibility measurements. When measuring integrated accessibility, weights, time thresholds, and travel impedance factors for each type of public facility should be determined, because of different user preferences and demands for different types of public facilities.
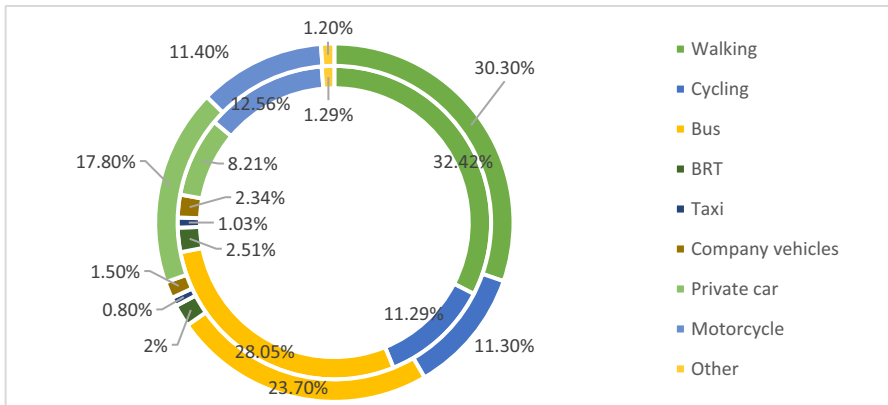
Fig. 1 The modal split for Xiamen in 2009 (inner circle) and 2015 (outer circle). Source: Xiamen household travel survey, 2009 and 2015

Methodology

Study Area

Xiamen is a sub-provincial city in southeastern Fujian, China. It has six districts (Siming, Huli, Haicang, Jimei, Tong'an, and Xiang'an) covering a total area of approximately 1700 square kilometers. At the end of 2015, the built-up urban area covered just over 317 square kilometers and had a population of 3.86 million (Xiamen Municipal Statistical Bureau, 2017). The urbanized area of the city has spread from Xiamen Island—where most of the city-level services and facilities are located—and especially from the southwestern coastal area to all six districts.

In terms of transportation, the household travel survey shows that non-motorized traffic, especially walking, is the main travel mode, accounting for 32.4% and 30.3% of all trips in 2009 and 2015, respectively. The proportion of trips by public transportation, including conventional buses and bus rapid transport (BRT), dropped from 31% in 2009 to 25.7% in 2015, while trips by private car (whether as driver or passenger) increased from 8.21% to 17.8% over the same period. However, public transportation remains the main motorized travel mode (Fig. 1).

Data Collection and Processing

We collected data that made it possible to study the geographic accessibility of basic public facilities and their correlation with socioeconomic attributes.

The 250*250 square meter grid layer and the number of residential users of China Unicom[1] for each grid were obtained from China Unicom. Since original 250*250 square meter grids produce large amounts of travel time matrix data that needs a lot of computing time, we merged 250*250 square meter grids into 1000*1000 square meter grids in order to save a substantial amount of time. For accessibility measurements, we selected urban built-up areas in Xiamen as the study area, rather than the whole administrative region, and only selected the grids with a population of more than 1,000 people. In addition, we only selected areas whose residents were included in the 2015 household travel survey.

We collected points of interest (POI)[2] data and road network data from the Gaode Map API. The GaoDe map (https://ditu.amap.com) is one of the most popular map services in China. From the POI data, we selected data on hospitals, parks, schools, senior activity centers, cultural facilities, and sports amenities. We conducted a preliminary screening of the data, including the information on basic public facilities.[3] Regarding healthcare facilities, we did identify clinics as community-level facilities and hospitals as district-level facilities. Regarding parks, we calculated their areas based on satellite data. According to the "Code for the Design of Public Park (GB 51,192–2016)", parks with an area of smaller than 5 hectares were identified as community-level facilities, and parks with an area bigger than 5 hectares were identified as subdistrict-level facilities (Ministry of Housing and Urban–Rural Development of the People's Republic of China (MOHURD), 2016). Regarding schools, we did identify primary schools as community-level facilities and secondary schools as subdistrict-level facilities. Regarding senior activity centers, cultural and sports facilities, we differentiated these into different levels according to their name. For instance, the Xiange community senior activity center was identified as a community-level facility while the Xiamen city youth palace was identified as a city-level facility. We classified city-, district-, and subdistrict-level facilities into one category because these facilities are generally accessed through motorized modes of transportation, while community-level facilities can be accessed mostly through non-motorized modes of transportation (Table 1). The distribution of public facilities at different levels in Xiamen is shown in Fig. 2.

Trip mode, trip purpose, travel time, and socioeconomic data were drawn from the 2015 household travel surveys. After deleting missing values and outliers, we were left with data on 39,147 households, 93,812 individuals, and 217,710 trips. Concerning the content of the datasets, data on individuals comprise age, gender, occupation, hukou type (family registration system), and education level. Household data comprise address, household size, car ownership, and residential housing area. Trip data comprise departure time, arrival time, trip purpose, and travel mode. Trip purpose data comprise work, education, picking up children, returning home, and business, shopping, recreational, social, medical, and other purposes. Recreational

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[1] China Unicom is a state-owned telecom operator and is the third-largest telecom operator in China.

[2] According to OpenStreetMap Wiki, "a point of interest or POI is a feature on a map that occupies a particular point" (http://wiki.openstreetmap.org/wiki/Points_of_interest).

[3] Urban public service facilities proposed in "Standard for urban public service facilities planning".

Table 1 Different types of public facilities

	Community level	City/district/subdistrict level
Healthcare	Clinic	Hospital
Park	Park	Park
School	Elementary school	Secondary school
Senior activity center	Senior activity center	Senior activity center
Culture	Cultural palace, library, recreation center	Cultural palace, library, recreation center
Sport	Sports stadium	Sports stadium

Source:Ministry of Housing and Urban–Rural Development of the People's Republic of China (MOHURD), (2016)

trips data comprise culture, sports, and entertainment (CSE). Travel mode data comprise walking, bicycle, electric bicycle, bus, bus rapid transport (BRT), taxi, private car, ferry, motorcycle, and other modes.

As open data sources provide real-time traffic data, which can improve the reliability of data, we developed from the Gaode API a travel time matrix for walking, public transportation, and driving. The best-path algorithm used by the Gaode API attempts to minimize the travel time from origin to destination. With the help of the Python programming language, travel distance and travel time were extracted and computed between each unit grid. In that, we set the departure time at 8:00 am, to be able to deal uniformly with the differences in the returned travel time results at different moments of time during the day.
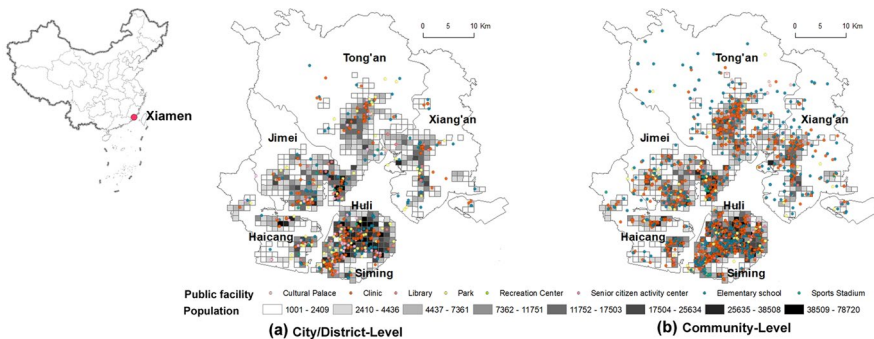
Fig. 2 Distribution of public facilities in Xiamen (Left: city/district-level facilities; right: community-level facilities) (This research mainly focuses on public service facilities within the built-up area; therefore, only grids with a population distribution of more than 1000 people are selected.)

Table 2 Facility types, weights, and threshold travel times

Type	Community level		District level			
	walking		public transportation		Private car	
	$W_{(t)}$	Threshold travel time	$W_{(t)}$	Threshold travel time	$W_{(t)}$	Threshold travel time
	0.411		0.348		0.241	
Healthcare	0.065	25 min	0.196	60 min	0.082	60 min
Park	0.218	30 min	0.285	70 min	0.158	60 min
School	0.656	20 min	0.305	35 min	0.488	30 min
Senior activity center	0.020	22 min	0.071	60 min	0.091	50 min
Culture	0.020	22 min	0.071	60 min	0.091	50 min
Sport	0.020	22 min	0.071	60 min	0.091	50 min

Source: (Xiamen urban planning and design research institute, 2015)

Weights, Threshold Travel Times, Decay Function, and High Demand Groups

For this research, we chose six types of basic urban public facilities, namely hospitals, parks, schools, senior activity centers, culture centers, and sports facilities. Weights and threshold travel times of various public facilities are presented in Table 2. The weights and threshold travel times of each type of public facility were set according to the household travel survey data. $W_{(t)}$ was determined by the frequency of each trip purpose. We included in our basic dataset trips on foot and by public transportation. In the household travel survey, cultural facilities (including entertainment) and sports facilities (CSE) are grouped in the same category of trip purpose. We divided trips for CSE by 3 to weight culture, sports, and entertainment individually.

The weights for hospitals, parks, schools, senior activity centers, and culture and sport facilities account for 0.065, 0.218, 0.656, 0.020, 0.020, and 0.020, respectively for walking; 0.196, 0.285, 0.305, 0.071, 0.071, and 0.071, respectively for public transportation; and 0.082, 0.158, 0.488, 0.091, 0.091, and 0.091, respectively for private car.

To determine the threshold travel time, we considered both the mean and the median value. However, both represent fewer than 50% of the trips. In order to cover the majority of trips, we chose the threshold travel time for each trip purpose, which covers 75% of the trips (Fig. 3). Threshold travel time for each trip purpose and travel mode are shown in Table 1. Figure 4 presents the distance decay phenomenon for each trip purpose and each travel mode. The number of trips on foot or by public transportation for each purpose decreases as the observed travel time increases. The relationship between travel time and the number of trips for each purpose was fitted by an exponential function with different R-square values. Table 3 lists the high-demand groups for each type of public facility.(see Table 4)
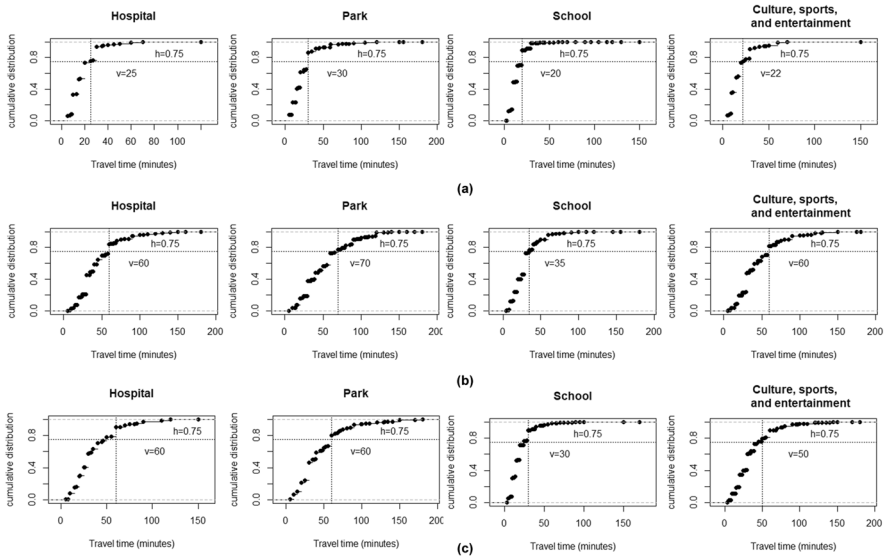
Fig. 3 Cumulative frequency of travel time for each trip purpose (**a**) on foot and (**b**) by public transportation (**c**) by private car

Integrated Spatial Accessibility

We measured integrated spatial accessibility using the enhanced 2SFCA method considering: 1) supply of different level facilities, 2) accessibility by different travel modes, 3) the travel time that covers 75% of the trips, 4) difference in distance decay
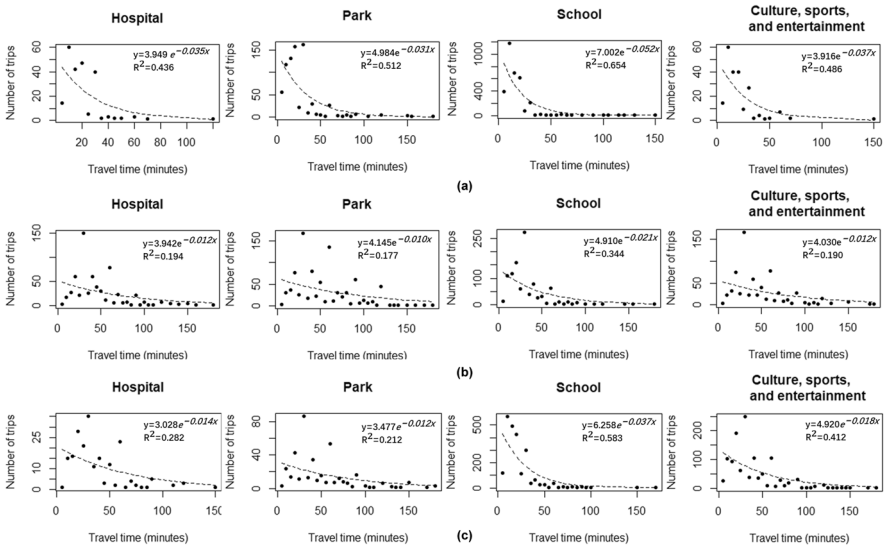
Fig. 4 Decay function with time impedances for each trip purpose (**a**) on foot (**b**) by public transportation and (**c**) by private car

Table 3 High demand groups for each public facility

	High demand groups
hospital	Children aged 0–4; women aged 15–44 (childbearing age); and seniors aged above 65
Park	Ages above 18
School	Children aged 6–12 for primary schools; children aged 13–15 for secondary school
Senior activity center	Seniors aged above 65
Culture	Ages above 18; women
Sports	People aged 5–55; male

Source: (Breuer et al., 2010; CIPFA, 2017; Field, 2000; Griffiths & King, 2008; Guan et al., 2019; Guo et al., 2019; Mak & Jim, 2019; Meade, 2014; National Health and Family Planning Commission of China, 2013; Pallegedara & Grimm, 2017)

for each purpose, 5) differences in demands between groups, 6) differences in preference for a type of public facility, and 7) integrated spatial accessibility. We also used Microsoft SQL Server to calculate accessibility in three steps (Fig. 5).

Step 1. Calculate the supply-to-demand ratio: First, we spatially joined public facility layers with population grid layers in ArcGIS. Second, we explored all population grids within obtained threshold travel time for each facility in SQL server. Third, we computed travel impedance based on the actual travel time between the facilities and population grids. Finally, we determined the supply-to-demand ratio R_j^t for t type facility by travel mode m:

Table 4 Service capacity for each type of public facility

	Service capacity	
	Community level	City/district/subdistrict level
Healthcare	10,000	100,000
Park	20,000	100,000
School	15,000	50,000
Senior activity center	50,000	500,000
Culture	10,000	200,000
Sport	10,000	100,000

Source: (Ministry of Construction of the People's Republic of China, 2018; Code for Urban Public Facilities Planning (GB50442-2008), 2008; Ministry of Housing and Urban–Rural Development of the People's Republic of China, 2018)
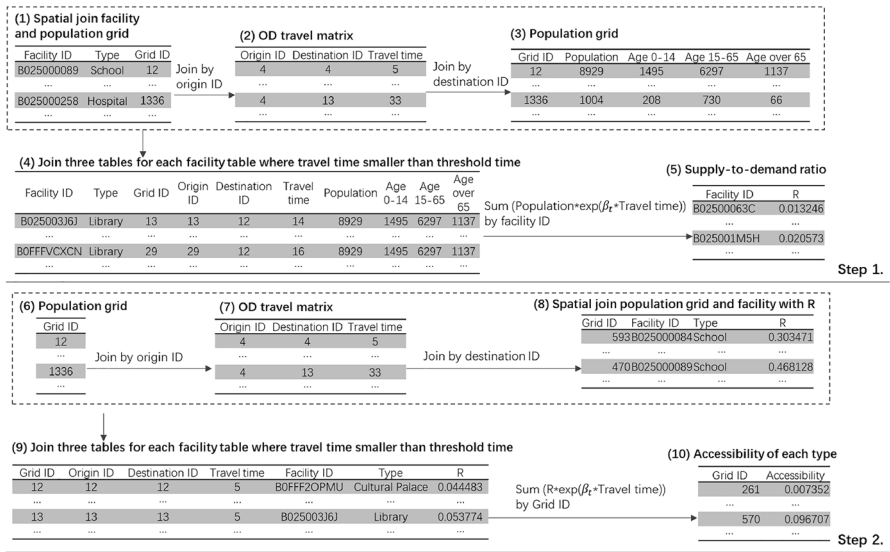
Fig. 5 Workflow of steps 1 and 2

$$R_j^{tm} = \frac{S_j}{\sum_{I \in \{d_{ij} \leq d_0\}} P_j^t f^{tm}(t_{ij})}$$

where S_j represents the service capacity of t type facility j. As service capacity data are not included in our dataset, we assigned service capacity for each facility according to the "Code for Urban Public Facilities Planning (GB50442-2008)", "Code for Planning of City and Town Facilities for the Aged (GB50437-2007)", "Standard for Urban Residential Area Planning and Design (GB50180-2018)", and "Code for the Design of Public Park (GB 51,192–2016)" (Ministry of Construction of the People's Republic of China, 2018; Code for Urban Public Facilities Planning (GB50442-2008), 2008; Ministry of Housing and Urban–Rural Development of the People's Republic of China, 2018).

P_j^t is the population high-demand groups for t type of facility at location i within the threshold travel time of j ($d_{ij} \leq d_0$). $f^{tm}(t_{ij})$ is the decay function of travel time for t type facility by travel mode m:

$$f^{tm}(t_{ij}) = e^{\beta^{tm} t_{ij}}$$

where β^{tm} means the decay coefficient for t type facility by mode m and t_{ij} represent travel time between location i and location j.

Step 2. Compute the accessibility value: We explored all facilities within a certain threshold travel time for each population grid. Then compute travel impedance based on the travel time between the population grids and facilities. After that, sum up the supply-to-demand ratios R_j^t travel impedance to calculate accessibility value A_i^{tm} for t type of facility.

$$A_i^{tm} = \sum_{i \in \{d_{ij} \le d_0\}} R_j^{tm} f_t(t_{ij})$$

Step 3. Determine the integrated spatial accessibility: We calculated the integrated spatial accessibility based on the weighted sum of all types of public facilities at population grid i.

$$A_i^m = \sum_{t=1}^{n} W_t^m A_i^{tm}$$

A_i^m is the integrated spatial accessibility at residential location i by m type of travel mode W_t^m represents the weight t type of facilities by m type of travel mode.

$$A_i = W^w A_i^w + W^p A_i^p$$

where W^w and W^p are the mean weights on foot and by public transportation, respectively. A_i^w and A_i^p represent integrated spatial accessibility at residential location i on foot and by public transportation, respectively.

Results

Horizontal Equity

Figures 6, 7 illustrate the disintegrated and integrated accessibility to urban facilities in Xiamen city. With respect to the disintegrated accessibility, each type of
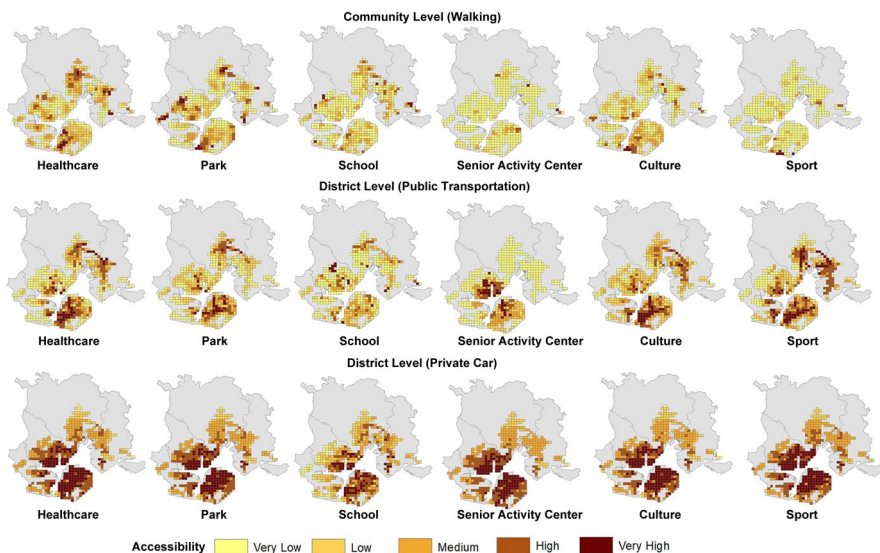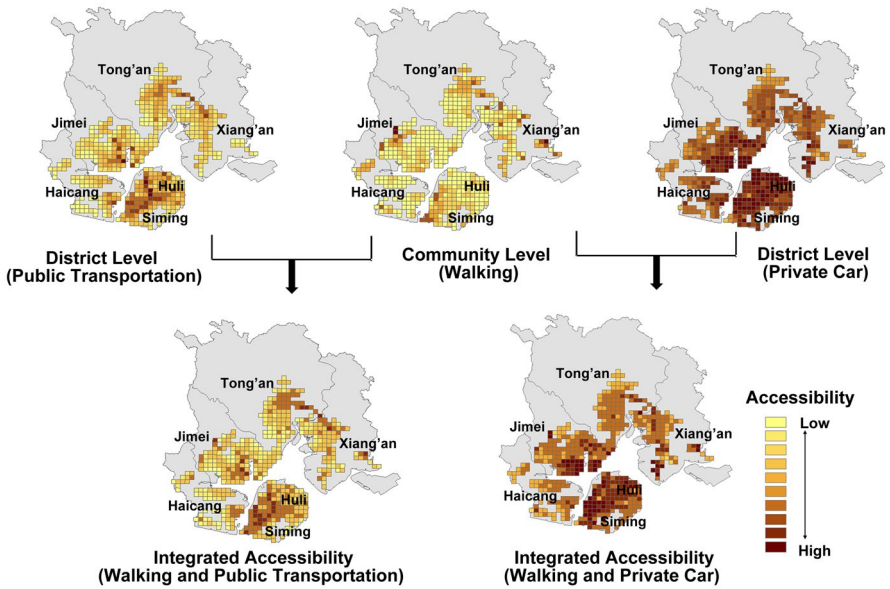

Fig. 6 Disintegrated accessibility

Fig. 7 Integrated accessibility by walking and public transportation (WP) and walking and private car (WC)

public facility has different degrees of accessibility. The spatial accessibility of community-level healthcare, parks, and cultural facilities has a polycentric structure. For most types of community-level public facilities (including healthcare, park, school, and culture), the central area of Siming District and the old towns of Tong'an and Xiang'an Districts enjoy relatively higher accessibility. For Siming District, this is mainly due to sufficient supply (see Fig. 8a), while for Tongan district and Xiang'an District, this is mainly due to reduced demand (see Fig. 8b).
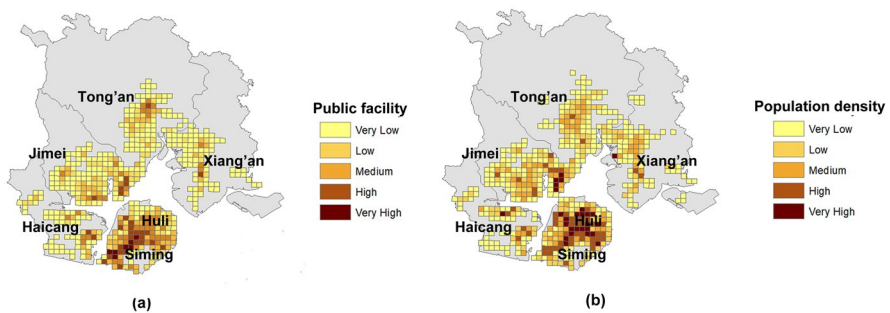

Fig. 8 (**a**) Distribution of public facilities (**b**) population density

Interestingly, the accessibility of district-level hospitals, parks, and cultural and sports facilities by public transportation present a corridor structure. This corridor structure can be attributed to the public transportation services by which different centers are connected. However, these public transportation services show to have no significant effect on the accessibility of schools and senior activity centers at the district level. A possible explanation for this is that shorter time thresholds for schools have weakened the role of public transportation.

With respect to the integrated accessibility, there are differences between the spatial accessibility of community-level public facilities and district-level public facilities. Low supply and high demand have led to low accessibility of community-level public facilities in Haicang, Jimei, Tong'an and Xiang'an districts near Xiamen Island. In contrast, the relatively efficient public transportation system in these areas has resulted in higher accessibility to district-level public facilities by public transportation. In terms of accessibility by car, the closer one is located to Xiamen Island, the better is the accessibility of district-level public facilities. Compared with the public transportation system, private cars can greatly improve the accessibility of public services. Two types of integrated accessibility were calculated. One is for people who do not have a private car. These people can access community-level public services on foot and city-level public services through public transportation; the other is for people who own private cars, who can access community-level public services on foot and city-level public services through private cars. Figure 7 implies that owning a private car can greatly improve the accessibility of public service facilities.

Vertical Equity for Different Social Groups

Litman (2002) divided vertical equity into: 1) "vertical equity with regard to income and social class", that is, "the distribution of impacts between individuals and groups that differ by income or social class"; and 2) "vertical equity with regard to mobility need and ability," namely "the distribution of impacts between individuals and groups that differ in transportation ability and need" (p. 3). To integrate sociodemographic variables and mobility needs and ability into a small number of factors, a factor analysis method can be used, in which the explained variances indicate the relative importance of different factors (Wang & Luo, 2005).

Based on a literature review and existing data (Wang & Luo, 2005), this study considered the following variables—all of which were derived from the 2015 Xiamen household travel survey data—namely, hukou status, education level, homeownership, low-skilled, and car ownership. The analysis was conducted using the principal axis factoring with the Varimax rotation technique. The factor analysis generated 2 factors with eigenvalues greater than 1 (Table 5). The Kaiser–Meyer–Olkin (KMO) value is higher than 0.5, which is acceptable.

Factor 1, which accounts for 45.33% of the total variance, mainly captures three variables: migrants, renters, and households without cars. This factor is mainly related to the non-local population, who are disadvantaged in terms of social welfare, housing, income, etc. As expected, areas with high scores are concentrated in

**Table 5** Rotated factor loadings (pattern matrix) and KMO

	Factor 1: socioeconomic disadvantages	Factor 2: educational disadvantages	KMO
Migrants (%)	0.9508	-0.0529	0.6154
Without high school diploma (%)	-0.0619	0.8533	0.6266
Renters (%)	0.9707	0.0147	0.5416
Household without cars (%)	0.6427	-0.6409	0.6886
Low-skilled groups (%)	0.0548	0.8797	0.6288
% of variance explained	45.33	38.32	
% of variance explained by the 2 factors	54.19	45.81	

urban villages—regarded as the clusters of migrants—in Huli, Haicang, and Jimei districts (Fig. 9a). Factor 2, which accounts for 38.32% of the total variance, mainly captures two variables: without high school diploma and low-skilled groups. Areas with high scores are concentrated in the outer areas of the city, where most of the population is composed of local villagers (Fig. 9b).

As demonstrated in Fig. 10, the accessibility of disadvantaged groups is lower than that of advantaged groups, regardless of whether they live in the inner area or the outer area. In general, people living in the inner area enjoy higher accessibility than those living in the outer area. Owning a vehicle can greatly improve accessibility, and WC-based integrated accessibility is twice that of WP-based integrated accessibility. For the first type of disadvantaged groups, 80% of them do not have a car, therefore having more difficulty in accessing public services than the advantaged groups. The existence of a large number of urban villages within the island allows them to settle within the island, and thus they enjoy higher accessibility than those living in the outer area. However, a large number of urban villages in the inner area are facing demolition, so this group may face displacement and experience
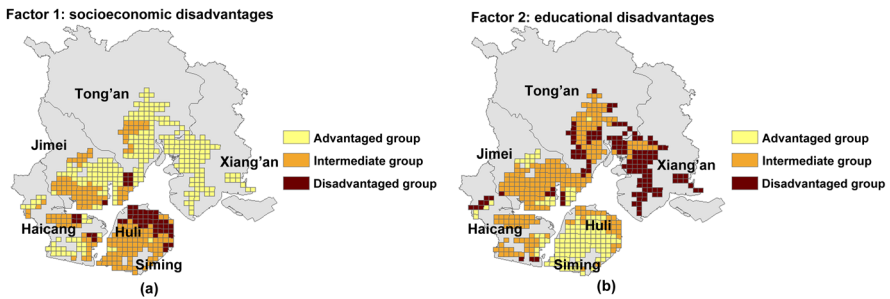
Fig. 9 The scores of (**a**) socioeconomic disadvantages (**b**) educational disadvantages
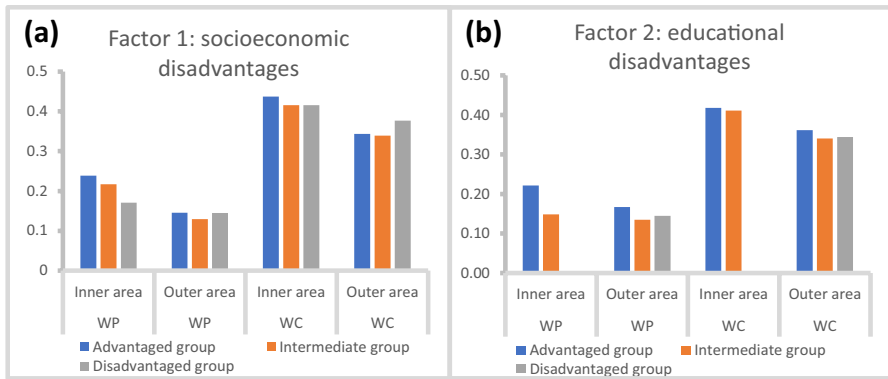
Fig. 10 Vertical equity by (**a**) socioeconomic disadvantages (**b**) educational disadvantages

the greatest injustice in the future. Regarding the second vulnerable group (most of whom are local residents living in the outer area), about 60% of them enjoy high accessibility by car, while only 40% of them have the lowest accessibility. Overall, those disadvantaged groups who live in the outer area without a vehicle have the lowest accessibility. To some extent, this suggests that vertical inequality is worse than horizontal inequality.

Conclusions

The present research contributes to international studies on the relationship between equity and the accessibility of public facilities. Previous studies paid little attention to the accessibility of various public facilities, the effects of different travel modes, and the interaction between different kinds of facilities (Ashik et al., 2020; Fasihi & Parizadi, 2020; Grubesic & Durbin, 2017). This research fills that gap. Taking Xiamen city as a case study, it measured the disintegrated and integrated accessibility of various public facilities by considering different travel modes. Compared with existing studies on integrated accessibility, the present research used smaller spatial units for the measurements in order to produce more accurate results and prevent the indicated MAUP problem. Besides, the research paid attention not only to the threshold travel distance but also to the travel time, which better reflects the differences in the accessibility of public facilities for certain population groups. It incorporated actual travel behavior into predefined thresholds, weights, and travel impedance factors. The thresholds were based on analyzing the cumulative frequency of actual travel time for each purpose, ensuring a 75% coverage rate. The weights were determined by travel frequency for each purpose. Although some previous studies also established integrated measurements of urban public facilities (Taleai et al., 2014; Tsou et al., 2005), basing calculations on data from the travel survey is a step forward, since it is more in accordance with actual travel behavior.

Specifically, the present research explored horizontal and vertical equity by examining the accessibility of community- and district-level public facilities in Xiamen city. Vertical equity was assessed by examining the integrated accessibility in terms

of advantaged, intermediate and, disadvantaged groups. The results show that the degree of vertical inequality is generally higher than that of horizontal inequality, indicating that disadvantaged groups experience a greater level of inequity. In particular, disadvantaged groups living in outer areas without access to vehicles experience the greatest inequities. It is worth noting that many urban villages in the inner areas are facing demolition, and many disadvantaged groups currently living in the inner areas are facing relocation. In order to alleviate the inequity in their access to public service facilities, on the one hand, the supply of a certain proportion of low-rent housing in the inner areas should be guaranteed; on the other hand, the accessibility of public transportation in the outer area with a high concentration of disadvantaged groups should be improved, so as to improve their overall accessibility.

In sum, this research provides new insights into different methods with which to identify specific places where public transportation or public facilities need to be improved based on people's demands. The results of disintegrated accessibility identify the areas without sufficient supply of specific types of public facilities. Measuring the difference between horizontal and vertical inequality can help identify areas where integrated accessibility of public facilities needs to be significantly improved. The identified accessibility provides information that can help planners to determine the appropriateness of existing public transportation facilities to and/or basic public facilities for certain socioeconomic groups in different areas of a city. Based on these insights, policymakers can enhance the equitable distribution of public transportation facilities to and/or basic public facilities at the spatial level and thus promote more equal access to public facilities. However, there are still some limitations of this study. On the one hand, POI data did not cover all data. For those facilities with a small number (such as senior activity centers), the omission of a point might have a big impact on the results. On the other hand, although income is an important factor in identifying disadvantaged groups, we did not consider this factor due to data limitations.

Declarations

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