Spatial Accessibility to Sports Facilities in Dongguan, China: a Multi-Preference Gaussian Two-Step Floating Catchment Area Method

Tong Xiao1,2,3 · Tengfei Ding1 · Xiaoke Zhang1 · Zhuolin Tao4 · Ye Liu1,2,3 *

Received: 12 June 2021 / Accepted: 12 January 2022 / Published online: 10 February 2022 © The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract
Equitable access to sports services has drawn much attention from policymakers and planners in China, as rapid urbanization and lifestyle changes have caused the pandemic of inactivity. An accurate measure of accessibility will enable the spatial equity of public facility allocation. Existing approaches to measure the spatial accessibility of sports facilities tend to ignore the heterogeneity in potential users’ preferences for facilities, thereby causing a bias in the measurement of accessibility. This paper proposes a multi-preference Gaussian two-step floating catchment area (MG2SFCA) method to measure the spatial accessibility of sports facilities, taking into account different travel modes, catchment sizes, and facility preferences among different age groups. Empirically, we adopted the MG2SFCA method in examining the spatial accessibility of sports facilities among children, young working-age population, old working-age population, and elderly population under walking, cycling, and driving modes in Dongguan. The results indicated a significant spatial disparity in the accessibility to sports facilities, with better accessibility in the north and poorer accessibility in the south. Children have the best access to sports facilities, followed by old working-age population, young working-age population, and older population. In the comparison among different transport modes, the accessibility distribution of sports facilities in walking mode showed the greatest spatial variation, while accessibility in driving mode was the most balanced. The MG2SFCA method is superior to the traditional Gaussian 2SFCA method because the former can capture disadvantaged people’s actual needs for sports facilities more accurately than the latter.

Keywords Sports facilities · Equity · Spatial accessibility · Multi-preference Gaussian two-step floating catchment area method · Dongguan

Tengfei Ding and Xiaoke Zhang contributed equally to this work.

* Ye Liu liuye25@mail.sysu.edu.cn

Extended author information available on the last page of the article
Introduction

Emerging evidence suggests that regular physical activity has a beneficial impact on physical and mental health, including increased positive effect, less loneliness, and reduced rates of obesity, diabetes and cardiovascular disease (Bourke et al., 2021; Gyasi et al., 2021; Hunter & Reddy, 2013; White et al., 2017; Zulyniak et al., 2020). With increasing emphasis on health and well-being, the promotion of physical activity has aroused intense attention from the government, the public, and researchers. In this regard, a plethora of studies have reported that the availability and accessibility of sports and recreational services play a prominent role in physical activity attainment (Halonen et al., 2015; Heath et al., 2012; Humpel et al., 2002; Liu et al., 2019). The World Health Organization (2020) recommended at least 600 metabolic equivalent minutes of physical activity each week. However, at present, approximately a quarter of adults and three-quarters of adolescents around the world fail to reach this recommendation, which is partially attributable to poor planning and design of sports and recreational facilities (World Health Organization, 2018). Although the quantity and quality of facilities in most high-income regions have improved significantly over the past few decades, there is still a shortage of facilities in many low-income to middle-income regions. Furthermore, facilities are unequally distributed in most areas, especially in developing countries.

In recent years, China’s sports industry has boomed, with a per capita sports field area of 1.86 m² by the end of 2019, but is still far smaller than that of developed countries (National Bureau of Statistics of China, 2020). Furthermore, this figure varies greatly among the eastern, central, and western parts of China. The 14th Five-Year Plan of China (2021) calls for public health protection to be given priority in the strategic position of development and sets the goal of building China into a leading sports nation, with the focus on ‘one old and one young’. Moreover, the construction of all-age-friendly cities also requires more attention to the needs of children and older population to enhance their sense of happiness and gain. Thus, it is necessary to propose a new approach targeted to examine the spatial accessibility of sports facilities among different groups in China, with particular focus on children and older population. An accurate assessment of accessibility helps to efficiently identify underserved areas and populations, thus further providing evidence-based guidelines for urban planners and policymakers on how to allocate sports facilities reasonably to improve equalisation of public services. A reasonable layout of sports facilities makes accessibility easier, thus increasing enthusiasm for physical activities and subsequently contributing to better physical and mental health.

Uneven geographic distributions of supply and demand lead to varied spatial accessibility to services (Wang & Luo, 2005). Spatial accessibility refers to the ease, potential, or opportunities for interaction between supply and demand points in the transport network, which highlights spatial separation that can act as either a barrier or a facilitator (Hansen, 1959; Morris et al., 1979; Pirie, 1979). Previous studies have proposed several approaches to evaluate accessibility to
public services for different purposes and understandings of the concept. Provider-to-population ratio and distance measures (i.e. the Euclidean/road network/travel time distance to the closet service) are the simplest and most widely used indicators (Neutens, 2015; Pirie, 1979). Nonetheless, the former does not consider the geographical barrier between supply and demand, while the latter ignores the functional diversity and scale differences of services. Therefore, slightly more complex geographic information system (GIS)-based approaches are employed to analyse the relationship between supply and demand from a spatial perspective, which can be summarised as three types of models: resistance models, cumulative opportunity measures, and gravity-type measures (Hansen, 1959; Kwan, 1998; Neutens, 2015). Among these, the two-step floating catchment area (2SFCA) model is relatively straightforward to interpret and easy to implement, and it has become one of the most popular methods for accessibility assessment. As a special case of the gravity-based model, it enables consideration of geographic barriers and interactions between suppliers and demanders, as well as distance decay effects (Luo & Wang, 2003). Moreover, it innovatively employs a dichotomous technique to address distance attenuation from consumers to providers based on a predefined catchment area, irrespective of the constraints of administrative boundaries, thus encompassing cross-boundary availability of services (Dai, 2010; Fransen et al., 2015; Tao & Cheng, 2016; Yang et al., 2006).

Several studies have investigated the spatial accessibility of sports facilities to provide insight into proper allocation and design (Billaudeau et al., 2011; Cereijo et al., 2019; Cutumisu & Spence, 2012; Halonen et al., 2015; Higgs et al., 2015; Karusisi et al., 2013; Martori et al., 2020; Shrestha et al., 2019). However, most researchers have used simple indicators, such as distance to the nearest facility and the number of facilities within a predefined circular buffer around the dwelling or in a specific administrative unit, with only some studies using 2SFCA models. For example, Cutumisu and Spence (2012) adopted an enhanced 2SFCA (E2SFCA) method to evaluate objective accessibility to sports fields at the census block level and further compared the impacts of objectively or subjectively assessed accessibility on physical activity levels among adults in Edmonton, Canada. Similarly, Higgs et al. (2015) applied the same model to examine the inequality of access to sports facilities among regions with different socioeconomic statuses in Wales. Moreover, Langford et al. (2018) created an add-in tool in ArcGIS to facilitate the calculation process of the E2SFCA. Martori et al. (2020) proposed a quintile cross tabulation of the minimum distance to the playground and the E2SFCA to jointly explain the potential spatial accessibility and potential congestion of the playground among different neighbourhoods. Nonetheless, these studies followed the previous methods and did not specifically consider the characteristics of sports facilities in evaluating accessibility (Luo & Qi, 2009). Additionally, these studies have taken census tracts or postal code areas as the minimum unit of accessibility analysis, failing to accurately determine the geographical location of demand points. Moreover, people of different characteristics, such as age, gender, ethnicity, education level and income, tend to have different preferences and levels of participation in physical activities, which affects the choice of sports facilities (Bélanger et al., 2011; Farrell & Shields, 2002). Although some studies compared the variations in access to sports facilities
in regions with different socioeconomic conditions, they did not go into detail at the population level and distinguished the demand population according to demographic characteristics and socioeconomic attributes.

In this study, we aim to propose an improved model, the multi-preference Gaussian two-step floating catchment area (MG2SFCA) method, for a more accurate and rational assessment of spatial access to sports facilities. To this end, we make methodological enhancements in terms of data accuracy, individual preference, catchment area, and travel mode. Specifically, fine-grained age-specific georeferenced population data were used and transformed into 100 m × 100 m gridded data to determine the demand points. This also allowed us to capture individual attributes and group the total population by age; thus, the accessibility for different age groups could be assessed separately. In particular, the preference index for different age groups was collected based on the usage of sports facilities derived from a national sample survey, which was introduced as the weight of service supply. In addition, considering the hierarchical characteristics of sports facilities, we allocated catchment areas of diverse sizes to facilities of different levels in accordance with their service scope. Multiple modes of transport were also incorporated into the accessibility evaluation. The MG2SFCA model is employed to estimate spatial access to sports facilities for four age groups (children, young working-age population, old working-age population, and older population) under three separate travel modes (walking, cycling, and driving) in Dongguan, China. This new approach not only uniquely focuses on the needs of children and older population, but also considers the preference heterogeneity of different groups. Therefore, the application of the MG2SFCA method provides a more realistic and reliable evaluation of spatial access to sports facilities, which is conducive to accurately identifying the unreasonable spatial layout of services. On this basis, evidence-based implications can be provided for the planning and redevelopment of public services to maximise the use efficiency and promote the equity.

Review of 2SFCA Metrics

Radke and Mu (2000) first proposed a spatial decomposition method to quantify spatial accessibility, which was subsequently modified by Luo and Wang (2003) and named as 2SFCA. The 2SFCA calculates the provider-to-population ratio within the catchment centred at a provider’s location, and then aggregates the ratios of all providers within the catchment centred on a population point to evaluate spatial accessibility.

Nonetheless, the traditional 2SFCA method has some deficiencies; thus, a number of improvements have been proposed (Table S1 in the Supplementary Material). First, the application of the dichotomous technique leads to consistent access to services within the catchment area, while services outside the catchment are completely inaccessible (Tao & Cheng, 2016). Accordingly, several distance decay functions and approaches have been proposed to delineate the differences in geographical accessibility within the catchment. For instance, Luo and Qi (2009) presented an E2SFCA that applied different weighting values calculated from the...
Gaussian function to three previously divided discrete travel time zones. However, the E2SFCA assigns equal access within each segment and has no uniform standard for segmenting the catchment. Then, the Gaussian function, the kernel density function, and many other distance decay metrics of the gravity model (e.g. linear, exponential, and inverse power) were employed to continuously capture the distance decay effect of accessibility within a catchment (Dai, 2010; Dai, 2011; Dai & Wang, 2011; Neutens, 2015; Tao & Cheng, 2016). Furthermore, to deal with the uncertainty caused by the selection of the impedance coefficient in a distance decay function, Lin et al. (2018) introduced a spatial access ratio, which was determined by the ratio of the accessibility score of a given place to the average accessibility score of the study area.

Second, it is not reasonable to establish a single catchment area for different facilities on account of their distinctions in category, scale, level, etc. To address this issue, Luo and Whippo (2012) proposed a variable 2SFCA that incrementally increased the catchment area until the minimum population threshold and minimum per capita service threshold were reached. McGrail and Humphreys (2014) implemented a five-level dynamic catchment size in accordance with population density and created smoother transition catchment sizes at remoteness-level boundaries. Additionally, given the assumption that people tend to choose facilities closer to them, Jamtsho et al. (2015) utilised a nearest-neighbour method to set catchment sizes. As different sizes of facilities have different spatial service scopes, larger facilities were designated with larger catchment areas in the multiple catchment sizes 2SFCA (Tao et al., 2014). However, Tao et al. (2020a, 2020b) later modified this view and determined catchment area size according to the hierarchy of services.

Third, considering the diversity of travel modes, Mao and Nekorchuk (2013) suggested a multi-mode 2SFCA method in which the population at each facility location was divided into \( n \) subgroups by transport modes. Then, Langford et al. (2016) assigned a dedicated transport network for each travel mode. In addition, Xing et al. (2018) set different travel modes according to the distance between population and services. Owing to the dynamic nature of human mobility, GPS trajectory data (e.g. mobile phone tracking data and taxi trajectories) have been applied to detect travel behaviour (Chen et al., 2020a; Xia et al., 2019). For example, Wang et al. (2020) incorporated taxi trip records to determine whether there was an actual interaction between population and healthcare facilities. Chen et al. (2020b) divided school trips into two types: Home-School and Home-School-Work, and applied the commuter-based 2SFCA proposed by Fransen et al. (2015) to delineate trip-chaining behaviour captured from mobile phone data.

Some advanced 2SFCA metrics concerning other aspects have also been proposed. To minimise demand overestimation, Ngui and Apparicio (2011) considered actual users as demanders instead of the total population, while Wan et al. (2012) proposed a three-step FCA (3SFCA) model that assigns a spatial impedance-based competition weight to each pair of population and service sites. Since 3SFCA has ignored the influence of supply capacity on selection behaviour, Luo (2014) adopted the Huff model to compute selection probability. Meanwhile, Delamater (2013) developed a modified 2SFCA method that calculated the specific supply ratios for each supply-demand pair to allow suboptimal configurations of services. Subal et al.
(2021) implemented a modified Huff 3SFCA method to consider absolute distance and avoid demand overestimation. Moreover, some studies have investigated the change in accessibility over time from a spatiotemporally dynamic perspective (Hu et al., 2020; Li et al., 2019).

Overall, the existing 2SFCA models have been improved to varying degrees in terms of distance attenuation, catchment area, supply and demand competition, and travel mode. However, these methods have mostly been proposed for healthcare facilities, residential care facilities, and green spaces. Few studies have considered the impact of individual heterogeneity and facility characteristics on the decision-making process, as well as the importance of accurate geocoding of demanders. Considering the above deficiencies, with fine-grained population and facility data, we used age as a basis for population grouping to extract the preference indexes for sports facilities of different groups and compare their accessibility, as well as set variable catchment sizes for different level of sports facilities. Also, various travel modes were considered to measure accessibility under different transport scenarios.

Data and Methods

Study Area

The case study area is Dongguan, located in south-central Guangdong, China, with jurisdiction over four subdistricts and 28 towns (Fig. 1). The city covered

![Fig. 1 Administrative division of Dongguan](image)
a total area of approximately 2460 km² and had a permanent population of more than 8.4645 million (Dongguan Bureau of Statistics and National Bureau of Statistics of China, 2020). As a famous sports city, the per capita sports field area reaches 3.19 m², ranking at the forefront. However, there is still a structural imbalance and low public openness in the construction of sports facilities in Dongguan, and the quality and layout must also be improved. Thus, enabling equitable access to sports facilities has become a pressing issue in Dongguan.

Data

Sports Facilities

In the present study, sports facilities refer to various types of facilities and fields that can be used for carrying out physical exercise, including privately or publicly owned, free or paid, indoor or outdoor sports facilities. Golf courses and other sports venues catering only to a very small number of users were not included. The exhaustive list of facilities obtained from the Dongguan Planning Bureau has provided information on the name, type, address, grade, and site area of the facilities. The final service dataset included 4048 facilities with complete attributes and coordinates, which were divided into three levels: municipal (48), town (210), and primary (3790) (Fig. 2).

Fig. 2 Spatial distribution of sports facilities. Notes: The final dataset included 1582 basketball courts, 272 fitness paths, 92 swimming pools, 77 fitness rooms, 18 track and field grounds, 44 badminton courts, 30 football fields, 142 other independent sports facilities, and 1791 comprehensive sports facilities.
Actual Population

Unlike previous studies that used census data (Bell et al., 2013), we used population data aggregated from individuals with georeferenced residential addresses. The population data were derived from the basic information database of ‘One standard and Three actualities’ collected by the Dongguan Public Security Bureau in 2018. ‘One standard’ refers to the standard address database, and ‘Three actualities’ refers to the real population (including registered, transient, and overseas population), real houses and real units. The total population (9,360,063) was classified into four age groups: children aged 0–14 years (454,184), young working-age population aged 15–44 years (6,851,663), old working-age population aged 45–59 years (1,623,887), and older population aged ≥60 years (430,329) (Fig. S1 in the Supplementary Material). To facilitate the analysis, a grid operation was carried out on the base map of the Dongguan administrative division, with 248,141 grid cells of 100 m × 100 m size in total. Assuming an even distribution of the population in each grid cell, the cells with population number attributes were converted into points as demand sites. After excluding pseudo-demand sites without any population, 66,071 demand sites were included in the analysis.

Road Network

The road network included all urban roads, excluding highways and tracks. Each road and street contained information on name, length, road level, and speed class. In reference to the Code for transport planning on urban road (GB 50220–95) and the actual traffic condition in Dongguan, the driving speed was set as follows: 60 km/h for expressway, 40 km/h for arterial road, 30 km/h for secondary trunk road, 20 km/h for branch road, and 10 km/h for other roads. The riding speed and walking speed of all roads were set at 250 m/min and 80 m/min, respectively.

Methods

Because sports facilities are a type of non-emergency leisure and entertainment services, and their functional differences do not have a significant impact on decision-making, the Gaussian function is more suitable in delineating the variation trend of distance attenuation in supply-demand interactions. The Gaussian 2SFCA method is implemented in two steps. The first step is to search all demand points (k) within the catchment \( d_0 \) centring on each supply point \( j \). The demand population is weighted by the Gaussian function \( G \), and then added as potential users to calculate the supply-to-demand ratio \( R_j \). The second step is to search all services \( l \) within the catchment \( d_0 \) centring on each population point \( i \) and add all supply-to-demand ratios \( R_l \) weighted by the Gaussian function \( G \). The formula is set as follows:

$$ A_i = \sum_{l \in \{ d_{ij} \leq d_0 \}} R_l G(d_{ij}, d_0) = \sum_{l \in \{ d_{ij} \leq d_0 \}} \frac{S_l G(d_{ij}, d_0)}{\sum_{k \in \{ d_{ij} \leq d_0 \}} P_k G(d_{kj}, d_0)} $$

(1)
where $P_k$ is the population falling within the catchment ($d_{kj} \leq d_0$), $S_j$ is the supply capacity at location $j$, $d_{kj}/d_{il}$ is the travel time between $k/i$ and $j/l$, and $A_i$ is the accessibility for population point $i$.

An MG2SFCA model based on the Gaussian 2SFCA with optimisation in catchment size, transport mode, and preference heterogeneity among different groups was proposed to evaluate the spatial accessibility of sports facilities in Dongguan. Specifically, different levels of sports facilities were assigned to catchments of distinct sizes, which were quantified by the amount of travel time (average in minutes) taken from population to service. According to the Standard for urban public Service facilities planning (GB50442), the travel time thresholds for municipal, township, and primary sports facilities were set at 30 min, 20 min, and 10 min, respectively. Considering the diversity of transport modes (Li et al., 2021), the spatial accessibility in walking mode, cycling mode and driving mode was measured separately.

Additionally, considering that age is a major determinant of the time spent on specific types of physical activity and behaviour related to using sports services (Bélanger et al., 2011), a weighting factor of facility supply based on the preference index of different age groups was incorporated into the modified model. Operationally, we divided the population into four age groups: children (0–14 years old), young working-age population (15–44 years old), old working-age population (45–59 years old), and older population (≥60 years old). We then computed statistics on the preference of each age group for various types of sports facilities based on the 2015 China Health and Nutrition Survey (CHNS 2015). The CHNS is a nationally representative longitudinal study that began in 1989, covering the eastern, central, and western parts of China, and was designed to investigate a series of economic, sociological, demographic, and health questions (Popkin et al., 2010). The preference index of an age group for a certain sports facility was quantified as the proportion of people in that age group who engaged in a particular physical activity (Table S2 in the Supplementary Material).

Overall, we measured the spatial accessibility to sports facilities for each of the four age groups under each of the three transport modes, thereby performing twelve rounds of accessibility analysis with the same model. Taking the children in driving mode (riding their parents’ or other adults’ cars) as an example, the MG2SFCA is implemented in the following two steps:

Step 1: For each service $j$ of Type $n$ ($n$ ranges from 1 to 7, as shown in Table S2 in the Supplementary Material), search all demand sites ($k$) within the corresponding catchment area ($d_{kj} \leq d_0$; $d_0$: 30 min for municipal level, 20 min for town level, and 10 min for primary level), and add up the population aged 0–14 years as potential users of service $j$. Then, the supply-to-demand ratio ($R_{Aj}$) at service site $j$ was calculated:
where \( P_{Ak}, P_{Bk}, P_{Ck} \) and \( P_{Dk} \) are the total number of children, young working-age population, old working-age population, and older population falling within the catchment \( (d_{kj} \leq d_0) \) of service \( j \), respectively; \( d_{kj} \) is the travel time from demand site \( k \) to service site \( j \); \( U_{An}/U_{Bn}/U_{Cn}/U_{Dn} \) refers to the preference index of children/young working-age population/old working-age population/older population for sports facilities of Type \( n \) (Table S2 in the Supplementary Material); \( W_{Aj} \) is the weight that represents the expected supply for the children group at service site \( j \) (Type \( n \)); \( W_{Aj} + W_{Bj} + W_{Cj} + W_{Dj} = 1 \); \( S_j \) is the capacity of service \( j \), which is quantified as site area \( (m^2) \); and \( G(d_{kj}, d_0) \) is the friction-of-distance between \( j \) and \( k \).

Step 2: For each demand point \( (i) \), search all services \((l)\) within the corresponding catchment area \( (d_{il} \leq d_0) \) and add up the supply-to-demand ratio \( (R_{Al}) \). Then, the total accessibility \( A_{Ai} \) for demand point \( i \) was obtained:

\[
A_{Ai} = \sum_{l \in \{d_{il} \leq d_0\}} G(d_{il}, d_0) R_{Al}
\]

where \( R_{Al} \) is the supply-to-demand ratio at service site \( l \) falling within the catchment of demand site \( i \) \( (d_{il} \leq d_0) \). The unit of \( A_{Ai} \) is per capita area (square metres per person). The 13th Five-Year Plan (2016) has set a target of 1.8 \( m^2 \) per capita by 2020. According to the People’s Government of Guangdong Province (2020), the per capita sports area should reach 2.6 \( m^2 \) by 2025 and 2.9 \( m^2 \) by 2035, while the Dongguan Municipal People’s Government (2020) requires that the city’s per capita sports area should reach 3.2 \( m^2 \) by 2025. Therefore, we define all target values as the break values of the accessibility interval.

Results

Separate Accessibility for Four Age Groups under Three Transport Modes

The spatial accessibility of different age groups under walking, cycling, and driving modes is shown in Fig. 3 and Table 1. There is a substantial spatial variation in the overall accessibility scores under the walking mode. For children, relatively low accessibility scores are distributed in the central (Dongcheng and Chashan), southeast (Tangxia and Fenggang), and southwest (Humen and Chang’an) areas. For young working-age population, the high scores are scattered, while the low scores are widespread in the middle (Dongcheng, Chashan, and Liaobu) and south
The spatial distribution of sports facilities accessibility for the old working-age population is basically the same as that for the young working-age population. For older population, the accessibility scores in most areas are low, except for a few northern areas (Qishi, Daojiao, and Wangniudun). With increase in age, the number of areas with high accessibility are decreased. Only 33.20% of the areas are underserved for children (<1.8 m² per capita), while the proportion of underserved areas for young working-age population, old working-age population, and older population is approximately twice (64.66%), twice (66.42%) and three times (84.83%) that of children, respectively. Moreover, the variances show that the spatial accessibility gap narrows as age increases.

In the cycling mode, the overall score of accessibility was slightly higher than that in the walking mode. For children, high accessibility scores cover almost the entire city, with 82.31% of the grids with scores ≥3.2 m² per capita. For young working-age population and old working-age population, high scores agglomerate in the north areas (Zhongtang, Wangniudun, Gaobu, Daojiao, Qishi, Qiaotou, and Wanjiang), while low scores are in the south areas (Humen, Chang’an, Tangxia, Houjie, Qingxi, and Fenggang). Most areas scored low on accessibility for older population, with high scores in a few areas (Qishi, Shatian, Wangniudun, Daojiao, and Wanjiang). The differentiation degree in spatial accessibility was the highest in the children group and lowest in the young working-age population group. Notably, the accessibility in the downtown and nearby areas is high for the young working-age population group and the old working-age population group but low for the older population group, which can be partly attributed to

Fig. 3 Spatial accessibility of sports facilities for four age groups
### Table 1  The statistical characteristics of spatial accessibility to sports facilities

| MG2SFCA score | Walking mode | Cycling mode | Driving mode |
|---------------|--------------|--------------|--------------|
|               | 0–14 | 15–44 | 45–59 | ≥60 | 0–14 | 15–44 | 45–59 | ≥60 | 0–14 | 15–44 | 45–59 | ≥60 |
| Mean value    | 8.71  | 2.48  | 2.69  | 1.30 | 7.30  | 2.10  | 2.35  | 1.15 | 6.84  | 1.94  | 2.17  | 1.03 |
| Median value  | 3.62  | 1.06  | 0.71  | 0.27 | 6.44  | 1.79  | 1.90  | 0.76 | 6.68  | 1.87  | 1.97  | 0.90 |
| Maximum value | 489.52 | 163.49 | 239.20 | 257.30 | 449.20 | 122.67 | 169.39 | 181.82 | 79.54 | 21.62 | 17.37 | 18.09 |
| Variance      | 361.40 | 28.82  | 47.59  | 21.36 | 28.09 | 3.97  | 7.71  | 6.93 | 7.18  | 0.73  | 1.43  | 1.00 |
| 0.00–1.80 (Proportion) | 33.20% | 64.66% | 66.42% | 84.83% | 4.66% | 50.46% | 46.98% | 87.69% | 1.20% | 46.11% | 40.36% | 93.85% |
| 1.81–2.60 (Proportion) | 8.23%  | 9.77%  | 8.15%  | 4.94% | 6.38% | 24.16% | 20.85% | 5.15% | 2.24% | 39.44% | 34.18% | 3.82% |
| 2.61–2.90 (Proportion) | 2.70%  | 2.59%  | 2.27%  | 1.06% | 3.18% | 5.46%  | 6.39%  | 0.96% | 1.40% | 5.59%  | 8.82%  | 0.30% |
| 2.91–3.20 (Proportion) | 2.52%  | 2.33%  | 1.94%  | 0.98% | 3.48% | 3.79%  | 4.86%  | 0.72% | 2.09% | 3.11%  | 6.04%  | 0.37% |
| 3.21–7.00 (Proportion) | 20.79% | 13.53% | 12.05% | 4.70% | 37.59% | 15.29% | 18.31% | 4.51% | 47.90% | 5.46%  | 9.97%  | 1.25% |
| >7.00 (Proportion)    | 32.56% | 7.12%  | 9.17%  | 3.48% | 44.72% | 0.85%  | 2.61%  | 0.97% | 45.18% | 0.29%  | 0.63%  | 0.41% |
more older population and relatively fewer young working-age population and old working-age population in these areas.

The spatial distribution of accessibility under the driving mode shares some features with those of the previous two modes. For children, the range of high-value areas is further expanded, but very few areas in the southwest still have low scores. For young working-age population and old working-age population, accessibility scores in the north are generally higher than those in the south. For older population, accessibility scores are mostly low except in the northeast of Dongguan (Qishi and Xiegang); the accessibility value in 93.85% of the area is <1.8 m² per capita, compared with only 1.20% for children, 46.11% for young working-age population, and 40.36% for old working-age population. In the driving mode, all age groups have more equalised values of spatial accessibility, with variances of 7.18 (children), 0.73 (young working-age population), 1.43 (old working-age population), and 1.00 (older population).

**Combined Accessibility of Four Age Groups under Three Transport Modes**

Defining the standard as 1.8 m² per capita, the accessibilities for four age groups measured by MG2SFCA are classified as sufficient (≥1.8) or insufficient (<1.8) (Fig. 4). Areas with adequate accessibility are mainly distributed in the north, which can be attributed to the supply of facilities adapted to residents’ needs and well-developed transport networks. Regardless of the transport mode used, the accessibilities in the southwest and southeast are at a relative disadvantage. The reasons for underservice varied in these areas. Although the southwest regions have a large number of sports facilities, they received lower accessibility scores due to the large population. Conversely, the southeast regions with a smaller population but fewer sports facilities also scored lower in accessibility.

![Fig. 4 Combined spatial accessibility of sports facilities. Notes: ‘a’, ‘b’, ‘c’, ‘d’ represent insufficient accessibility of children, young working-age population, old working-age population, and older population, respectively. For example, ‘ab’ indicates insufficient accessibility in both children group and young working-age population group](image)
Comparison of Accessibility Results between Gaussian 2SFCA and MG2SFCA

The accessibility results for total population measured using Gaussian 2SFCA and MG2SFCA were compared (Fig. 5, Table 2). Regardless of the method used, as the travel speed increases, spatial distribution of high-accessibility areas becomes even. The average accessibility values under the three transport modes all reach the 2020 target of *The 13th Five-Year Plan* (1.8 m² per capita), while only under the walking mode exceeds the 2025 target of Guangdong Province (2.6 m² per capita). From the point of view of the median, the median accessibility scores in cycling and driving modes measured by the two models are greater than 1.8 m² per capita. Nonetheless, there are subtle differences between the results of the two methods. In areas with high accessibility, the overall accessibility calculated by MG2SFCA is much higher than that calculated by Gaussian 2SFCA, whereas in areas with low accessibility, the overall accessibility calculated by MG2SFCA is generally lower than that calculated by Gaussian 2SFCA. This indicates that the preferences of different age groups for sports facilities do exert an impact on the evaluation of spatial accessibility to some extent. The facility preference indexes are calculated based on the usage of different types of sports facilities by different age groups. The MG2SFCA model incorporating facility preferences enables policymakers and urban planners to more accurately assess which types of facilities actually serve which age groups and

![Spatial accessibility measured by MG2SFCA and Gaussian 2SFCA. Notes: ‘Difference’ represents the accessibility score calculated by MG2SFCA minus the accessibility score calculated by Gaussian 2SFCA.](image)
Table 2 The statistical characteristics of accessibility measured by MG2SFCA and Gaussian 2SFCA

| Accessibility score | MG2SFCA | Gaussian 2SFCA |
|---------------------|---------|----------------|
|                     | Walking mode | Cycling mode | Driving mode | Walking mode | Cycling mode | Driving mode |
| Mean value          | 2.85    | 2.42          | 2.23         | 2.84         | 2.40          | 2.21         |
| Median value        | 1.10    | 1.98          | 2.05         | 1.13         | 2.03          | 2.10         |
| Maximum value       | 274.82  | 131.31        | 19.46        | 185.79       | 126.02        | 19.33        |
| Variance            | 44.29   | 5.76          | 1.33         | 40.69        | 5.26          | 1.05         |
| 0.00–1.80 (Proportion) | 62.56% | 44.17%        | 38.18%       | 61.66%       | 42.65%        | 35.48%       |
| 1.81–2.60 (Proportion) | 9.27%  | 22.19%        | 35.05%       | 9.78%        | 23.61%        | 37.71%       |
| 2.61–2.90 (Proportion) | 2.63%  | 6.06%         | 7.68%        | 2.70%        | 6.81%         | 9.73%        |
| 2.91–3.20 (Proportion) | 2.23%  | 4.93%         | 5.36%        | 2.29%        | 5.59%         | 6.08%        |
| 3.21–7.00 (Proportion) | 14.29% | 20.51%        | 13.12%       | 14.68%       | 19.81%        | 10.63%       |
| >7.00 (Proportion)  | 9.02%   | 2.13%         | 0.61%        | 8.90%        | 1.53%         | 0.38%        |
more reasonably design the capacity of these sports facilities. Not considering sports preferences underestimates the inequality of accessibility and thus mismatches the real situation.

**Discussion and Conclusion**

**Main Findings**

This paper has suggested an improved model, namely the MG2SFCA method, based on the traditional 2SFCA for determining spatial accessibility. The proposed method not only considers three transport modes separately, but also classifies the total population by age and incorporates the weighting value of each age group’s preference for different types of sports facilities. We have applied the MG2SFCA method to estimate spatial patterns of accessibility to sports facilities among four age groups under multiple transport modes in Dongguan. Generally, the evaluation results show significant disparities in spatial accessibility to sports facilities among different age groups, transport modes, and regions. Specifically, the MG2SFCA score in the north was generally higher than that in the south. Compared with cycling and driving modes, the spatial accessibility in the walking mode presents a more striking distinction, which is partially attributable to the restrictions in travel range. Regardless of the travel mode used, children had the highest accessibility score, followed by old working-age population, then young working-age population, and finally, older population. Nonetheless, the spatial differentiation of accessibility in the children group was the most prominent, indicating that the supply of sports services suitable for children in Dongguan is adequate but relatively inequitable.

Methodologically, our results confirm that the application of different methods for accessibility measurement can influence the results (Apparicio et al., 2017). In this case, the MG2SFCA method offers an insight into how preferences of different age groups might affect the real accessibility of sports facilities. When the Gaussian 2SFCA is applied, the spatial inequality of accessibility is weakened by the ignorance of preferences, which deviates from the actual situation due to inclusion of facilities not commonly used by a specific population in the analysis.

**Strengths and Limitations**

Compared with the Gaussian 2SFCA metric, the proposed method has several strengths. The use of individual-based population data not only allowed us to incorporate age, an important factor affecting service choice, into accessibility analysis, but also provided more accurate information on the number and geographic location of demanders, thereby delineating a more realistic spatial accessibility. One of the most obvious strengths is that, rather than assuming that facilities can serve all people within a catchment, we identified which facilities might serve which groups of people with the introduction of preference index, which is calculated based on the use of each facility derived from a large national sampling survey. Then, the
preference heterogeneity index is converted into a weight of service delivery in combination with the number of people, thus giving an idea of what percentage of the facility is likely to be used by a certain age group. Besides, the MG2SFCA allocates variable travel time thresholds for different levels of sports facilities. Moreover, the introduction of multiple travel modes reaffirmed a previous finding that a larger travel time threshold leads to more balanced spatial accessibility (Luo & Wang, 2003).

However, several limitations should be noted. First, the MG2SFCA method only reflects the spatial accessibility discrepancies among different age groups, ignoring other non-spatial factors, such as personal interests, household income, car ownership, and other demographic profiles and socioeconomic characteristics that exert a stronger influence on facility selection. In addition to spatial accessibility, information access, economic access, socio-cultural access, and social-managerial environment should also be considered to reveal both horizontal equity (for all populations) and vertical equity (for different social groups) (Cheng et al., 2012; He et al., 2020). From a service point of view, the capacity, quality, supporting activities, availability, affordability, ancillary facilities (e.g. locker rooms, shower rooms, and parking lots), and other characteristics of services significantly influence people’s perceptions of specific facilities. Second, we used running speeds based on the road grade instead of actual commuting speeds. In addition, we only considered three independent travel modes, not considering travelling by public transit or a combination of multiple transport modes. Third, the thresholds for different levels of sports facilities are ideal values set according to service scopes, rather than the coverage that facilities can actually provide and the travel time that people are willing to spend. Fourth, we did not distinguish between fee-paying and free services, nor between public and private services. Finally, due to the lack of population data and facility data of nearby cities, we were not able to take into account the edge effect (for example, sports facilities located in nearby cities may also provide services to the residents of Dongguan, and residents of nearby cities may use sport facilities located in Dongguan). Neglecting this effect would overestimate or underestimate the supply-to-demand ratio of population points.

Policy Suggestions

The MG2SFCA method allows a more accurate and realistic spatial accessibility assessment, making it possible to distinguish sufficiently served and underserved areas, thus contributing to rational allocation and utilisation of public resources and a significant minimisation of resource waste and inequity. To improve spatial accessibility, the priority is to strengthen the development of sporting infrastructure. In this regard, the densely populated southwest region in Dongguan should appropriately increase the number of comprehensive venues to improve efficiency of land use, while the sparsely populated southeast region should lay out more and varied sports facilities near the residential neighbourhood. It is also important to reinforce facility maintenance, improve the venue environment, and provide ideal supporting facilities to increase their attractiveness. Meanwhile, the types of facilities should be adjusted according to regional
population attributes related to sporting preferences. In addition, the performance of transport networks is so crucial that urban planners should pay more attention to transport planning and road network design to improve geographical accessibility. Among them, the configuration of sidewalks and cycle paths suitable for short-distance travel and public transport suitable for long-distance travel are particularly critical. Furthermore, it is suggested that the public be encouraged to participate in the planning and construction of sports infrastructure to better meet their actual needs.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s12061-022-09436-4.

**Authors’ Contributions** TX and YL developed the research idea and completed the study design. TX conducted basic processing on the real population data. TD and XZ conducted basic processing on the data of sports facilities. TX, TD and XZ carried out the statistical analysis and wrote the manuscript. TX, YL and ZT revised the manuscript. All authors read and approved the final manuscript.

**Funding** This work was supported by the National Natural Science Foundation of China (No. 41871140 and No. 41971194) and the Fundamental Research Funds for the Central Universities (No. 20lgzd10).

**Data Availability** Not applicable.

**Code Availability (Software Application or Custom Code)** Not applicable.

**Declarations**

**Ethics Approval** Not applicable.

**Consent to Participate** Not applicable.

**Consent for Publication** Not applicable.

**Conflicts of Interest/Competing Interests** The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Tong Xiao¹,²,³ • Tengfei Ding¹ • Xiaoke Zhang¹ • Zhuolin Tao⁴ • Ye Liu¹,²,³

Tong Xiao
xiaot9@mail2.sysu.edu.cn

Tengfei Ding
dingtf@mail2.sysu.edu.cn

Xiaoke Zhang
zhangxk9@mail2.sysu.edu.cn

Zhuolin Tao
taozhuolin@bnu.edu.cn

¹ School of Geography and Planning, Sun Yat-Sen University, Xingang Xi Road, Guangzhou 510275, China

² Guangdong Key Laboratory for Urbanization and Geo-simulation, Sun Yat-Sen University, Xingang Xi Road, Guangzhou 510275, China

³ Guangdong Provincial Engineering Research Center for Public Security and Disaster, Guangzhou 510275, China

⁴ Faculty of Geographical Science, Beijing Normal University, No.19, XinJieKouWai St., Haidian District, Beijing 100875, China