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Delineating Walking Catchment of the Existing and Proposed Public Sports Facilities with Open-Source Data: A Case Study of Nanjing

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Abstract
Public sports facilities, featuring exercise equipment and athletic facilities as well as professional support services, serve as a critical exercising and active living hub for citizens. Regarded as a component of public welfare, their distribution usually plays an integral role in urban planning for healthy and active cities. Ensuring that these facilities are located within a reasonable walking distance is crucial for encouraging people to visit them; hence, planners must consider walking distance when evaluating the rationale for these facilities' existing and proposed distribution. Using Nanjing, China as a case study, we employed the Baidu Maps online mapping service to implement a city-scale catchment delineation of public sports facilities. We scraped the shortest walking routes between residents' homes and the public sports facilities to delineate the walking catchments, then combined population data to explore the potential gaps between demands and needs. The results revealed significant differences in service areas and potential service capabilities across the sports facilities, demonstrating spatial inequity of sports resources and an insufficient number of public sports facilities in the study area. The walking accessibility of facilities in the peripheral areas was inferior to that of facilities in the central areas, which were expected to be overloaded with a citizen population. If implemented, the proposed plan would remediate this inequity to some extent, but considerable areas outside of 15-min catchments would persist in the study area. These findings highlight the spatial inequity of sports facilities within the city, in both the existing and proposed situation, implying disparities in physical activity opportunities among citizens. Such a straightforward estimation, reinforced with a big data approach, will prove useful for planners and policymakers, although it remains rarely adopted in China for supporting active city planning, and it will be transferable to other cities as a means of rapid assessment.

Keywords Public sports facilities · Open-source data · Accessibility · Walking catchment · GIS

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Introduction

An increasing proportion of people have adopted a sedentary lifestyle and are spending less time engaged in physical activity (PA) due to their occupation, modern lifestyle, and urbanization (Miao & Wu, 2016; Ng & Popkin, 2012). Physical inactivity has been identified as one of the world's greatest public health problems of the 21st century, which could increase the rate of chronic diseases. The *WHO Guidelines on Physical Activity and Sedentary Behavior* (2020) issued by the World Health Organization (WHO) recommend that all adults, including those with chronic diseases, engage in at least 150–300 min of moderate-intensity aerobic physical activity each week. However, a quarter of adults and four-fifths of adolescents around the world fail to reach this recommended level of activity at present (WHO, 2020). The need for improved physical activity and health has generated concern from many fields, such as public health, sports, and urban planning. Research has shown that an appropriate level of physical activity has a positive effect on individuals' physical and mental health in multiple ways, including reducing the rate of obesity, helping prevent noncommunicable chronic diseases, and relieving psychological pressure (Keats et al., 2020; Marques et al., 2018, 2019).

Some researchers have categorized the determinants of physical activity as three factors: individual factors, environmental factors, and national policy factors (Panter et al., 2008). A previous study showed that the built environment can influence a population's level of physical activity (Karmeniemi et al., 2018), which was positively associated with physical environmental determinants including availability (Hallmann et al., 2012; Sreeramareddy et al., 2012), accessibility (Roemmich et al., 2006; Witten et al., 2008), and the suitability and attractiveness (Ball et al., 2001; Borena et al., 2020; Sugiyama et al., 2010) of a destination. In addition, whether residents perceive the presence of sports facilities near their neighborhood will also affect the use of these facilities. The availability and accessibility of parks, fitness trails, and gymnasiums in the built environment is particularly important in encouraging people to engage in physical activities. Public sports facilities, featuring professional and exercise facilities as well as professional training support, serve as a critical hub wherein citizens can meet their physical activity needs (Cereijo et al., 2019; Limstrand, 2008). Studies have established a relationship between proximity to sports facilities and rates of engagement in physical activity, which may be affected by the actual travel times and distances to the facilities (Higgs et al., 2015). Short travel times can reduce the inconvenience of travel, thereby increasing people's willingness to engage in physical activity (Giles-Corti & Donovan, 2002; MacDonald, 2019). Meanwhile, research has demonstrated that people find a 15-min walk acceptable for their daily non-commuting travel (Sun & Chai, 2017), and 1,000 m (a 15-min walking catchment) from one's home to a sports facility is the distance with the highest correlation to moderately vigorous physical activity (MVPA; Cereijo et al., 2019). Thus, ensuring that such facilities are located at a reasonable walking distance from residents' homes is necessary to encourage people to engage in physical activity, and the distance of 1,000 m can be used to roughly estimate the supply efficiency of the facility. Furthermore, as public sports facilities are regarded as a component of public welfare, their distribution plays an integral role in urban planning for healthy and active cities.

In recent years, China's sports industry has boomed, reaching a per capita sports field area of 2.41 m^2 by the end of 2021 (National Bureau of Statistics of China, 2022). However, it remains far smaller than that of developed countries. The 14th Five-Year Plan of China (2021) set the goal of developing China into a leading sports nation and called for improving the public service system to increase national fitness. Although the quantity and quality of facilities in most high-income regions have improved significantly over the past few decades, there remains a shortage of facilities and an imbalance between the demand and supply of resources in many low-income to middle-income regions and suburbs (Xiao et al., 2022). Similarly, being one of the most rapidly growing cities in China, Nanjing also faces the problem of inequitable spatial distribution and insufficient numbers of sports resources. An assessment of the spatial distributions of sports resources and population contributes to exploring potential demands and needs gaps, providing guidelines for urban planners and policymakers on how to allocate public sports resources in reasonable ways. Therefore, an accurate measurement of a facility's accessibility is essential to accomplishing this goal.

The spatial equity of public service facilities has become an important research topic in the field of urban planning. Since Hansen (1959) first proposed the concept of accessibility, it has become a crucial indicator by which to evaluate the equitable establishment of facilities. Some studies have shown that many factors influence accessibility, including distance from residences to facilities, road conditions, and traffic modes. Studies have also proposed several tools for measuring accessibility and walking catchment within urban settings. Many researchers have used the Euclidean distance buffer method of defining a park's service area (radius), which some planning and research approaches still utilize, even though non-straight-line travel will be ignored by researchers in most cases (Carr et al., 2011). However, other researchers have employed a more precise method than the Euclidean distance buffer. By connecting the discrete endpoints of routes that can be reached within a certain distance, an irregular polygon can be created as the pedestrian catchment area (Frank et al., 2005). However, some areas within the polygon may actually remain inaccessible, due to factors such as distance, barriers to private land, and water bodies. Oliver et al. (2007) proposed a route network buffer-based approach, which assumed that most walks occur on public sidewalks and only the center-line area of the routes is accessible. However, this method, based on GIS network analysis, has proven quite expensive in terms of acquiring the available spatial data. Online maps offering open-source data on factors such as travel time or travel distance have provided opportunities to acquire route networks and can be combined with GIS data to provide more precise measurements for obtaining spatial information.

Traditional tools in the urban planning field lack new urban data measurement methods. Scraping, a method of automatically collecting data from internet users, proved more useful in our research. In this study, we used Python to scrape the walking routes based on the Baidu Map online mapping service,

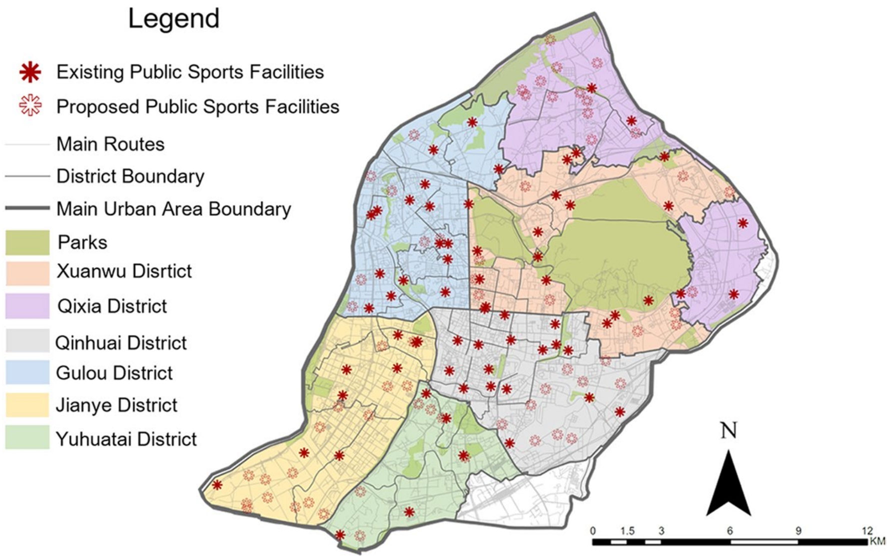

Fig. 1 Distribution of public sports facilities in Nanjing

aiming to provide a quantitative description of the walking routes. We delineated the walking catchment, then combined population data to explore the potential gaps in demands and needs to create a more accurate and rational assessment of the accessibility of public sports facilities. The findings of this study will help urban planners to allocate public sports facilities appropriately, thereby fostering an active city in an efficient and equitable manner.

Methodology

Study Area

The sports industry in Jiangsu Province, China has enormous potential for expansion. Nanjing, as the capital city of Jiangsu Province, has a per capita sports field area of 3.21 m^2. Nanjing ranked 10th worldwide (2nd in China) in the annual rankings of cities with global sports influence released by British sports market intelligence (Zhu, 2018). Further, it was the birthplace of modern sports in China and hosted the Youth Olympic Games in 2014. The distribution of sports facilities in Nanjing is shown in Fig. 1.

The study area covers the main urban area of Nanjing, including six districts: Gulou, Xuanwu, Qinhuai, and Jianye, as well as parts of Qixia and Yuhuatai (Fig. 1). This area encompasses a total of 44 sub-districts (*jie-dao*), an area of 308.52 km^2, and a population of around 3.66 million.

Research Objective

Public sports facilities refer to sports gymnasiums, equipment, and supporting service facilities built with investment by the government. Such facilities are open to the public to meet the needs of the masses for physical exercise, provide a place to watch and participate in sports competitions, and allow for the training of amateur athletes. The disposition system of public sports facilities in Nanjing spans the following levels: city (province) level, sub-city level, district level, community level, and grassroots community level. According to *The Special Plan for Public Sports Facilities in Nanjing* (2019), there are 68 existing public sports facilities in Nanjing, and 130 are proposed to be constructed by 2035 in the study area.

Data Sources

The shortest routes to a sports facility determined by this study were based on the recommended routes on the Baidu Map Application Programming Interface (API), which includes information about route distance, duration, starting and ending points, turns, and steps. The shortest walking routes were generated and combined with population data to analyze the relationship between the spatial distribution of facilities and the distribution of the resident population. This study also relied on data from *The Special Plan for Public Sports Facilities in Nanjing* (2019) as well as population density data for Nanjing (100 × 100 m precision raster data from 2010).

Methods and Indices

Based on this public sports facility data, we used a particular set of indicators to evaluate the potential service capacities of the public sports facilities. The analysis procedure and relevant indices were as follows (Fig. 2):

First, we identified the number of public sports facilities within the main urban area, according to *The Special Plan for Public Sports Facilities in Nanjing* (2019). Then, we used the Baidu Coordinate Picker to obtain the position of the entrances of each public sports facility.

Second, we used Python 3.8 to scrape the recommended routes (the shortest routes) from the points of interest (POIs) of residential buildings to the entrances of public sports facilities within a 25 km^2 area. We used ArcGIS10.6 to filter the routes from the residential building POIs (origins) to the entrances of the facilities (destinations) within 1,000 m from all recommended routes, which represented the true spatial distance between the origin and the destination when compared with the Euclidean distance.

Third, we used a line-based network buffer of 50 m on each side of the shortest routes within 1,000 m to delineate the service area of all public sports facilities in the study area. Meanwhile, we used the Euclidean distance method to calculate the

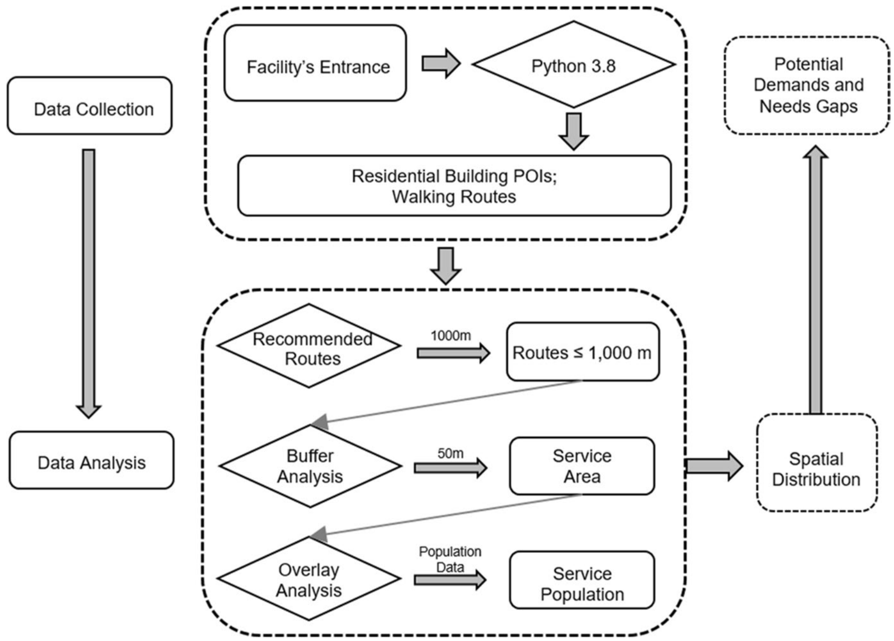

Fig. 2 Research framework

service area with a 1,000 m circular buffer and compared the difference in service capacities between the two methods at the city level.

Fourth, we combined population data to calculate the service population. Finally, we analyzed the spatial distribution and comprehensive service capacities (service POIs, service areas, and service populations) of existing and proposed facilities. Table 1 explains the relevant indices that were used.

Results

The Spatial Distribution and Service Capacity of Public Sports Facilities at the City Level

The results of our analysis revealed spatial inequality of sports resources within the 1,000 m walking catchment and significant differences in potential service capability across public sports facilities (Fig. 3). The accessibility of public sports facilities in the peripheral areas is inferior to that of facilities in the central areas. The facilities are mainly distributed around Xinjiekou (the CBD of Nanjing), which is known as "the first business district in China," and the configuration of public infrastructure is relatively completed there, indicating that these facilities in the central areas can service the residents in these areas well. Notably, a small-scale point-like agglomeration exists in the CBD of Hexi, but no obvious core structure can be found there at present, and its concentration and service capacity require further improvement. More

Table 1 Indices relevant to the walking routes to the public sports facilities

Index	Definition	Comments
Euclidean Distance	The Euclidean distance refers to the straight-line distance from the entrances to the POIs	Some planning and research approaches still utilize this method
Route Distance	The actual route distance is the length of the pedestrian road network from the facility's entrances to the residential building POIs	Describes the distance of walking routes based on Baidu Map. These routes were derived from the travel navigation function of Baidu Maps, and the routes were the shortest routes in the walking algorithm of the Baidu Map API
Service POIs	This represents the number of residential building POIs within the walking catchment (1,000 m) of the public sports facilities	Describes the number of residential building POIs that the facility can service
Service Area	Based on the method of determining Euclidean distance buffer and walking route separately, the service area was calculated with a 1,000 m circular buffer by the former and a line-based network buffer of 50 m on each side of the shortest routes by the latter	Describes the area that the facility can service
Service Population	We combined the service area and population density data of Nanjing to analyze the service population in ArcGIS10.6	Describes the size of the population that is in the service area of, and serviced by, a facility
Facility Option	We considered how many facilities the same residential building POI can reach within the 1,000 m walking catchment area	Describes how many facilities a POI can reach with a 1,000 m threshold

Fig. 3 Comparison of service areas based on the route distance and Euclidean distance. (**a**) 1,000 m Buffer Zone, (**b**) 50 m Buffer Zone (Existing), (**c**) 50 m Buffer Zone (Proposed)

Table 2 Public sports facilities' service capacity in terms of various approaches, thresholds, and measures

	Route-based buffer method			Euclidean distance buffer method		
	Service POIs	Service Area (ha)	Service Population	Service POIs	Service Area (ha)	Service Population
Existing (68)	9,452 (31.27%)	5,279.34 (17.11%)	1,124,299 (30.72%)	16,531 (54.68%)	15,430.26 (50.01%)	2,596,915 (70.95%)
Proposed (130)	14,196 (46.96%)	7,422.26 (24.01%)	1,640,108 (44.81%)	21,515 (71.15%)	22,773.61 (73.81%)	3,142,770 (85.87%)

specifically, this urban area contains largely underserved areas, such as the northern part of Gulou District, the southeast part of Qinhuai District, and the southern part of Jianye District (Fig. 3b). Some newly proposed facilities would increase the service POIs, service area, and service population by 15.69%, 2,143 ha, and 515,809, respectively (Table 2). Within a 1,000 m walking distance, significant differences were found in potential population across the public sports facilities, which may bring challenges to some residents, especially in Yuhuatai District. The planned facilities, if implemented, would remediate the inequity to some extent, but considerable areas would remain outside of the 1,000 m catchments in the study areas (Fig. 3c).

According to Fig. 3, the service capability determined by the route-based method was significantly less than that determined by the Euclidean distance buffer method. The conventional (Euclidean distance) buffer-based catchment delineation (16,531) overestimated serviced POIs by 70% using a route-based approach (9,452). Similarly, the service area and service population determined through the former method were less than those determined by the latter method (Table 2).

As well-equipped college gymnasiums can satisfy the daily exercise needs of residents to some extent, we included college gymnasiums in our estimation of service areas in the study area. The results showed that the service area of 30 college gymnasiums spans 6,646.59 ha, accounting for the conventional buffer-based existing catchment area of 43.08%. However, the utilization rate of college gymnasiums is low at present. Opening the schools' gymnasiums to the public would relieve the problem of the insufficient number of facilities.

Fig. 4 Service capacity of public sports facilities. (**a**) Existing Service POIs, (**b**) Proposed Service POIs, (**c**) Existing Service Area(ha), (**d**) Proposed Service Area(ha), (**e**) Existing Service Population, (**f**) Proposed Service Population

The mean values of service POI, service area, and service population were all greater than the median, and the outliers represented the public sports facilities with the highest service efficiency. The Wutaishan Sports Center in Jiangsu Province, located in Gulou District, features the highest comprehensive service capacity. For this facility, 410 residential POIs are served, spanning a service area of 221.58 ha and a service population of approximately 88,300. Nanjing Olympic Sports Center has the highest service area, reaching 331.82 ha. Those facilities are located in the central area, which is densely populated and has a high road network density. Significant differences in service capacity exist between different public sports facilities (Fig. 4). Existing facilities have a median residential building POI of 180, a service area of 91.86 ha, and a service population of 17,073. For proposed facilities, the medians are 138, 69.26 ha, and 9,498, respectively.

The 1st quartile, 2st quartile (median), and 3st quartile of each index showed a decreasing trend, which revealed that most new facilities are allocated in areas with fewer residential building POIs, low population density, and low road network density within a 1,000 m walking catchment. This finding affirms that reasonable planning choices have been made in these cases.

The Service POIs at the District Level

As shown in Table 3, Gulou District has the largest number of served POIs (2,844 existing; 3,821 proposed), and more than a quarter of residential building POIs benefited in Gulou District from access to public sports facilities, with 30.08% of the

Table 3 The number of residential building POIs for public sports facilities in each district

District	Number of facilities		Based on a 1,000 m actual route distance		Based on a 1,000 m Euclidean distance	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
Gulou	16	23	2,844 (30.08%)	3,821(26.92%)	4,800(29.4%)	5,439(25.28%)
Xuanwu	17	27	1,900(20.10%)	2,720(19.16%)	2,946(17.82%)	3,996(18.57%)
Jianye	9	25	1,098(11.62%)	1,771(12.48%)	1,895(11.46%)	2,457(11.42%)
Qinhuai	16	26	2,100(22.22%)	2,912(20.51%)	3,760(22.75%)	4,711(21.90%)
Qixia	5	18	651(6.89%)	1,680(11.83%)	1,450(8.77%)	2,781(12.93%)
Yuhuatai	5	11	859(9.09%)	1,292(9.10%)	1,680(10.16%)	2,131(9.90%)
Total	68	130	9,452	14,196	16,531	21,515

residential building POIs now and 26.92% standing to benefit in the future. That indicates the residents of Gulou District may enjoy more benefits of public sports facilities than residents of other districts. The next is Qinhuai District, with 22.22% of the residential building POIs benefitting, while Qixia District and Yuhuatai District had small percentages of beneficiaries. Jianye District, with a higher density of commercial buildings, has been focusing on developing commercially and economically. The number of residential building POIs is fewer, the proposed facilities are probably for the use of employees.

According to the *The Special Plan for Public Sports Facilities in Nanjing* (2019), Qinhuai District has the lowest per capita sports land area (only 0.09 m^2) at present, indicating that the public sports facilities in Qinhuai District may be seriously overloaded by the citizen population. The per capita sports land area of Xuanwu District is the highest (2 m^2), but Zhong Mountain (39.42 km^2) and Xuanwu Lake (5.13 km^2) occupy 49.45% of the area of Xuanwu District, which may imply that the per capita sports land area utilized may be less than 2 m^2.

The Density of Service POIs in Different Sub-Districts

We summed the service POI numbers of each sub-district (*jie-dao*) and divided it by the sub-district area to calculate the density of service POIs. After the creation of proposed facilities, the density of service POIs in some sub-districts will increase significantly, but some peripheral sub-districts will continue to have low density of service POIs (Fig. 5). When considering only the existing facilities, the sub-districts with the highest density of service POIs are Hunan Road jie-dao and Wulao Village jie-dao, followed by Renan Road jie-dao and Shuangtang jie-dao.

If the proposed plan is implemented, the Xinjiekou jie-dao, Hunan Road jie-dao, and Jiangdong jie-dao will have the highest density of service POIs, followed by Wulao Village jie-dao and Mochou Lake jie-dao (Table 4). These jie-dao are located in historic areas, whose blocks have a compact layout and a high road network density. However, most public sports facilities in Shuangzha jie-dao, Jianye District

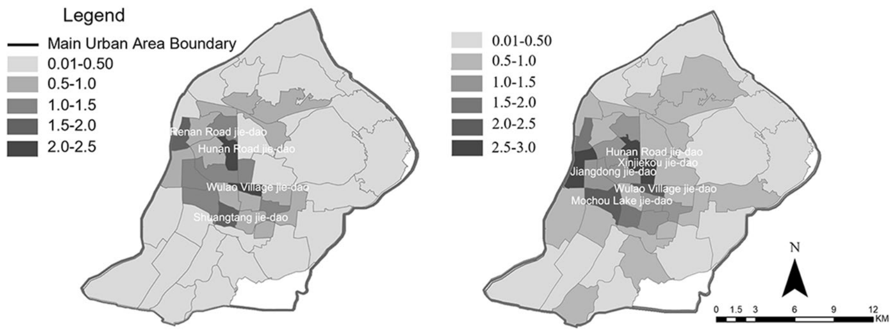

Fig. 5 The accessibility at sub-district level within a 1,000 m walking catchment. (**a**) Existing Facilities' Accessibility, (**b**) Proposed Facilities' Accessibility

Table 4 The ratio of the sum of POI assignments to the sub-district area

	Sub-district	POIs	Ratio
Existing	Hunan Road jie-dao	358	2.32
	Wulao Village jie-dao	240	2.09
	Renan Road jie-dao	283	1.83
	Shuangtang jie-dao	301	1.37
Proposed	Xinjiekou jie-dao	269	2.88
	Hunan Road jie-dao	372	2.64
	Jiangdong jie-dao	725	2.57
	Wulao Village jie-dao	240	2.09
	Mochou Lake jie-dao	509	2.00

have a lower service capability. For example, no residential POIs allow residents to reach the proposed Jianye District National Fitness Center within 1,000 m. This may be due to the continued growth of the financial service industry in Jianye District in recent years, which has kept the number of residential building POIs lower.

The Spatial Distribution and Service Capacities of the Community-Level Facilities

Community-level public sports facilities refer to indoor or outdoor sports gymnasiums constructed in combination with residential community centers to enable people to exercise. Community-level sports facilities are more numerous and widely distributed than other types of sports facilities, and they are one of the most frequently utilized types of facilities in people's daily lives.

Among the 130 public sports facilities in Nanjing, the number of community-level sports facilities is 102, accounting for a relatively high proportion. Our results reveal a significant disparity within their potential service populations. Most public sports facilities can serve few residential building POIs due to being located far from the central area with a high density of permanent residents, while facilities located

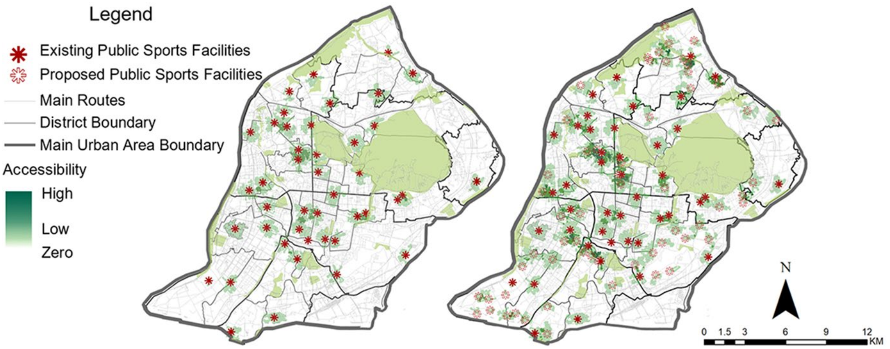

Fig. 6 Comparison of the service area between existing and proposed community-level facilities based on route distance. (**a**) 50 m Buffer Zone (Existing), (**b**) 50 m Buffer Zone (Proposed)

Fig. 7 Service capacity of community-level public sports facilities. (**a**) Existing Service POIs, (**b**) Proposed Service POIs, (**c**) Existing Service Area(ha), (**d**) Proposed Service Area(ha), (**e**) Existing Service Population, (**f**) Proposed Service Population

in densely populated areas or constructed around the central area have a high service capacity, benefitting more residential building POIs (Fig. 6). If the proposed plans are implemented, they would help remediate the inequity, though considerable POIs would still lie outside of the 1,000 m catchments in the study area.

As Fig. 7 shows, the median of the serviced residential buildings' POIs, the service area, and the service population of the existing facilities are 191, 90.20 ha, and 16,564, respectively. When considering proposed facilities, those numbers reach

135, 70.14 ha, and 8,864, respectively, indicating that despite the increased number of these facilities, most proposed community-level facilities will be distributed in areas that are not densely populated. In addition, community-level sports facilities are close to the residential building POIs, so most facilities have a comprehensive service capacity. However, the proposed facilities in Jianye District have low service efficiency, which may be due to the lower number of residential building POIs in the district.

Facility Options

Comparing the existing and proposed facilities, we found that for 2,142 (22.66%) of POIs in the former situation, at least two facilities were available within 1,000 m. Meanwhile, in the proposed situation, 3,595 (25.32%) facilities were available within 1,000 m, indicating an improvement in the facility options for residential building POIs. Among those residential building POIs, three POIs had a high degree of facility options, reaching five public sports facilities within 1,000 m (Fig. 8). These three residential buildings were the Shuizuogang, No. 140–2 Jiangsu Road, and Jinshan Building–A in Gulou District, respectively. The five sports facilities included the existing district-level sports center in Gulou District of Nanjing City, community-level sports facilities in Ninghai Road Sub-District GL[1]-12 and Hunan Road Sub-District GL-13, and the proposed community-level sports centers in Yijiangmen Sub-District GL-09 and Ninhai Road Sub-District GL-11 (Fig. 8). Comparing the route distances from residential building POIs to these facilities, we found that the distances from these POIs to the Nanjing Sports Center in Gulou District are the shortest, at 322.47 m, 418.15 m, and 319.15 m, respectively.

Discussion

Main Findings

This study acquired data from an online mapping service, using a method of investigating actual routes to delineate the walking catchment area. Its findings have planning-related policy implications. There were significant differences in service areas and potential capabilities across the facilities, and a mismatch existed between the spatial distribution of facilities and the distribution of the population. The central areas had a higher population density, and those facilities were overloaded when considering their service capacity, while some facilities in the peripheral area had a lower potential service efficiency. This phenomenon also occurs in other cities. Liu (2009) found through a field investigation that sports facilities in England were not

[1] According to *The Special Plan for Public Sports Facilities in Nanjing* (2019), GL represents community-level public sports facilities in Gulou District, QH represents Qinhuai District, XW represents Xuanwu District, JY represents Jianye District, YHT represents Yuhuatai District, and QX represents Qixia District.

Fig. 8 The distribution of the three residential building POIs with the highest degree of choice. (**a**) Distribution of Five Facilities and Three POIs, (**b**) Sports Center in Gulou District of Nanjing City, (**c**) Yijiangmen Sub-District GL-09, (**d**) Ninhai Road Sub-District GL-11, (**e**) Ninghai Road Sub-District GL-12, (**f**) Hunan Road Sub-District GL-13

proportionally matched to the population. Chen et al. (2021) employed the Lorenz curve and location entropy to measure the equity of the distribution among spatial units and the intra-district disparity, and they found a mismatch between the spatial distribution of the facilities and the distribution of the permanent population. The facility distribution should be suitably controlled in order to ensure it corresponds to the distribution of residential dwellings. However, it is difficult to predict social changes, such as possible shifts in the demographic composition of the region. In fact, in the planning of various public infrastructures, most research methods display a certain hysteresis quality. In other words, homogenized concepts such as "per capita area" and "service radius" have been used as evaluation indices for a certain scope in an attempt to ensure that the distribution of public sports facilities meets

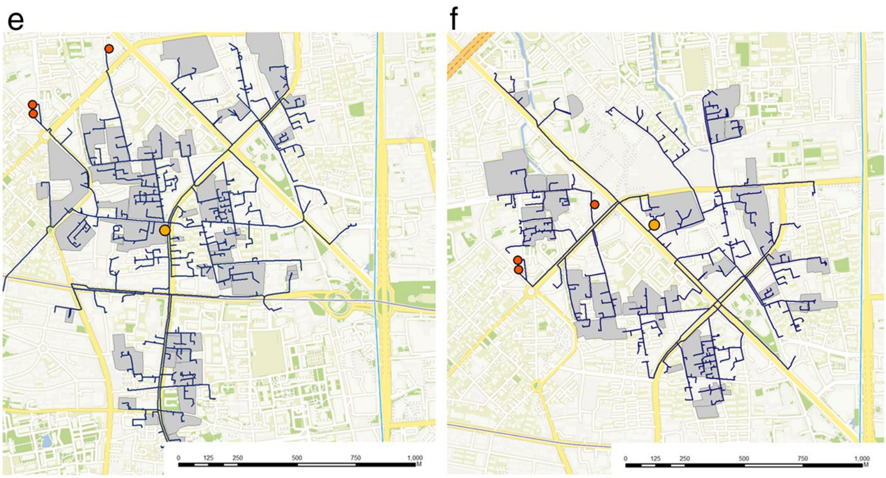

Fig. 8 (continued)

the goal of social equity (Ji & Gao, 2012). However, this method lacks consideration of the inner space of the city, resulting in urban peripheral areas that are underserved or facilities of central areas that are overloaded (Hu & Ma, 2021).

Our results revealed that the accessibility of facilities in the peripheral areas is inferior to that of facilities in the central areas, and that distribution of facilities is extremely uneven. This result means that while residents living within central areas can fully enjoy these facilities, residents living within peripheral areas benefit little. This uneven distribution of facilities appears consistent with the findings of previous studies. The patterns revealed in this analysis suggest that accessibility to sports facilities tends to be highest in the central areas of a city and lowest in the peripheral areas (Mora et al., 2021; Panter et al., 2008). In fact, most of the public sports facilities in the marginal areas are newly built and well-equipped, and the low service efficiency of some facilities is mainly affected by the differences in population, residential density, and supporting infrastructure construction. Affected by the characteristics of the Chinese government's planning policies, the peripheral areas may suffer from a high vacancy rate of housing and a low utilization rate of facilities for a period of time. Thus, the construction or renovation of existing facilities in underserved areas must be based on the government's comprehensive judgment of the development orientation and economic development of the area. In addition, due to limitations of the land area of urban built-up zones, it is impossible to exploit a large area to build new facilities. Even if the proposed public sports facilities are completed, it is impossible to predict whether they will distract from the use of existing facilities or prompt residents to exercise because of oversupply.

In addition to considering the population density in residential building areas, locations near workplaces should be considered for proposed facilities. Most citizens are of working age and spend substantial time at work each week, so public sports facilities near residential areas may not be used as often as those near workplaces. A previous study suggested that a high level of accessibility of sports facilities could increase exercise among workers, reduce barriers to exercise, and promote physical activity (Crump et al., 1996; Lee et al., 2016). The Nanjing government may also consider these demographic characteristics when designing plans for sports facilities. Jianye District is the main economic and commercial development center of Nanjing, with a large number of employees, and proposed facilities in the area might be highly accessible for employees.

Further, the issue of population density is not the only potential barrier to exercise. Rather, underlying population factors must also be taken into account, such as financial accessibility. One study has shown that while people in Madrid living in low socioeconomic status (SES) areas have better access to exercise facilities, residents in higher-SES areas benefit from greater availability of exercise facilities, and the likelihood of having more than one available facility rises as area-level SES increases (Cereijo et al., 2019). Ellaway & Macintyre (1996) and Estabrooks et al. (2003) also found that the most deprived members of the population have poorer access to affordable exercise resources. In contrast, Giles-Corti et al. (2002) and Panter et al. (2008) found that residents of low-SES areas have superior access to facilities, including sports and recreation centers, gymnasiums, and swimming pools, although they were less likely than residents of wealthier areas to use them. Although we focus on reporting the accessibility of public sports facilities based on the actual routes to them, people with low accessibility to sports facilities do not necessarily have lower incomes. Another underlying population factor that may be important is car ownership. If areas with low facility accessibility have more households with cars, then they may travel to places with more appealing environments and well-equipped facilities. This research only focuses on public sports facilities with comprehensive service capacity and a wide range of services, some informal places where physical activity can be undertaken, such as parks as well as walking and cycling lanes. In addition, people may have access to private facilities that charge a fee but are still available, and geographically accessible, to them.

The spatial inequality of facilities not only relates to the urban planning layout, population density, and underlying population factors of Nanjing but also to the geographical elements of the city. Zhong Mountain and Xuanwu Lake are located in the northeast of Nanjing, which substantially limits the extension of Nanjing's sports facilities distribution toward the northeast part of the city. Meanwhile, several facilities in Qinhuai and Yuhuatai Districts have lower service efficiency, with fewer residential building POIs served within the 1,000 m walking threshold. This may be due to the topographical factors forcing people to bypass these surface obstacles to reach facilities, leading to longer-distance travel (> 1,000 m) to reach them. Such differences reflect the influence of surface obstacles on the accessibility of facilities.

Optimization of Suggestions

Based on the above conclusion, the current study can provide some suggestions for optimizing the spatial structure of Nanjing's public sports facilities and formulating a reasonable urban public sports facilities development plan. First, college gymnasiums can be opened to the public in appropriate ways and incorporated into urban planning. The opening of college gymnasiums to the broader society has become an inevitable development (Yang & Li, 2013). Although the sports programs and equipment of college gymnasiums in Nanjing are excellent, the degree of openness to the public remains relatively low at present, according to *The Special Plan for Public Sports Facilities in Nanjing* (2019). Thus, the government should improve specialized management of sports facilities, reinforce the security of college gymnasiums, and enact policies for opening them to the public to alleviate the imbalance between the public demand and current resources.

Second, the layout of Nanjing's sports resources requires optimization, and the service capability of sports facilities must be enhanced. The government should locate public sports facilities in areas with convenient transportation, combined with appropriate demographic characteristics, to optimize the spatial layout of these facilities, considering the phenomenon of insufficient facilities in peripheral areas. In addition, the government must encourage the accelerated development of support for sports industries, which complement community service centers to further optimize a facility's comprehensive service capacity.

Finally, cities should construct active living infrastructure (ALI) by improving their walking and cycling infrastructure along with access to open spaces. "Active living" is the best way to improve people's physical activity levels, and it is advisable to integrate sports into people's daily lives. The construction of ALI in communities has been carried out in England (Le Gouais et al., 2020a, b), and urban planners and policymakers can help build quality ALI by improving parks, walking trails, and other infrastructure that promotes increased physical activity (Le Gouais et al., 2020a, b). However, the research on active living infrastructure in China has been limited to learning from and translating the experience of European and American countries into active living design guidelines (Liu & Guo, 2006; Liu & Song, 2015; Sun et al., 2019; Xiao, 2016); research on theoretical improvements and explorations of case studies based on the Chinese context remain insufficient. Meanwhile, China's cities have a high population density and compact land use practices, making it essential to integrate active living design into urban planning. This represents a critical public health intervention that will cultivate an active city.

Limitations and Future Research

The current results should be interpreted with a degree of caution due to several limitations. First, considering the urban morphology of Nanjing, we regarded the 50 m buffer as the service area, which may cause a certain amount of deviation in the results of this study. Second, we assessed sports facility accessibility by the actual distance between an individual's home and the facility, and this research lacked a self-reported questionnaire to measure the perceived accessibility among residents. The findings suggest that some sports facilities are overloaded, but whether this presumption holds true in daily life remains unclear. Other factors clearly influence people's level of physical activity as well, including individual-level characteristics such as age, gender, socioeconomic status, and subjective perception of facilities (Giles-Corti & Donovan, 2002). Our research has not made any attempts to examine the relationship between objective measures of accessibility derived from data-based analysis and people's perceptions of accessibility, which may differ from the actual use of a facility. Therefore, a questionnaire should be utilized to facilitate comprehensive analysis in the future. Finally, it should be noted that in this study, we did not consider the use of public sports facilities within 1,000 m outside the boundary of the city of Nanjing, which may also serve some residential building POIs in the study area, resulting in the issue of the modifiable areal unit problem (MAUP). Therefore, it is necessary to combine the granularity and zoning principles of geographic units for comprehensive analysis in the future, and to seek the most suitable granularity for expression, so as to reduce the error of the MAUP effect in spatial analysis.

Even with these limitations, however, this study highlights the emerging strength of utilizing open-source data in city planning. Such straightforward estimations, reinforced with a big data approach, will prove useful for planners and policymakers in building healthy and active cities. We believe that with the development of information technology and the promulgation of open data policies, the accuracy of such information will be greatly improved for future research, which will also enhance related research by governments.

Conclusion

This study focused on the spatial distribution of the existing and proposed public sports facilities, mainly through three key steps. First, we employed the Baidu Maps API to acquire the shortest routes from residential buildings to public sports facilities and delineate the walking catchment. Second, we identified data on walking routes within a 1,000 m threshold. Finally, we obtained the service areas and potential capacities of public sports facilities by using buffer analysis and overlay analysis. The results revealed significant differences in service areas and potential capabilities across the facilities. More specifically, the results underscored spatial inequities in sports resources and found an insufficient number of public sports facilities in the study area. This method of using online maps allowed for a more accurate and realistic spatial accessibility assessment, enabling us to find the served and underserved areas, thereby guiding planners and policymakers in making rational allocations of sports resources and achieving a significant reduction of resource waste and inequity. This study provided a new measure combined with big data for urban planners and policymakers to use in improving planning standards, enhancing the rationality of the spatial distribution of public sports facilities, and achieving healthy cities.

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