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Does COVID-19 Affect the Accessibility of Outdoor Sports Venues? A Case Study in Nanchang, China

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Abstract: The COVID-19 pandemic has been a great challenge to society, the economy, and population health. It has become a significant public health event and social problem. Exploring the impact of COVID-19 on the accessibility of outdoor sports venues is crucial for people's health. Based on spatial theory, the quantitative and qualitative analyses of outdoor sports venues' spatial distribution and accessibility were conducted, and the epidemic's impact on them was analyzed. The results show that: (1) The existing outdoor sports venues in Nanchang show a distribution pattern of "sparse in the north and south, and strong aggregation in the middle". (2) As a result of the epidemic, the center of the standard deviation ellipse in outdoor sports sites shifted to the southeast, while the number of open venues decreased by 68%. (3) Before COVID-19, the entire study area could achieve full coverage by driving for 17 min, riding for 70 min, or walking for 119 min. After COVID-19, the time increased to 29, 109, and 193 min, respectively. (4) Under the high-risk scenario of COVID-19, the average walking time for people to reach outdoor sports venues increased from 6.2 min to 14.0 min in the study area, with an increase of 126%. Finally, according to the findings of this study, recommendations were made on how government departments could build or re-open outdoor sports venues during and after this epidemic.

Keywords: COVID-19; outdoor sports venues; spatial distribution; accessibility; GIS

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1. Introduction

At the end of 2019, the 2019 novel coronavirus disease (named "COVID-19" or "epidemic" hereafter) suddenly spread around the world, causing serious disasters and threatening our lives, health, and property [1,2]. COVID-19 has a close relationship with Severe Acute Respiratory Syndrome (SARS), both of which can be transmitted through the respiratory tract and are characterized by high transmission capacity, rapid spread, and widespread infection [3–6]. This epidemic has become widespread in various parts of the world. According to the data published by the World Health Organization (WHO), as of 26 August 2022, COVID-19 has been transmitted to 221 countries, with a total of 597 million confirmed cases and 6.46 million cumulative deaths. Among all countries in the world, China is the one with the largest population, and it has had 586,000 cumulative confirmed cases and 25,000 cumulative deaths [7]. To effectively protect people's health and life safety, according to the needs of epidemic prevention, many cities have conducted nucleic acid testing on their residents and prohibited cross-district activities to achieve

"static management". In particular, in the spring of 2022, there was a sudden increase in COVID-19 cases in Nanchang. Many public service facilities and public transportation stations stopped their services, inducing serious pressure on government management and public life. Centralized segregation, home segregation, activity restrictions, and out-of-district zoning have been operating periodically ever since. Residents have also become afraid to go out because of psychological reasons such as fear of infection. These factors have exerted a detrimental effect on health and lifestyle, notably on outdoor sports [8–11].

With a large patient base and insidious transmission, COVID-19 has become a new pathogen that is difficult to eradicate. Thus, we must face a new long-term coexistence with the infectious disease. When people were "frozen" by COVID-19, the importance of healthy lifestyles gradually became increasingly widely recognized, leading to a redoubled demand for outdoor sports. As one of the most important infrastructures for urban residents' outdoor fitness, urban outdoor sports venues directly affected the physical and mental health of residents, especially during the early stages of COVID-19 [12–14]. Exercising outdoors strengthens the immune system and reduces the risk of infection. Comprehensive data analysis showed that those who did outdoor exercise regularly had an 11% lower risk of COVID-19, a 36% lower risk of hospitalization, a 44% lower risk of developing severe COVID-19, and a 43% lower risk of dying from COVID-19 compared to their inactive peers [6,15]. COVID-19 has brought the public's attention to health to an unprecedented level. The contradiction between the public's demand for outdoor fitness sports and the current distribution of outdoor sports venues in cities has put forward new requirements for high accessibility to reach urban outdoor sports venues. Moreover, this contradiction brings challenges to public health and urban facility construction. Therefore, it is necessary to analyze the spatial distribution and accessibility of urban outdoor sports venues in the epidemic period, to make cities "more inclusive, accessible and efficient" for their residents.

Accessibility usually refers to how convenient it is for people to go from a specific location to a designated destination [16]. As an important indicator of urban livability, public facility accessibility refers to the quantitative description of the distance, time, or cost from residents to public facilities [17]. It reflects the convenience of public service facilities and whether urban public service resources are allocated fairly and efficiently [18]. Many investigations have been conducted to analyze the accessibility of urban public facilities, such as parks and green spaces, medical facilities, research and education [19–25]. Spatial accessibility of urban facilities has become a hot topic for evaluating spatial distribution and urban construction, which can be reflected in the following aspects. Firstly, the accessibility level of urban service facilities can be obtained by using spatial analysis and modelling methods, such as the proportional method, spatial barrier method, and opportunity accumulation method [26,27]. Likewise, the accessibility results of urban public facilities are used to assess the service facilities' distribution pattern [18,28–30]. Secondly, suggestions for the rational planning of public facilities can be made by constructing a new model based on the distribution of service facilities and societal characteristics [31–33]. Pearce, Jet al. investigated the impact of physical changes on community residents' health by constructing resource accessibility indices for New Zealand communities, and gave valuable advice to urban planning and construction based on the trend direction of residents' health [29]. Zhang, XY et al. analyzed the accessibility of parks by constructing a potential spatial accessibility index, which provided data support and valuable suggestions for the construction of US community parks [34]. Thirdly, the connections and relationships between specific events and public service accessibility have been explored in connection to the occurrence of disasters or high-impact events [35–37]. Da Schio et al. validated a strong positive correlation between urban accessibility and air pollution using the capital region of Brussels as a case study [38]. Yang, LC et al. used a spatial model to quantify transit accessibility and derived the result that the accessibility of bus stops directly affects the price of housing and property services [39]. Saghapour, T et al. analyzed the accessibility of communities in metropolitan Melbourne, Australia, through an independent ordered logistic regression (OLR) model, and concluded that community

accessibility significantly impacts residents' moving behavior [40]. With the outbreak of COVID-19, Michels, A et al. analyzed the accessibility of healthcare facility resources for patients with COVID-19 and high-risk populations in Illinois, USA, based on the enhanced two-step floating catchment area (E2SFCA) model. Their study has important implications for policymakers and public health practitioners in allocating existing healthcare facility resources or allocating new resources. Moreover, outdoor sports venue has become an essential public service facility for improving immunity and preventing viral infections after COVID-19. The spatial distribution and accessibility of outdoor sports venues directly affect the exercise and health status of the public. However, to the best of our knowledge, no studies have focused on analyzing the impact of this epidemic on the spatial distribution and accessibility of outdoor sports venues.

Therefore, to fill this research gap, the objective of this study is to analyze the epidemic's impact on the spatial distribution and accessibility of outdoor sports venues (including basketball courts, track and field courts, badminton courts, tennis courts, and soccer courts). First, based on spatial theory and methods, including kernel density estimation (KDE), buffer analysis, and origin-destination (OD) cost matrix, the spatial distribution and the spatial accessibility of outdoor sports venues were analyzed in Nanchang City. Next, the epidemic's effects on the spatial distribution and spatial accessibility of outdoor sports venues were investigated. In addition, according to the findings of this study, recommendations were made on how government departments could build or open outdoor sports venues during and after this epidemic.

2. Materials and Methods

2.1. Study Area

Occupying 7195 km^2 with 6 districts and 3 counties, Nanchang is the capital city of Jiangxi Province in southeastern China. Nanchang is one of the critical pivots connected to the "Belt and Road" economic belt, with an important strategic position in national and regional development. With an area of about 2797.5 km^2, the study area covers the major urban part of Nanchang City, including Xihu District, Donghu District, Qingshanhu District, Qingyunpu District, Honggutan District, and Xinjian District, as shown in Figure 1. Its topography mainly decreases from west to east, and the main central city is concentrated in the Qingshanhu District and the surrounding areas. The urban spatial development strategy of "eastward expansion, westward advancement, southward extension, and northward control" was proposed in the "Nanchang Urban Master Plan (2003–2020)". This plan helps to form a spatial pattern of "Ganjiang River as the main axis, its two banks grouped and networked development" in the center of Nanchang. Nanchang insists on taking the "Health China 2030" and the "Nanchang National Fitness Implementation Plan" as the guiding principle to promote the development of Nanchang sports and fitness and bring about a high-quality leap forward in it. With the continuous expansion of the Nanchang metropolitan area and the dramatic increase in population, the demand for outdoor sports venues in Nanchang is also increasing. In particular, there was a dramatic increase in COVID-19 infections in Nanchang in the spring of 2022. The average daily sampling volume of nucleic acid testing reached 5.25 million, accounting for about 85% of the resident population in Nanchang. Moreover, residents in high-risk areas have a restricted range of motion and a lack of outdoor sports venues, which dramatically affects the outdoor sporting activities of Nanchang residents.

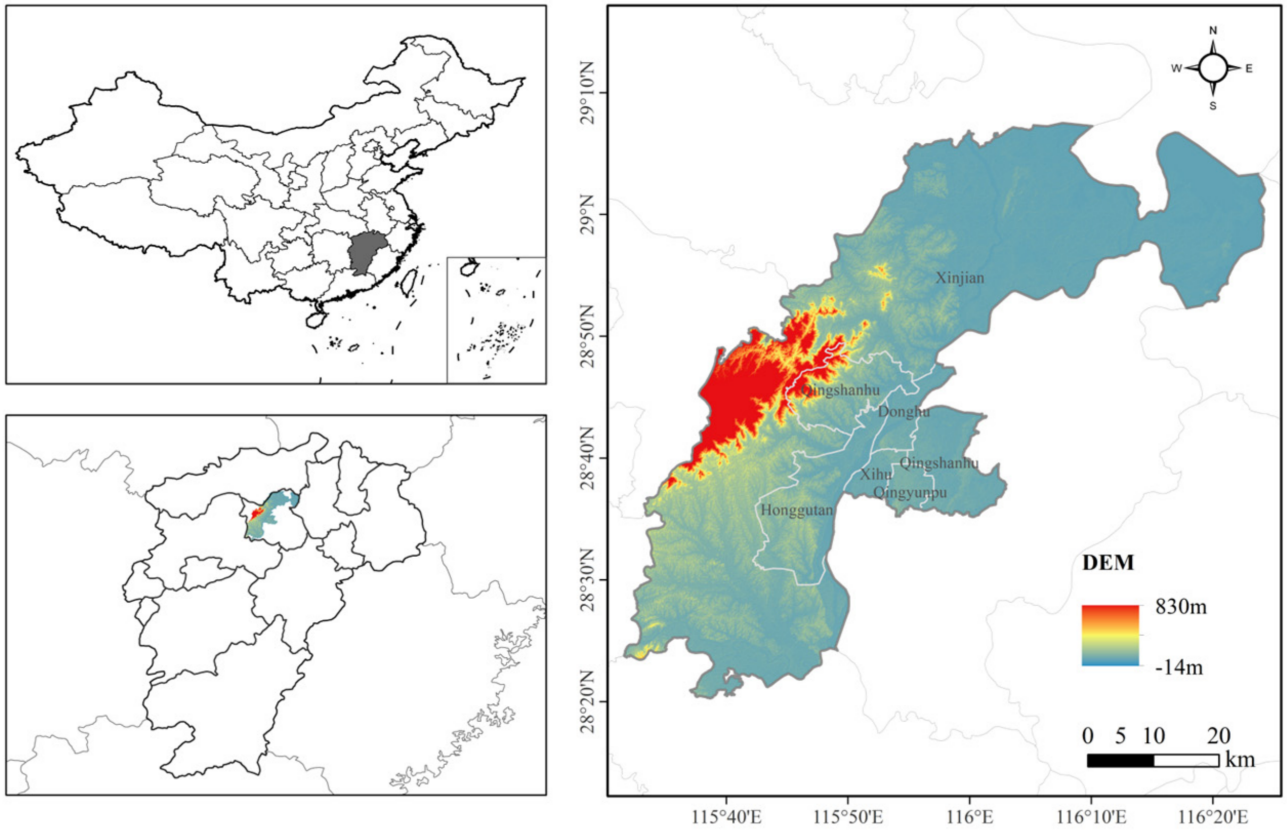


Figure 1. Overview of the study area.

2.2. Data Preparations

This study mainly collected data from the Internet. As shown in Figure 2, these include the following: (1) The administrative division data are vector data obtained from 1:1 million national primary geographic information data. (2) The settlements data is text information data, which is obtained according to the Point of Interest (POI) category through the API of AutoNaviMAP (AMAP), and a total of 4612 settlement point data was obtained after filtering and cleaning, as shown in Table 1. (3) The road network data are vector data derived from Open Street Map (OSM) open-source maps, based on the current remote sensing satellite images of Nanchang and real photos for correction and improvement. Moreover, according to the "Technical Standards of Highway Engineering of the People's Republic of China (JTGB-2003)" and "Road Traffic Safety Law", the grade of road has been divided into first-class, second-class, third-class, provincial, and expressway. (4) The remote sensing images are raster data obtained from the National Geographic Information Public Service Platform. Using the manual visual interpretation method based on ArcGIS and Pixel Information Expert (PIE) Map software, the outdoor sports venues (courts for basketball, track and field, badminton, tennis, and soccer) in Nanchang are extracted from the remote sensing images, and the remote sensing satellite images of each type of outdoor sports venue are shown on Figure 3. Based on POIs and geographic information, the outdoor sports venues are classified by neighborhood, community, school, and sports stadium.

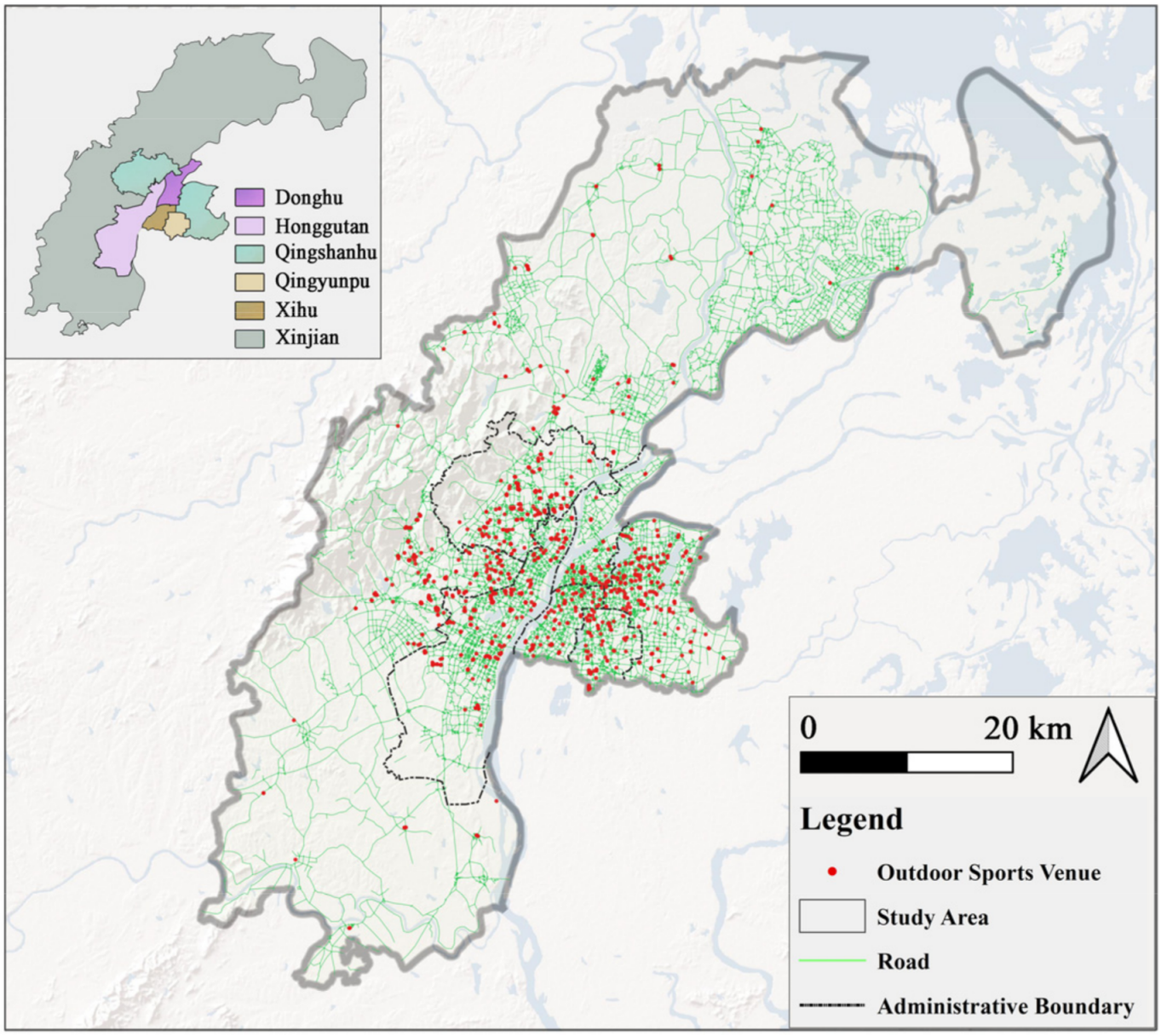


Figure 2. Data collected in the study area.

Table 1. Settlements in each district.

District	Number
Donghu	626
Xihu	764
Xinjian	650
Qingshanhu	1479
Qingyunpu	409
Honggutan	684
Total	4612

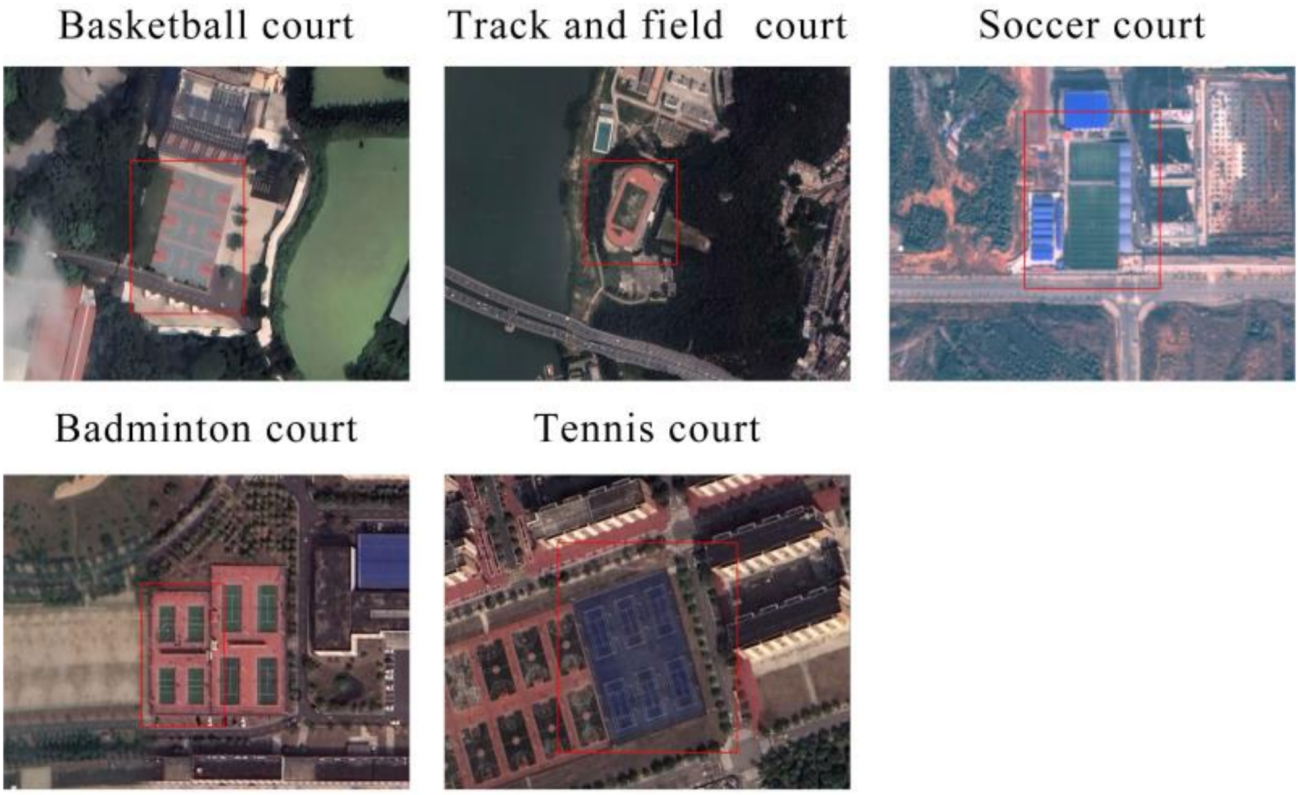


Figure 3. Remote sensing satellite images of each type of outdoor sports venue.

2.3. Methods

2.3.1. Kernel Density Estimation

Kernel density estimation (KDE) is one of the most widely used statistical methods for non-parametric density estimations to measure the degree of data clustering and agglomeration patterns, which can visually represent the distribution of the study object. The numerical magnitude of the kernel density indicates the relative degree of aggregation of the study object in its spatial distribution. In this study, the density of outdoor sports venues in the study area was calculated in ArcGIS. The degree of concentration of outdoor sports venues on the spatial scale and the state of change on the temporal scale were reflected by the natural intermittent classification method. The equation for KDE is given in Equation (1):

$$f_n = \frac{1}{nh} \sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \quad (1)$$

where f_n is the density estimate of outdoor sports venues; n is the number of outdoor sports venues; k is the kernel density function; $x - x_i$ is the distance from the measured outdoor sports venues x to the sample outdoor sports venues x_i; and h is the search radius (band width or kernel size).

2.3.2. Buffer Analysis

Buffer analysis is the most commonly used method to describe spatial objects' influence on the surrounding area. It is important to explore the influence of geographic objects on their surroundings. With a point, line, or surface object as the core, a buffer area of a certain width is generated around the core by setting certain distance conditions, to analyze the radiation coverage or the degree of influence on neighboring objects. The basic idea of this method is that after determining a spatial element, its sphere of influence is determined

by the radius of the specified neighborhood. For the object, its buffer can then be defined as Equation (2):

$$B = \{x \| d(x, A) \ll r\} \quad (2)$$

where A is the spatial object, B is the buffer, d is the distance to the buffer (the general value being the minimum Euclidean distance), and r is the radius of the neighbourhood, which is the condition for buffer establishment.

2.3.3. Standard Deviation Ellipse

Standard deviation ellipse (SDE) is one of the classical methods to study the directional characteristics in the spatial distribution of geographic elements, which can reveal the distribution characteristics and clustering patterns of spatial elements. The center, long axis, short axis, and azimuth of the ellipse reflect the central position, primary direction, secondary direction, and distribution trend of the spatial distribution among the elements. In this study, we used the SDE to reveal the impact of the epidemic on the spatial distribution characteristics and changing trends of outdoor sports venues in Nanchang.

2.3.4. Accessibility Analysis

Accessibility analysis indicates how convenient it is for people to go from a starting point (origin) to an ending point (destination) and has essential applications in the evaluation of the service level of urban roads and public facilities. This method can measure the convenience of reaching outdoor sports venues from the residential areas, and thus help to evaluate the rationality of the spatial distribution of outdoor sports venues. The OD cost matrix is one of the most widely used accessibility analysis methods, which is part of the network analysis in ArcGIS. Moreover, the result of the OD cost matrix is a network cost dataset that contains the cost of each origin to all destinations. The following is the process of OD cost matrix analysis. Firstly, the researcher can specify the number of origins and destinations or set the maximum search distance. Secondly, the minimum cost of accessibility can be easily obtained from each origin to the destination. Thirdly, according to the technical standards of "Highway Engineering (JTGB01-2014)" and road network data, the speeds of different commuting modes in different grades of road are determined, as shown in Table 2. Fourthly, the new OD cost matrix is created, regarding time as a cost, settlements as the starting point (origin), and outdoor sports venues as the ending point (destination). Finally, the time cost table is calculated, and the shortest time is selected. Moreover, to visualize the results, the spatial distribution of minimum time accessibility is generated by the inverse distance weighting (IDW) interpolation algorithm.

Table 2. The speed table for each commuting mode in different grades of road.

Road Grade	Walking (km/h)	Riding (km/h)	Driving (km/h)
First-class	6	8	50
Second-class	6	10	35
Third-class	6	13	30
Provincial	7	15	60
Expressway	/	/	90

/ denotes a commuting mode that is forbidden in a given road grade.

3. Results and Analysis

Based on spatial theory, this study used KDE, SDE, and accessibility analysis to analyze the impact of COVID-19 on outdoor sports venues in Nanchang City, including quantitative features, spatial distribution characteristics, and spatial accessibility.

3.1. Quantitative Features

Outdoor sports venues in Nanchang were identified by manual visual interpretation based on remote sensing satellite images, as shown in Figure 4. Outdoor sports venues numbering 1044 were unevenly distributed in the study area, namely: 395 in Qingshanhu District, 255 in Xinjian District, 199 in Honggutan District, 71 in Xihu District, 68 in Qingyunpu District, and 56 in Donghu District. As a result of COVID-19, public access to all types of school was restricted due to the relevant epidemic prevention and control management regulations. Up to 68% of the total number (710) of outdoor sports venues at schools changed from being open to being closed after the epidemic. Only 334 outdoor sports venues remained open to the public, namely: 129 in Qingshanhu District, 78 in Xinjian District, 69 in Honggutan District, 26 in Xihu District, 21 in Qingyunpu District, and 11 in Donghu District. By comparing Figure 4a with Figure 4b, it is evident that the coverage of outdoor sports venues in Nanchang has decreased. The epidemic closed 266 in Qingshanhu District, 177 in Xinjian District, 130 in Honggutan District, 47 in Qingyunpu District, 45 in Xihu District, and 45 in Donghu District. In summary, the epidemic had a clear impact on the quantitative features of outdoor sports venues, as reflected in Figure 5.

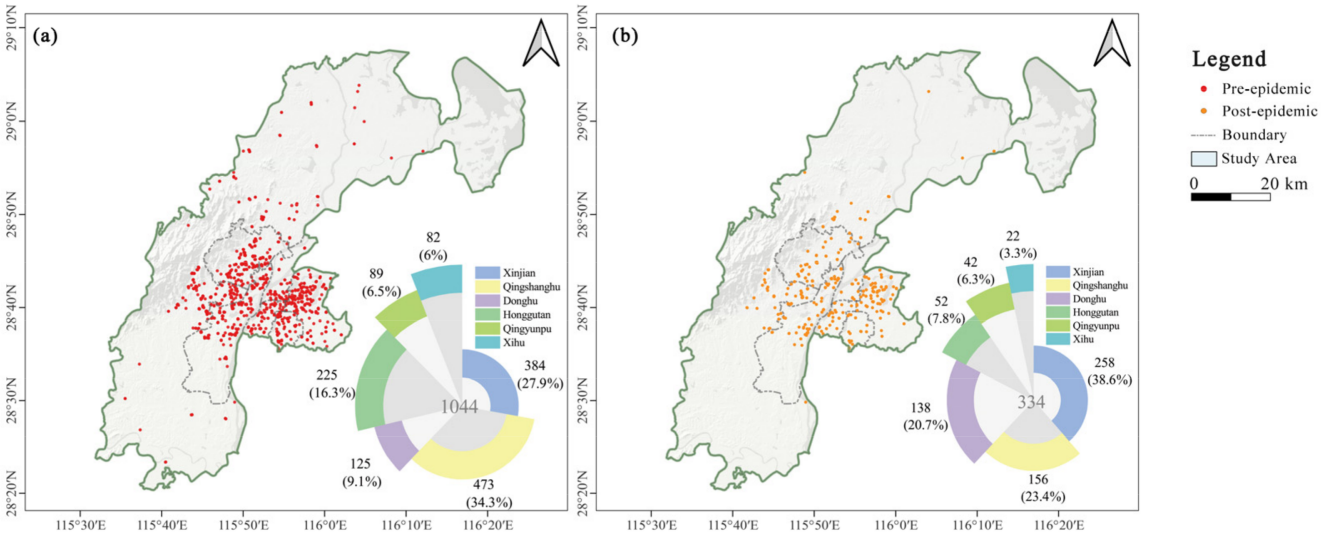


Figure 4. The open outdoor sports venues in Nanchang: (**a**) pre-epidemic; (**b**) post-epidemic.

As shown in Figure 6, there were 710 outdoor sports venues closed to the public, including 275 basketball courts, 255 track and field courts, 103 badminton courts, 67 tennis courts, and 10 soccer courts. It can be concluded that the epidemic had the most significant impact on basketball courts, followed by track and field courts, badminton courts, tennis courts, and finally, soccer courts. Moreover, the structural balance in the types of outdoor sports venue was compared before and after the epidemic in this study. The epidemic had little effect on the proportion of badminton courts, tennis courts, and soccer courts but significantly affected basketball courts and track and field courts. The proportion of track and field courts declined from 30.2% to 18%. By contrast, the proportion of basketball courts increased from 42.3% to 50%, mainly due to the imbalance between on-campus and off-campus sports venues. Of the 442 basketball courts, there are 275 on-campus and 167 off-campus. The results in Figure 6 reflect a severe structural imbalance in the proportion of outdoor sports venues in Nanchang, where basketball courts and track and field courts account for nearly 70%; in comparison, soccer courts account for only 3%. This imbalance inevitably affects residents' choice of outdoor sports: for example, people must choose basketball more often than soccer. This phenomenon is therefore not conducive to the diversity of residents' outdoor sports and requires the rationalization of urban construction.

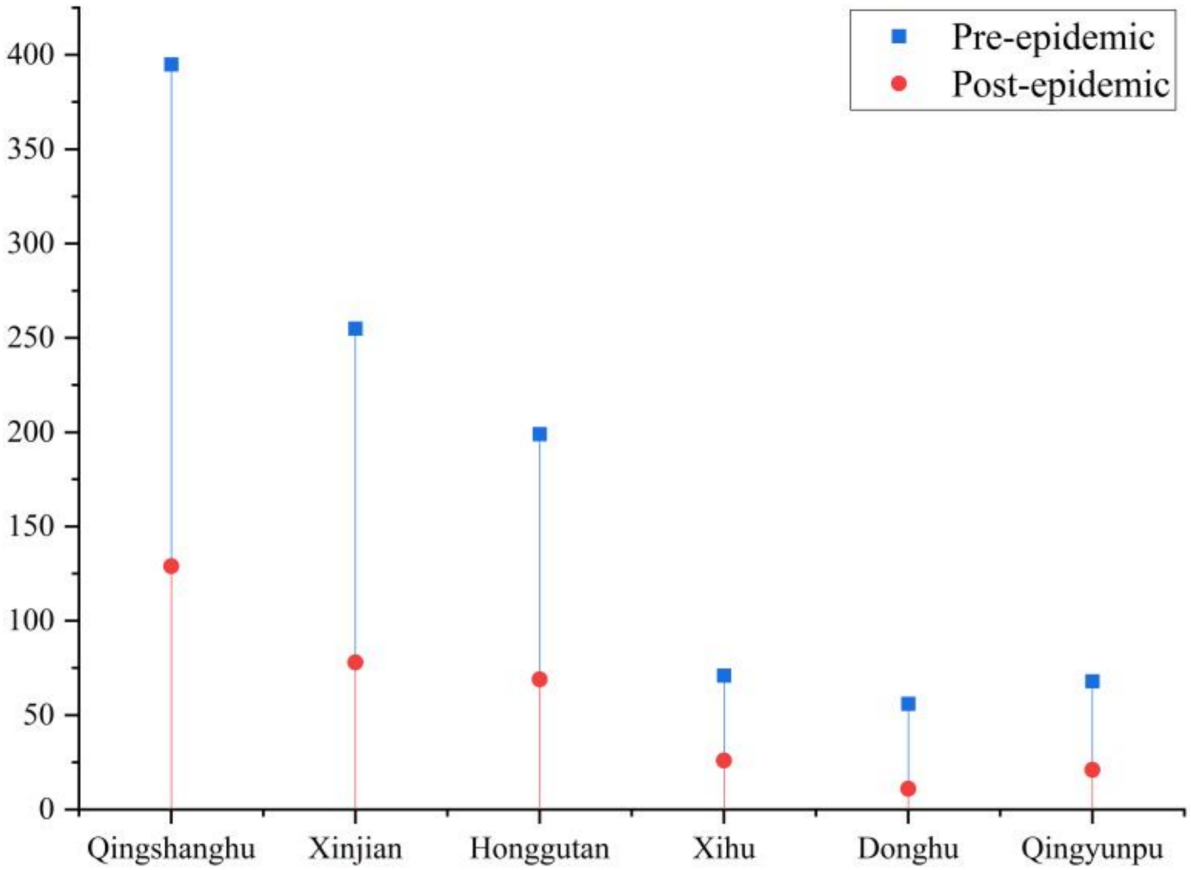
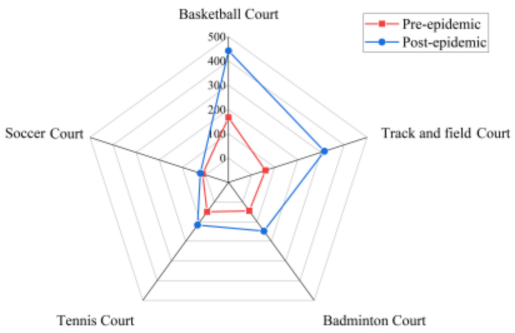


Figure 5. The number of outdoor sports venues in each district.



Type	Pre-epidemic	Post-epidemic
Basketball Court	442(42.3%)	167(50%)
Track and field Court	315(30.2%)	60(18%)
Badminton Court	148(14.2%)	45(13.4%)
Tennis Court	117(11.2%)	50(15%)
Soccer Court	22(2.1%)	12(3.6%)
Summation	**1044(100%)**	**334(100%)**

Figure 6. Changes of the structural proportion of the outdoor sports venues in Nanchang.

The structural imbalance in the proportion of outdoor sports venues in different districts is explored in Figure 7. The results show both similarities and differences in each district. On the one hand, the relative proportion of outdoor sports venues is unbalanced, with basketball accounting for the largest percentage of courts and soccer the smallest in all districts. On the other hand, Qingyunpu District is the most unbalanced compared to other districts, with the largest percentage of basketball courts and no soccer courts (the smallest percentage is for tennis courts). In conclusion, this structural imbalance will affect residents' choice of outdoor sports venues, reducing the diversity of sports pursued.

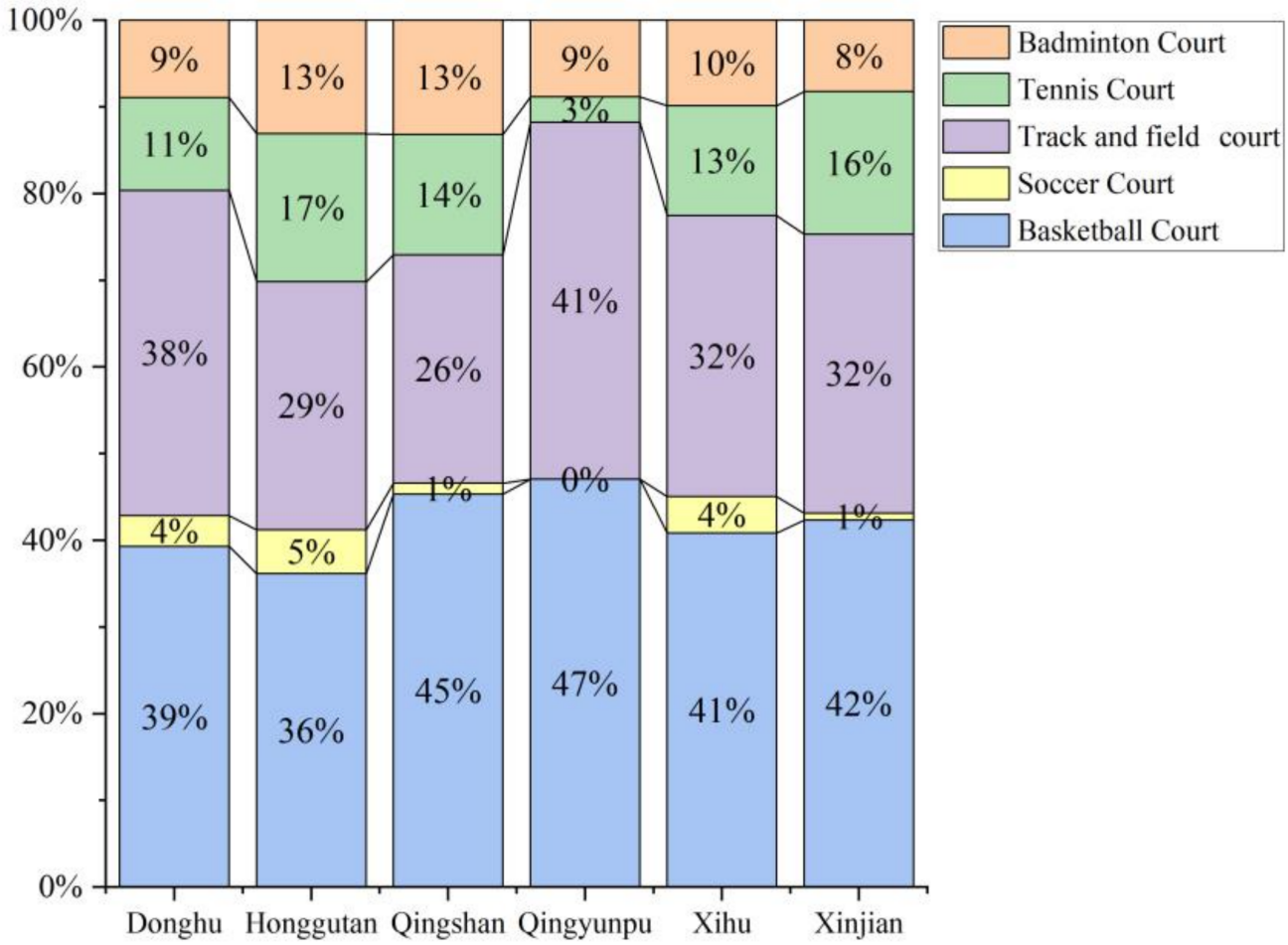


Figure 7. The relative structural proportion of outdoor sports venues in each district.

3.2. Spatial Distribution Characteristics

To analyze the spatial distribution characteristics and clustering phenomenon of outdoor sports venues, this study used the KDE method, and the results are shown in Figure 8. Before COVID-19, as shown in Figure 8a, outdoor sports venues in Nanchang formed a spatial distribution pattern of "sparse in the north and south, dense in the center", with two core areas of high density. The junction between Honggutan District, Qingshanhu District, and Xinjian Districts becomes the primary high-density core area for outdoor sports venues, with a ring-like decreasing phenomenon at the periphery. In relation to Nanchang's development policy, Honggutan District has been a critical development and construction area since 2000, insisting on people-oriented and high-standard construction standards. There are many large outdoor sports venues in Honggutan District, such as the Nanchang National Sports Center. The secondary high-density core area is located at the junction of Xihu District and Qingyunpu District. These belong to the earliest built-up urban area of Nanchang, with a large population, many schools, and a large set of sports venues. The medium-density core areas are mainly located around the high-density area, without apparent strong aggregation. However, after COVID-19, as shown in Figure 8b, in general, the coverage of venues in the study area is more aggregated, at lower density and without evident high-density aggregation regions. Moreover, the medium-density core region is located mainly in the east of Qingshanhu District, which had been a high-density aggregation area before the epidemic. Meanwhile, there is no aggregation in the north and south of the study area. This is because there are no public outdoor sports venues in the townships of Xinjian District.

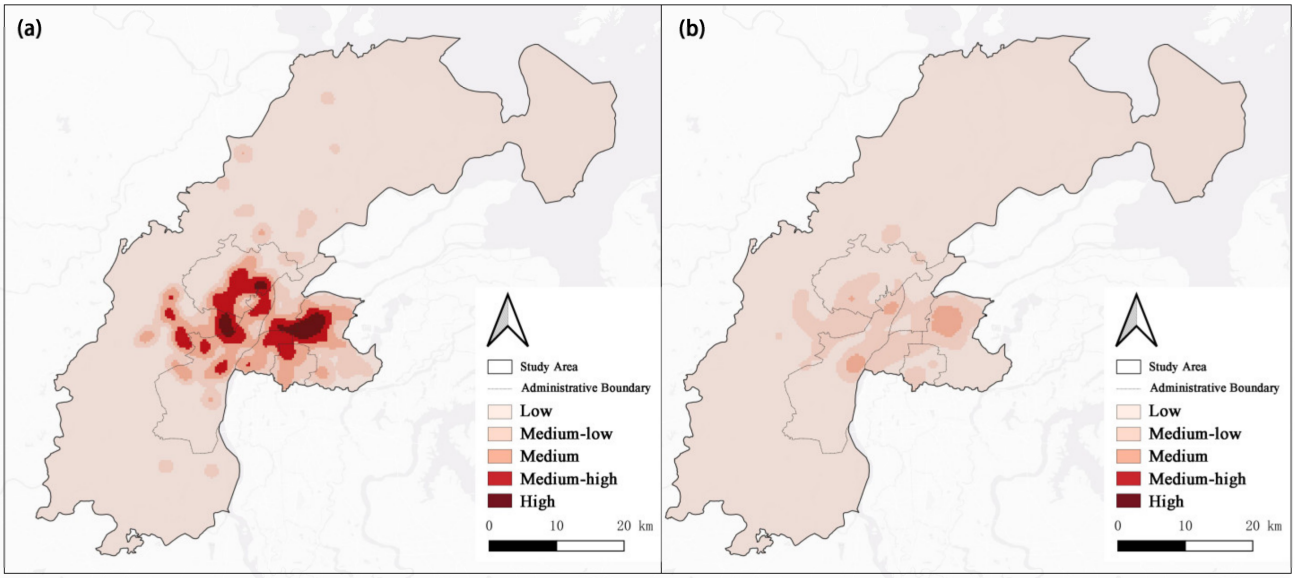


Figure 8. The density map of outdoor sports venues based on KDE: (**a**) pre-epidemic; (**b**) post-epidemic.

In addition, this study used the SDE method to analyze the epidemic's impact on the spatial distribution of the outdoor sports venues from a wider perspective, as shown in Figure 9. The elliptical characteristics before COVID-19 include a short semi-axis equaling 0.121, a long semi-axis equaling 0.099, a relative area equaling 0.037, and a rotation angle equaling 51.63°. After COVID-19, the elliptical characteristics changed to the short semi-axis equaling 0.115, the long semi-axis equaling 0.0810, the relative area equaling 0.029, and the rotation angle equaling 67.73°. Although the center of the standard deviation ellipse was shifted 780 m eastward by the epidemic, it can be assumed that there was no significant change in the study area. There is a 22% decrease in the distribution coverage of outdoor sports venues in the study area, which further reflects the decrease in the number of outdoor sports venues.

Figures 10 and 11 illustrate the buffer analysis utilized in this study to analyze the epidemic's impact on the overall outdoor sports venue service coverage. As shown in Figure 10, the epidemic reduced the number of open outdoor sports venues in the south and north of Nanchang, severely affecting the distance to outdoor sports venues from settlements. Figure 11 shows a detailed analysis by calculating the number of settlements around their nearest outdoor sports venues for different buffer distances. Before COVID-19, there were 4440 (96%) settlements within 1 km of an outdoor sports venue and 37 (0.8%) located beyond 2 km. After COVID-19, 3866 (84%) settlements were located within 1 km of an outdoor sports venue, and 130 were located beyond 2 km. Interestingly, the furthest distance between settlements and outdoor sports venues was 7 km before COVID-19. After COVID-19, as shown in Figure 12, for 14 settlements, the distance exceeded 7 km to their nearest outdoor sports venue, and the furthest distance was 19.92 km. As a result, the worst affected residents now need to spend >2 h walking or >1 h riding time to reach their nearest outdoor sports venue. The most affected area was Xinjian District, while other areas centered on Xihu District were less affected, including Donghu District, Honggutan District, Qingshanhu District, and Qingyunpu District. In summary, the distance to outdoor sports venues in Nanchang became longer for most residents as a result of the epidemic, and very considerably so in some cases.

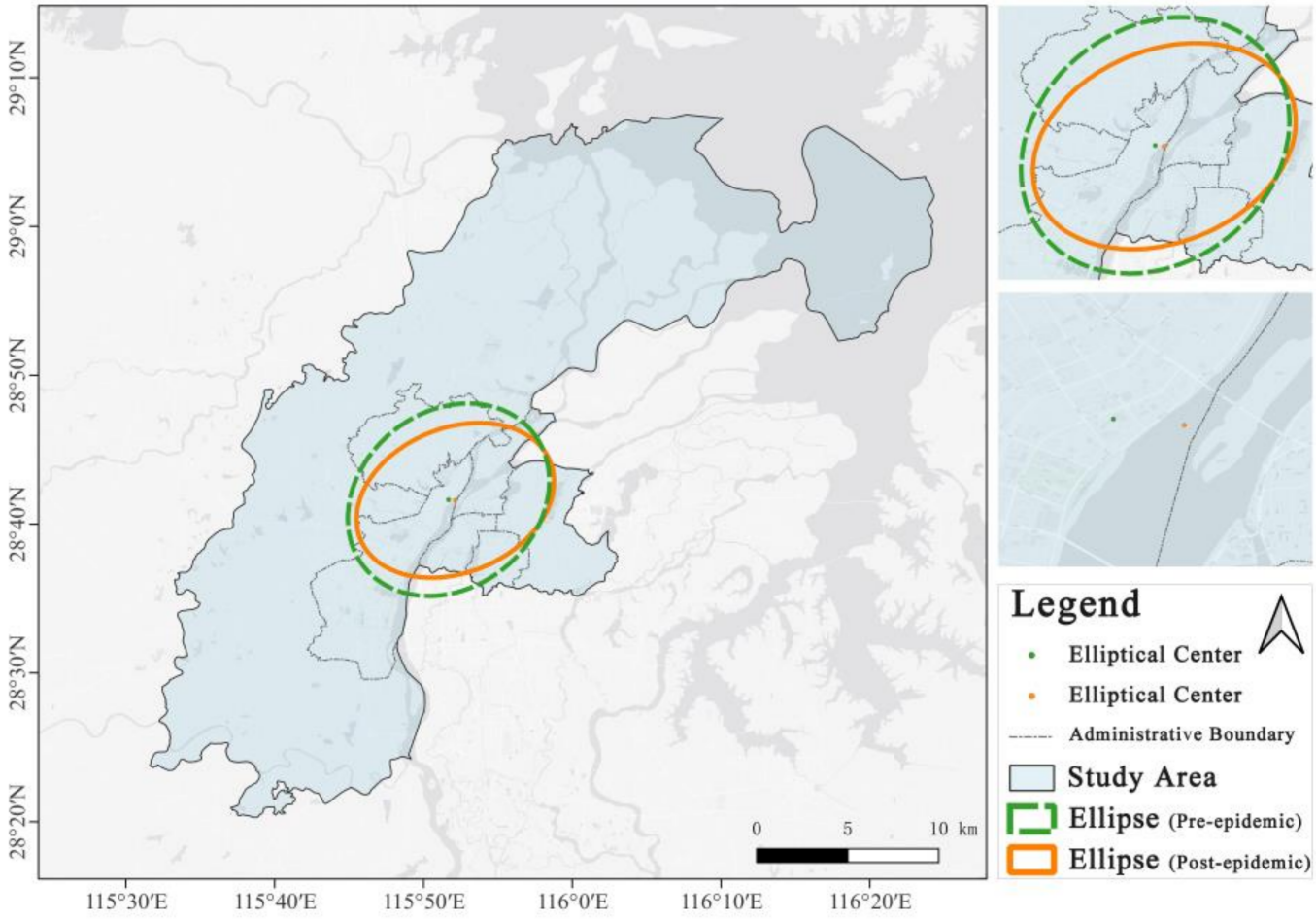


Figure 9. The standard deviation ellipse of outdoor sports venues.

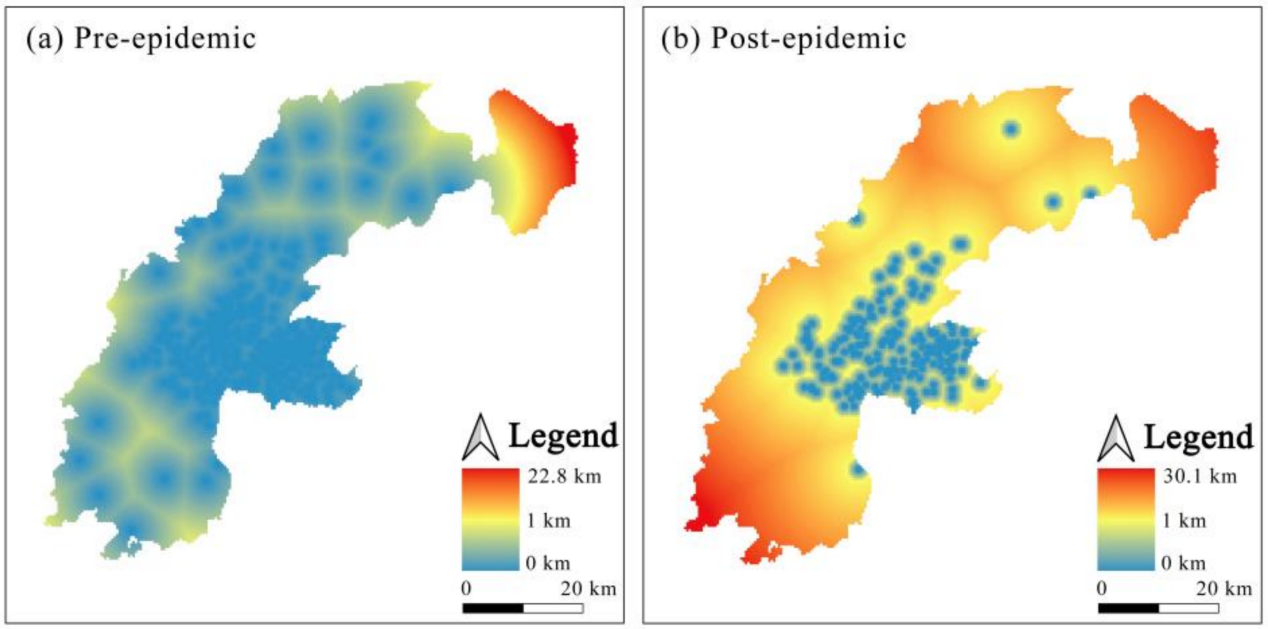


Figure 10. The buffer distance to outdoor sports venues: (**a**) pre-epidemic; (**b**) post-epidemic.

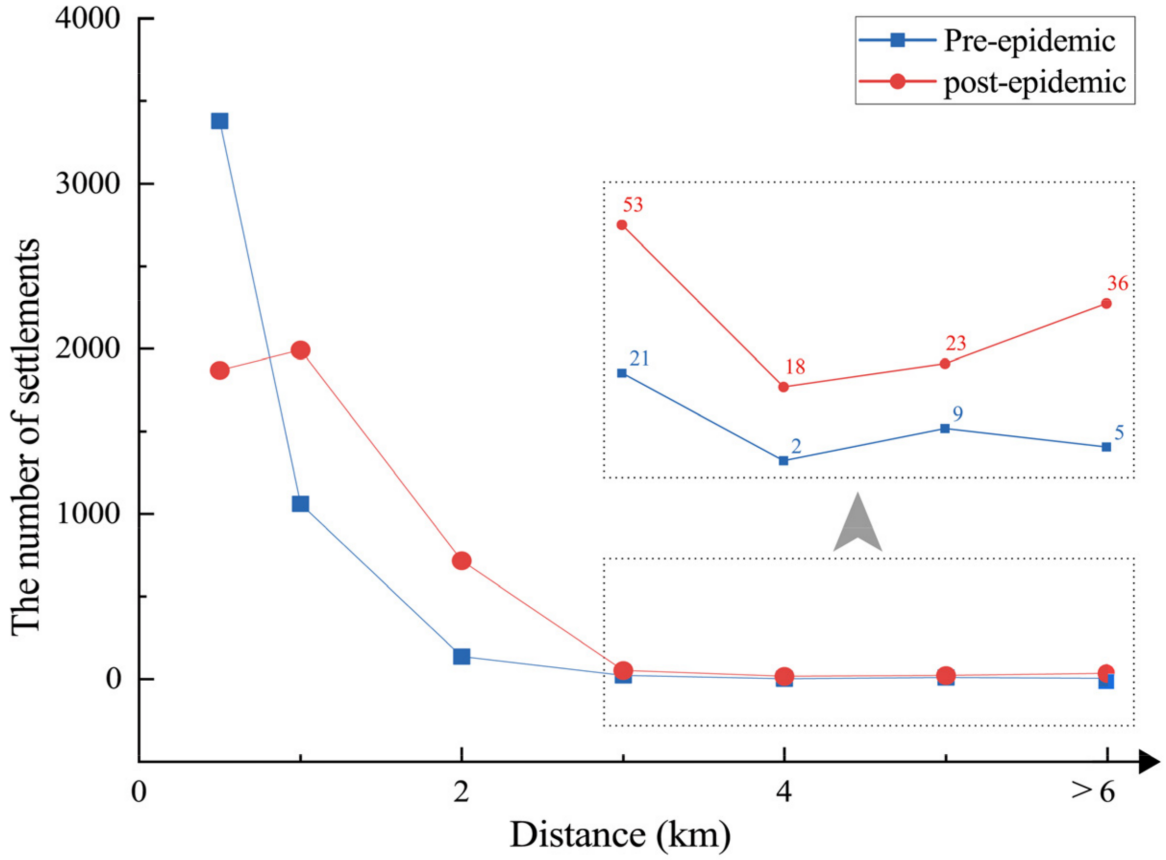


Figure 11. The number of settlements to the nearest outdoor sports venue for different buffer distances.

3.3. Spatial Accessibility

Using the OD cost matrix, accessibility was evaluated in three commuting modes, including walking, riding, and driving, as shown in Figures 13 and 14. Before the epidemic, Figure 13 shows significant regional differences in accessibility in the study area, whereby accessibility in the central region was obviously better than in the southern, western, and northern regions. Taking >30 min, the poorest accessibility regions were the western and southern parts of the study area. The accessibility of the three commuting modes was affected by the epidemic, especially in the red area in Figure 14, where the accessibility time clearly increased as a result of the epidemic. These red areas are mainly in the south and north of the study area. More specifically, it took 17 min of driving, 70 min of riding, and 119 min of walking to reach full accessibility. COVID-19 has caused accessibility to deteriorate and time costs to increase, where it took 29 min by driving, 109 min by riding, and 193 min by walking. This effect of an increased time cost inevitably negatively impacts the level of use of outdoor sports venues for fitness.

Regarding walking and riding as the preferred commuting modes, Figure 15 illustrates the average cost of time spent to reach outdoor sports venues in each district. The results show that the average time cost of these two commuting modes increased in all districts, from 6.2 to 14.0 min and from 4.7 to 8.6 min for walking and riding, respectively. The regions most heavily affected by the epidemic were Xinjian District, followed by Honggutan District, Qingyunpu District, and Donghu District, while those more slightly affected were Xihu District and Qingshanhu District. In terms of riding accessibility, residents in all districts except for Xinjian District were within 10 min of outdoor sports venues after the epidemic. In terms of walking accessibility, the average walking time increased by 7.8 min in the total study area, which is equivalent to walking 1 km more after the epidemic than before it. In conclusion, due to the impact of the epidemic, the time cost spent

reaching outdoor sports venues in Nanchang City has increased, which is not conducive to outdoor exercise.

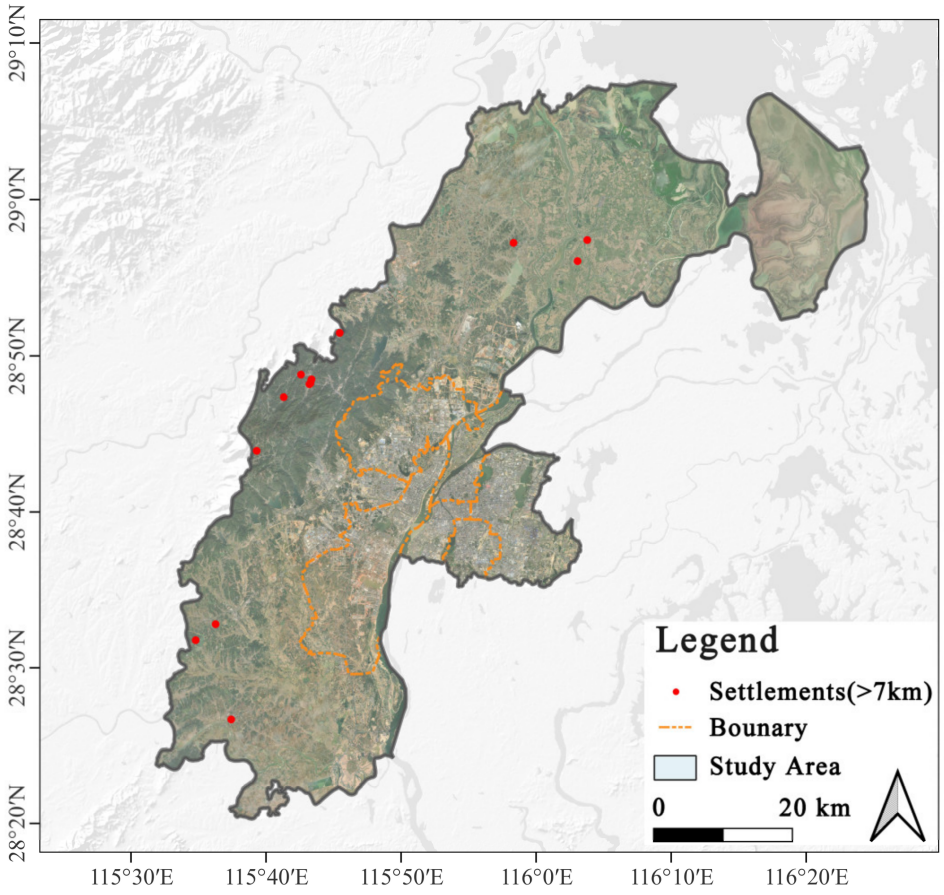


Figure 12. Settlements located more than 7 km from outdoor sports venues after the epidemic.

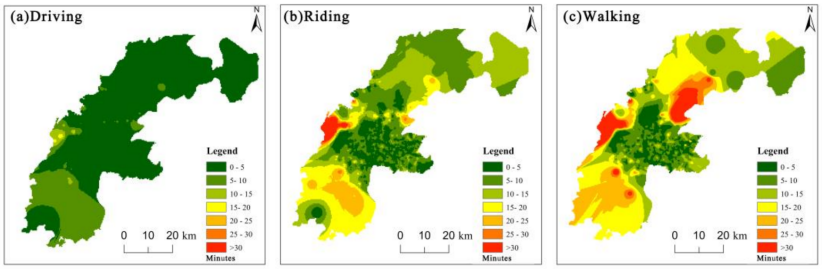


Figure 13. The map of accessibility before the epidemic: (**a**) driving; (**b**) riding; (**c**) walking.

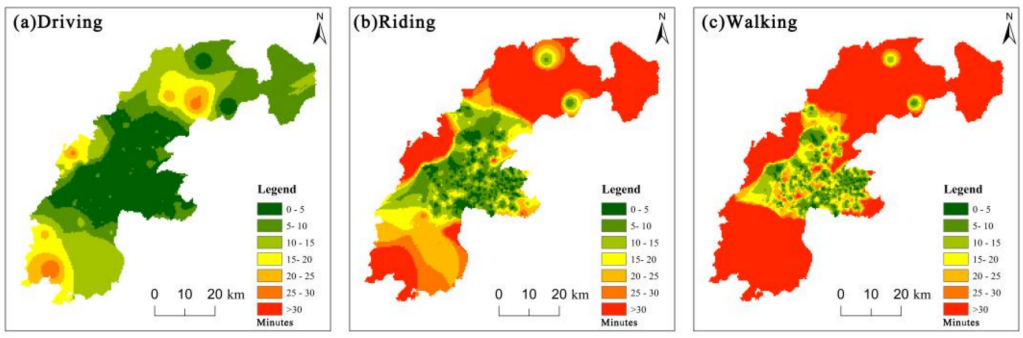


Figure 14. The map of accessibility after the epidemic: (**a**) driving; (**b**) riding; (**c**) walking.

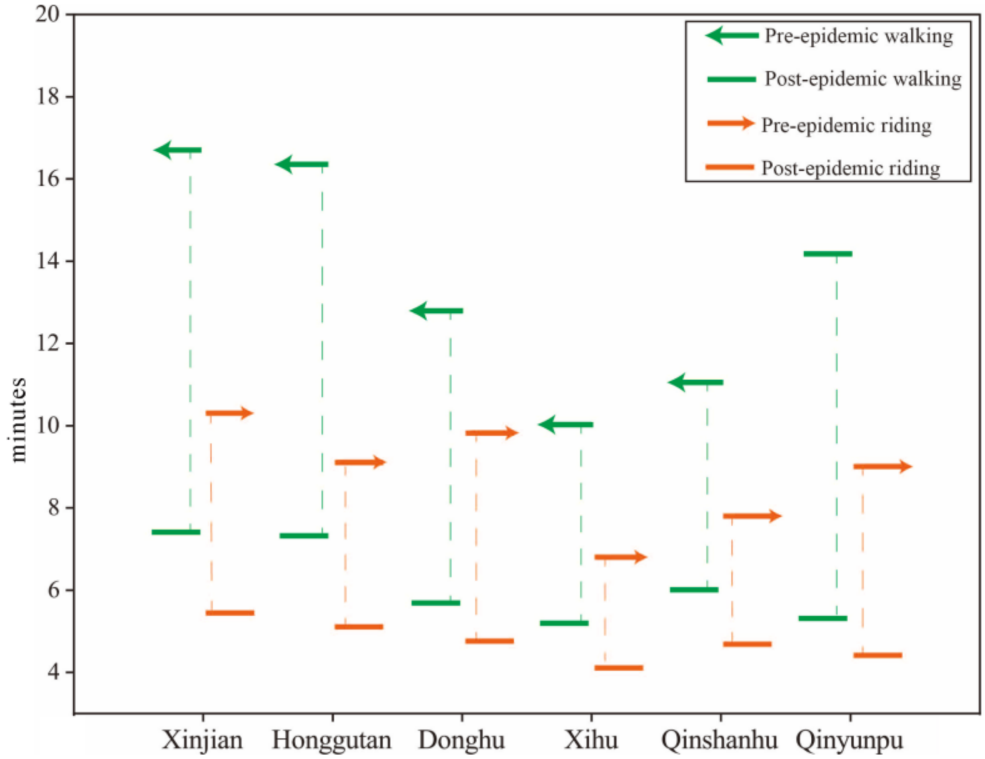


Figure 15. The average time cost of walking and riding in each district.

This study also analyzed the walking accessibility for different types of outdoor sports venue, as shown in Figure 16. Among the kinds of outdoor sports venues, the most severely impacted by the epidemic were soccer courts, with an average walking time of more than 30 min throughout the study area after the epidemic. The epidemic's impact on outdoor basketball courts mainly lay in the northern part of Xinjian District. The epidemic's impact on track and field courts primarily lay in the junction of Xinjian District and the northern part of Honggutan. The epidemic's impact on badminton courts primarily lay in the eastern part of Xinjian District. Finally, the epidemic's impact on badminton courts mainly lay in Qingshanhu District. These results show that the epidemic affected all types of outdoor sports venue. Moreover, Figure 16 indicates that the walking accessibility of track and field courts has the most imbalanced spatial distribution, requiring a 30-minute walk to reach full accessibility. Other outdoor sports venues have different degrees of the imbalanced spatial distribution of accessibility, especially in the north and south of Xinjian District. In summary, the walking time cost has increased for all types of outdoor sports venue in Nanchang, due to the imbalanced distribution of outdoor sports venues.

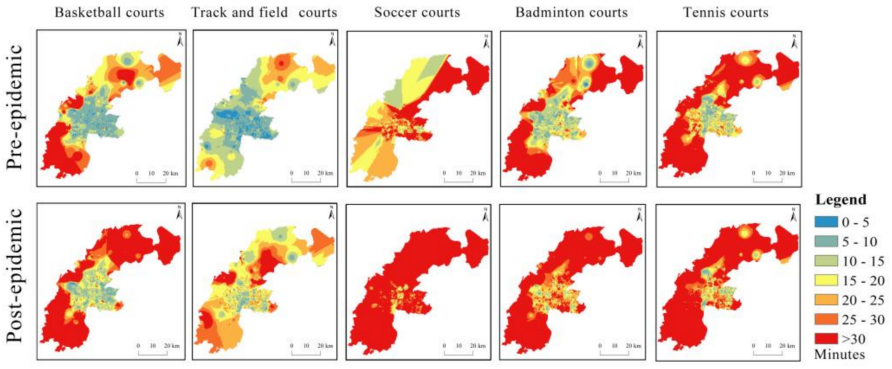


Figure 16. The walking accessibility for different types of outdoor sports venue.

In addition, according to the relevant provisions of "the Novel Coronavirus Pneumonia Prevention and Control Program (Ninth Edition)", the study area was divided into high-risk, medium-risk, and low-risk. People in high-risk areas are prohibited from moving across the district, and the walking accessibility was analyzed for each district under this scenario, as shown in Figure 17. Comparing before and after the epidemic, the necessary time to reach full accessibility was extended from 150 to 162 min in Xinjian District, from 38 to 47 min in Qingyunpu District, from 15 to 26 min in Xihu District, from 17 to 43 min in Donghu District, from 26 to 51 min in Honggutan District, and from 44 to 47 min in Qingshanhu District. The results show that the Donghu District and Honggutan District experienced the longest extension time of about 25 min, followed by Xinjian District, Qingyunpu District, and Xihu District. The slightest impact was an extension time of 3 min in Qingshanhu District. In terms of the average walking time to reach outdoor sports venues before and after the epidemic, Xinjian District was extended from 25 to 34 min, Qingyunpu District from 10 to 17 min, Xihu District from 6 to 12 min, Donghu District from 8 to 16 min, Honggutan District from 11 to 17 min, and Qingshanhu District from 9 to 13 min. In summary, the epidemic's restrictions, and the reduction in the number of open outdoor sports venues, have weakened residents' accessibility to outdoor sports venues.

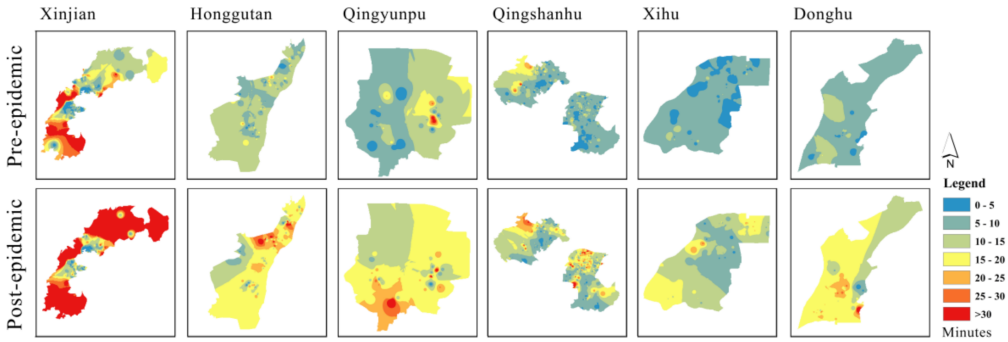


Figure 17. The walking accessibility under the high-risk scenario.

As an essential way to improve immunity, outdoor sports venues are the most reliable infrastructure guarantee for residents to exercise. However, due to the epidemic, the accessibility of outdoor sports venues in all districts has deteriorated to varying degrees, directly affecting residents' exercise patterns and health behavior. From the analyses above involving quantitative features, spatial distribution characteristics, and spatial accessibility, it can be found that the epidemic had the most significant impact on Xinjian District, followed by Qingshanhu District, Honggutan District, and Qingyunpu District, while the slightest impact was on Donghu District and Xihu District. These results can provide valuable guidance to the relevant departments.

4. Discussion

4.1. The Impact of COVID-19 on the Accessibility of Outdoor Sports Venues in Nanchang

Assessing the impact of COVID-19 on outdoor sports venues is beneficial for analyzing the spatial distribution of public sports infrastructure. The spatial distribution and clustering patterns of outdoor sports venues have been analyzed based on KDE and SDE. Moreover, the accessibility analysis method was used to calculate the accessibility and the service area of outdoor sports venues.

The results show that Nanchang's existing outdoor sports venues reveal a regional imbalanced spatial distribution. The eastern part of the Qingshanhu District (the junction of the northern part of Honggutan District and Xinjian District) has become a high-density core area for outdoor sports venues, as shown in Figure 8a. Consistent with Yang's findings, this reflects the apparent spatial divergence in the development of Nanchang's overall infrastructure and weak internal connections [41–43]. This phenomenon is related to the history of the development of the whole urban spatial pattern [44], especially the strategy

of "gradually transforming the old urban areas, enriching and improving the new urban areas, supporting the construction of the northern areas of Nanchang, and developing small towns in a planned manner" as proposed in the "Nanchang Master Plan" [45]. The northern and southern parts of the study area have a limited number of outdoor sports venues, due to low investment in sports development and a severe lack of sports venue equipment, confirmed in Jinping's study [46]. The rapid spread of COVID-19 has led to many regions limiting people's outdoor space and commuting patterns in different ways. In this context, many outdoor sports venues are no longer accessible to the public, adversely affecting the public's health-enhancing exercise. The distribution of closed outdoor sports venues has significant similarities to the distribution of educational resources in Nanchang [47].

Accessibility by the three commuting modes considered was affected to different degrees by the epidemic, as shown in Figures 15 and 16. The reasons for the heaviest impact lying in Xinjian District are the epidemic-resulting closure of outdoor sports venues and poor road construction [48]. Therefore, the construction of the road infrastructure and public outdoor sports venues need to be strengthened in the future. Additionally, there is an imbalance in the diverse structure of outdoor sports venues in Nanchang, with almost no soccer courts in many districts. Especially after COVID-19, the average time to reach soccer courts extended from 18 min to more than 30 min, significantly impacting the diversity of outdoor sports venues available to residents. Under the high-risk scenario, residents are prohibited from moving across districts, which has an even more detrimental effect on their accessibility to outdoor sports venues. The results of this study can be combined with relevant policies to further reduce the epidemic's impact on residents' fitness derived from outdoor sports.

4.2. Suggestions for Outdoor Sports Venues in the Context of COVID-19

Under the epidemic's impact, many outdoor sports venues canceled their services to the public, which affected people's healthy outdoor lifestyles to some greater or lesser extent. As a result, outdoor activities became more limited, and many people suffered from health problems due to a lack of exercise. Facing the spread of epidemics, health awareness summarized by "the more you exercise, the healthier you are" is gaining popularity. However, many regions do not fulfill the requirements of exercise and fitness. By combining the findings of this study with relevant policies, the epidemic's impact on residents' accessibility to outdoor sports venues could be further reduced.

Based on the existing outdoor sports venues in Nanchang, as shown in Figure 4, a "30-minute sports circle" needs to be created to achieve the target of reaching outdoor sports venues within 30 min of walking. It is suggested that the number of outdoor sports venues should be increased in those regions where the time to reach them exceeds 30 min, including the junction of Taiping Town and Zhaoxian Town, the junction of Shibu Town and Shengmi Town, and Jiao Si Town, as shown in Figure 18a. COVID-19 caused 68% of Nanchang's outdoor sports venues to close, inconveniencing the people and reducing their outdoor exercise. Assuming that each outdoor sports venue serves a standard of 20 people, these closures have reduced the service capacity of outdoor sports venues by about 14,000 people in Nanchang. Under the low-risk scenario of COVID-19, the campus-based outdoor sports venues in Xinjian District and Luojia Township are recommended to be re-opened to the public, as shown in Figure 18b. Not only is the opening of outdoor sports venues in line with the purpose of the national fitness movement, which can increase the enthusiasm of the surrounding residents to exercise, but it can also relieve the tension caused by the lack of outdoor sports venues for the public, and increase their service capacity.

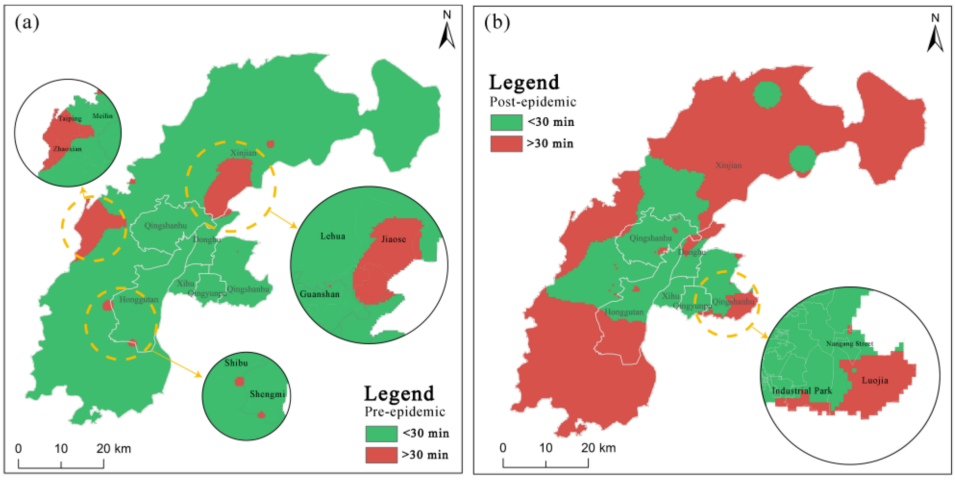


Figure 18. The 30-minute accessibility of residents to outdoor sports venues: (**a**) pre-epidemic; (**b**) post-epidemic.

All kinds of outdoor sports venues can play a good role in promoting the development of diversified sports for the public. The walking accessibility was averaged based on the accessibility results of the five types of outdoor sports venue, where 30-minute accessibility was generated as shown in Figure 19. The following recommendations are made to meet the demand for diversified outdoor sports, where residents can reach all types of outdoor sports venue within 30 min by walking. It is necessary to build multiple types of outdoor sports venue in those regions having only single-type outdoor sports venue, including Meiling Town, Xixiang Town, Shigang Town, and the northern part of Xiangshan Town. In short, building different types of outdoor sports venue would facilitate a diversified choice of outdoor sports and promote healthy lifestyles.

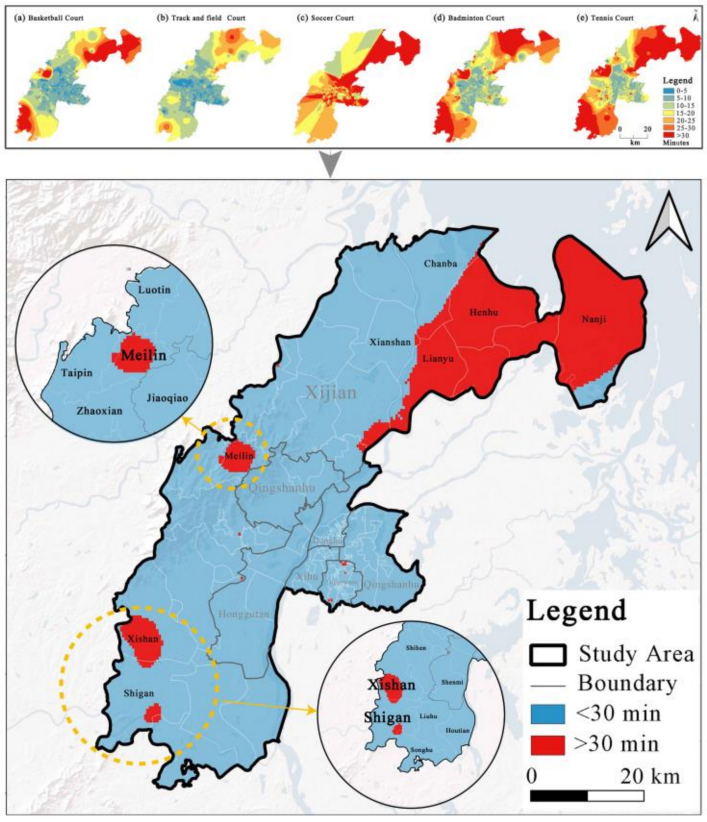


Figure 19. The averaged accessibility based on the results of the five types of outdoor sports venue.

In addition, following "the Novel Coronavirus Pneumonia Prevention and Control Program (Ninth Edition)", the government prohibits residents from moving across districts to avoid spreading the epidemic. Under the high-risk scenario of the epidemic, the accessibility to outdoor sports venues was generated for each district as shown in Figure 20. It is recommended that outdoor sports venues could be appropriately re-opened or constructed to meet the needs of reaching outdoor sports venues within 30 min, especially for those regions including the southern part of Qingyunpu District, the northern part of Honggutan District, and the north and south of Xinjian District. These measures would shorten the time for residents to reach outdoor sports venues and motivate them to exercise, which would help to improve their immunity and prevent the epidemic.

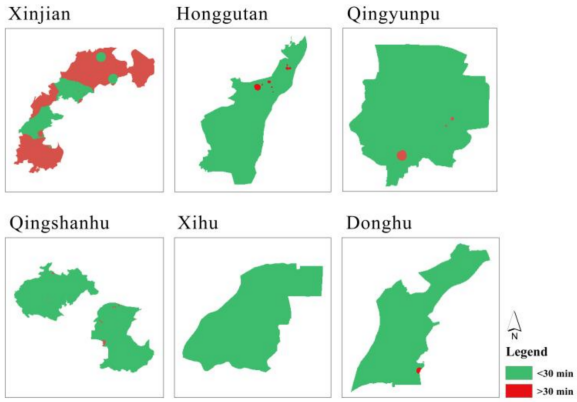


Figure 20. The 30-minute accessibility to outdoor sports venues in each district under the high-risk scenario.

4.3. Limitations and Future Work

This study investigated the epidemic's impact on outdoor sports venues in Nanchang, including quantitative features, spatial distribution characteristics, and spatial accessibility. According to the findings of this study, recommendations were made on how government departments could build or re-open outdoor sports venues as a preventative measure in the wake of the epidemic. These initiatives will shorten the time needed for residents to reach outdoor sports venues and motivate them to exercise, which will help improve their immunity and prevent epidemics. The shortcomings of this study can be addressed in future work as follows. Indoor sports venues can be included in the research to further synthesize the epidemic's impact on the spatial distribution and accessibility of sports venues in the city. The carrying capacity analysis of outdoor sports venues can be incorporated into the research method to further improve the comprehensiveness of the accessibility analysis. In addition, the study area could be expanded and research applied to a larger scale, such as urban agglomerations, nationwide, and globally, in order to more comprehensively analyze the mechanisms of COVID-19 effects on the accessibility of outdoor sports venues.

5. Conclusions

COVID-19 has severe implications for public health, fitness, and wellness for the global public, raising public health issues to a high level. As the most convenient place for residents to exercise, outdoor sports venues improve immunity and reduce mental stress. Therefore, as a matter of great importance for people's health, it is necessary to investigate the epidemic's impact on the accessibility of outdoor sports venues.

The results of this study show that (1) Nanchang has 1044 outdoor sports venues in 5 categories, forming a spatial pattern of "sparse in the north and south, strongly concentrated in the center". The epidemic caused 710 venues to be closed to the public, leaving 334 remaining open. (2) The center of the overall spatial distribution of outdoor sports venues shifted to the southeast, with a 22% reduction in distribution coverage due to the epidemic, whereby the most significant impact lay in the Xihu and Xinjian districts. (3) In the accessibility analysis, the epidemic resulted in the time cost increasing from

17 to 29 min by driving, from 70 to 109 min by riding, and from 119 to 193 min by walking. (4) Under the high-risk scenario of the epidemic, the average walking time increased from 6.2 to 14.0 min across the study area, with an increase of 126%. The impact in descending order is Xinjian District > Honggutan District > Qingyunpu District > Donghu District > Qingshanhu District > Xihu District.

In summary, this study reveals the epidemic's impact on the accessibility of outdoor sports venues in Nanchang City, based on which recommendations for re-opening services and constructions are made. The findings could provide references for government to optimize the distribution of the opening outdoor sports venues during the epidemic.

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