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A Comparison of GIS-based Methods for Modelling Walking Accessibility of Parks in Guangzhou Considering Different Population Groups

Yueshan Ma[1], Paul Brindley[2], Eckart Lange[2]

[1]Univeisity of Sheffield, Sheffield/UK · yma51@sheffield.ac.uk
[2]University of Sheffield, Sheffield/UK

Abstract: The contribution of urban green space (UGS) to an ecologically and socially sustainable city has been recognized by a large body of research. Parks, as a multifunctional types of UGS, provide places for a range of daily activities. The ability to access parks by residents is important for the full use of their functions. Using a case study from Guangzhou, China, we investigate perceived accessibility among different population groups by using questionnaires both onsite and online. In addition, we compare modelling park accessibility using four accessibility measurements using both linear and network distance. We found that whilst age was significantly correlated to the walking time to urban parks, both gender and the level of education were not significantly correlated. Additionally, we identify differences among different accessibility modelling methods, which help specify a more scientific selection of accessibility measuring methods.

Keywords: Park accessibility, comparison of modelling approaches, population groups, GIS-based

1 Introduction

1.1 Background

As rapid urbanization has challenged the natural or semi-natural areas in cities around the world, urban green space (UGS) has ever increasing importance. China is heavily urbanized and parks are a comprehensive type of UGS for providing residents with places for undertaking daily activities. The ability to access parks located within a reasonable distance has positive effects on both physical and psychological health (MANANDHAR, SUKSAROJ & RATTANAPAN 2019, DATZMANN et al. 2018, GHIMIRE et al. 2017).

The measurement of park accessibility of residents has become a key issue in improving public health and physical activities. Accessibility of parks can be seen as a quantified expression revealing how much time, physical power and 'cost' that people are willing to pay for visiting parks (WANG, BROWN, & LIU 2015). Accessibility is closely related to the distribution of parks, the surrounding land use and the distribution of the population (OH & JEONG 2007). Moreover, patterns of park visitation are correlated with different population groups of visitors such as age and income level (CLARKE & NIEUWENHUIJSEN 2009) or gender.

A key question remains how to best analyse UGS accessibility, as it can significantly affect a study's output (MEARS & BRINDLEY 2019). When measuring park accessibility on the city scale, the most common approach utilizes buffer analysis within a Geographic Information System (GIS), whereby the buffer represents distance in terms of walking time. For example, West, Chum and P'Campo (2015) set 10-minute walking distance for analysing the correlation between park quantity and risks of cardiovascular disease. Whilst variants of the simple buffer approach exist, the two-step floating catchment area (2SFCA) method, first proposed

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by Radke and Mu (2000) and subsequently followed by the enhanced two-step floating catchment area (E2SFCA) (LUO & WEI 2009) and three-step floating catchment area (3SFCA) (WAN, ZOU & STERNBERG 2012), there has been little research comparing the effects of the different approaches on park accessibility. Furthermore, fundamentally, it is unlikely that all people will have the same willingness to travel and therefore different groups' preferences for time costs on traveling to a park requires further attention.

1.2 Study Aims and Design

We conducted a case study in Guangzhou, China to firstly investigate the walking preference for park visiting relating to socio-demographic characteristics of age, education and gender. This paper secondly explores the park accessibility levels with four modelling methods at a city scale:

- General Buffer (unweighted) (GB),
- Population-Weighted Buffer (PWB),
- Mean Two-Step Floating Catchment Area (M2SFCAA) and
- Population-Weighted Two-Step Floating Catchment Area (PW2SFCA).

Given two modes of distance measurement methods: straight-linear (crow-flies) and network distance; in total, there are eight types of park accessibility produced for the comparison. Our study focuses on exploring the effect of different parameters and weights on modelling methods. Therefore, we only select 2SFCA for demonstration purposes, although there are alternative methods of basic 2SFCA such as enhanced 2SFCA, Three Step Floating Catchment Area (3SFCA), etc. The paper finally explores the relationship between demographic characteristics (gender, age and education) and park accessibility measurement, which should be then quantified for constructing accessibility models. Additionally, comparison of the output from the various modelling methods is able to contribute to identify that the impact of parameters of accessibility models. Thus, this study enables a more scientific and user-based guidance on park accessibility modelling principles.

2 Materials and Methods

2.1 Study Region and Materials

The study area of this paper is Guangzhou, located in southern China, known as an important part of the Pearl River Delta. The study region (left map in Figure 1) consists of 11 districts including 170 townships and 494 parks (right map in Figure 1). We have standardized several data sources that include 2015 population distribution data at 250-meter resolution from the product Global Human Settlement Layer [1] and public parks, residential areas, roads and township boundaries data from the OpenStreetMap [2], and demographics data from Guangzhou Statistic Bureau [3]. Within each residential area, population distribution data were aggregated with demographic attributes in ArcMap10.7.1, which were then used as the demand object. Park data was processed using park entry points which required manual editing to ensure data completeness. These processes, for example re-projection, merge, spatial relating, weighted overlay and so on, were all conducted in ArcGIS. The investigation on correlation between population groups and preference for walking to parks was analysed by statistical analysis of the questionnaire survey that recruited 2254 respondents online and onsite. This series of statistical analysis was implemented using SPSS Statistics 26.

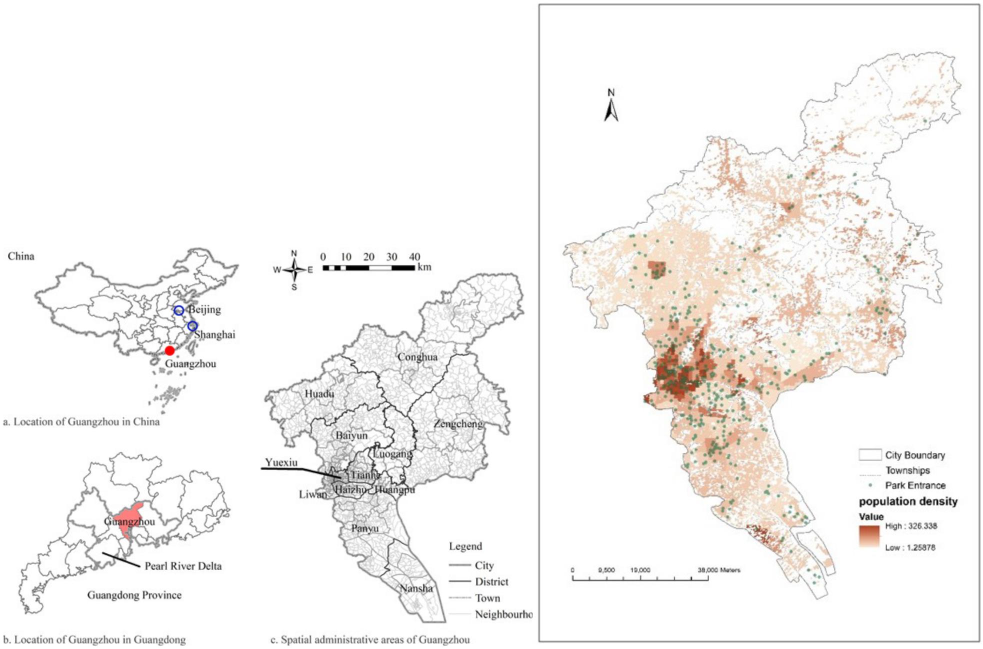

Fig. 1: Location of Guangzhou and administrative district division (the three on the left) (YE et al. 2018) and park entrance distribution and population density in Guangzhou (right)

2.2 Methods

As mentioned above, there are four types of measurement. To be more specific, GB uses mean preferred walking time for modelling population accessing area. The mean preferred walking time is obtained from the calculation on the correlation between relating demographic characteristics and preferred walking time by analysing the questionnaire. PWB employs demographic composition characteristics of different regions for gaining various walking time to generate the buffers. M2SFCA utilises mean preferred walking time for modelling the two catchments based on the traditional 2SFCA analysis method. PW2SFCA uses demographic composition characteristics of different regions for gaining various walking time to conduct the two floating areas on basis of the traditional 2SFCA method. Finally, straight-linear and network distance are used for each method to get eight types of park accessibility.

The demographic characteristics for weighting these models are selected according to their statistical relationship with traveling time, which we used preferred walking time to depict. The data come from questionnaires. In terms of the measure of traveling time, this could be expressed as either the actual traveling time, preferred traveling time or longest traveling time. To be more specific, the actual traveling time stands for the realistic time duration that a person may spend on traveling to a park. The preferred traveling time refers to the amount of time that the person is generally willing to walk until he/she reaches a park. The longest time means the longest time that the person accepts to spend on traveling to a park. We applied the preferred traveling time here as it could reflect the accessibility level based on the public preference aspect. The preferred traveling time is collected from answers responding to a question in the questionnaire, 'Chose the most suitable duration when you walk to a park'. The weights of population groups consist of proportion of correlated demographic groups at each residential point. The demographic weighted traveling time are calculated as Equation (1).

$$T_i = \sum_{n}^{j=1} \frac{D_j}{DG} \times MT_{D_j} \tag{1}$$

T_i is the walking time for residential point i. D_j is the jst group of the correlated demographic group DG. n indicates the number of groups of DG. MT_{D_j} is the statistical mean time for D_j.

Subsequently, different traveling time were used for calculating accessibility grades using four different modelling methods as elaborated in Section 1.2. The final results represent the absolute area of parks per capita at residential locations (2015 population distribution data at 250-meter resolution [1]). The result of accessibility level was depicted by the size of symbols on the map, where these absolute values were classified into five groups with Natural Breaks (Jenks) classification method for explaining the hierarchical distribution of accessibility levels more clearly.

3 Results

The analysis results of this study can be summarized into two parts: (1) explore effects of demographic characteristics on park accessibility, (2) comparison of four types of park accessibility modelling analysis. These results show which demographic characteristics (age, gender, education) correlate with park accessibility, how these correlations can be quantified as parameters for improving park accessibility analysis, what differences occurred between the different modelling methods, and how to sensibly reduce the impact of the instability of different models on the analysis results.

3.1 Explore Possible Effects of Demographic Characteristics on Park Accessibility

The first step of this research is to identify whether different groups of people have the same preference for walking to urban parks and which demographic characteristics are statistically significant. We conducted statistical analysis to explore the relationship between the preferred walking time to parks and three demographic characteristics of age, level of education and gender.

The age groups show a significant correlation with the preferred walking time with the Asymptotic Significance (p-value) less than 0.01 and less than 10% cells having expected count less than 5 (Table 1). In contrast, there was no significant statistical relation between the preferred walking time and gender (Table 2). In terms of level of education, although the Asymptotic Significance is less than 0.05, the test fails the model's assumption as greater than 10% of cells had an expected count less than 5 (Table 3) – despite aggregating the number of levels of education categories (one is senior high school and below, another is junior college and above). As a result, we cannot be confident to prove a significant correlation between level of education and preferred walking time whereby the preferred walking time increase as the level of education increase until the junior college, after which the preferred walking time decrease as the level of education increase.

Table 1: Chi-Square Tests for the correlation of the preferred walking time and age groups

	Value	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	141.117a	16	.000
Likelihood Ratio	128.475	16	.000
Linear-by-Linear Association	43.049	1	.000
N of Valid Cases	2254		
a. 2 cells (8.0%) have expected count less than 5. The minimum expected count is 1.88.			

Table 2: Chi-Square Tests for the correlation of the preferred walking time and the gender groups

	Value	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	3.111a	4	.539
Likelihood Ratio	3.123	4	.538
Linear-by-Linear Association	1.000	1	.317
N of Valid Cases	2254		
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 31.41.			

Table 3: Chi-Square Tests for the correlation of the preferred walking time and level of education groups

	Value	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	169.703a	20	.000
Likelihood Ratio	132.041	20	.000
Linear-by-Linear Association	2.650	1	.104
N of Valid Cases	2254		
a. 4 cells (13.3%) have expected count less than 5. The minimum expected count is 1.18.			

Therefore, we summarized the preferred walking time for each age group using the mean value of the preferred walking time range, in which '2' stands for '10 to 20 minutes' and '3' stands for '21 to 30 minutes', and then transformed into specific minutes as shown in Table 4. Surprisingly, we also observed that the preferred walking time continues to increases with age, which is at odds with some previous studies that states older people tend to make shorter trips to the park (LIANG 2018, RAHMAN & ZHANG 2018, DE SOUSA SILVA et al. 2018).

Table 4: Statistical mean of proper walking time ranges and transformed specific minutes in each age group (2254 pieces of data in total)

Age Group	Counts	Statistical Mean	Minutes	Std. Error
18 to 24 years old	263	2.16	21.6	.066
25 to 30 years old	782	2.30	23.0	.033
31 to 40 years old	931	2.46	24.6	.029
More than 40 years old	278	2.74	27.4	.072

3.2 Comparison of Four Types of Accessibility Modelling Analysis

This analysis applied four modelling methods to calculate park accessibility as explained in the introduction, namely GB, PWB, MSFCAA and PW2SFCA. Additionally, the distance measure used for modelling included both straight-linear and network distance for the four methods. Output for all eight measures of park accessibility were summarized in Table 5. Figure 2 depicts these eight types of park accessibility in the central city area for showing detailed geographic differences.

Table 5: Four types of accessibility modelling methods with two kinds of distance measure

	GB	PWB	M2FCA	PW2SFCA
Straight-linear distance	Straight-linear distance buffers; none-weighted walking time	Straight-linear distance buffers; none-weighted walking time	Straight-linear distance 2SFCA; none-weighted walking time	Straight-linear distance 2SFCA; population-weighted walking time
Network distance	Network distance buffer; none-weighted walking time	Network distance buffer; population-weighted walking time	Network distance 2SFCA; none-population weighted walking time	Network distance 2SFCA; population-weighted walking time

The differences in park accessibility between different modelling methods have been reflected in the size of the green area in Figure 2 above. In order to demonstrate these differences more clearly, we quantified the differences and compared them under three cases as shown in Table 6: PALD value greater than PAND value, PALD value less than PAND value, and PALD value less than PAND value. It can be found that there are differences when using different modelling methods, types of distance and weights to conduct the park accessibility levels.

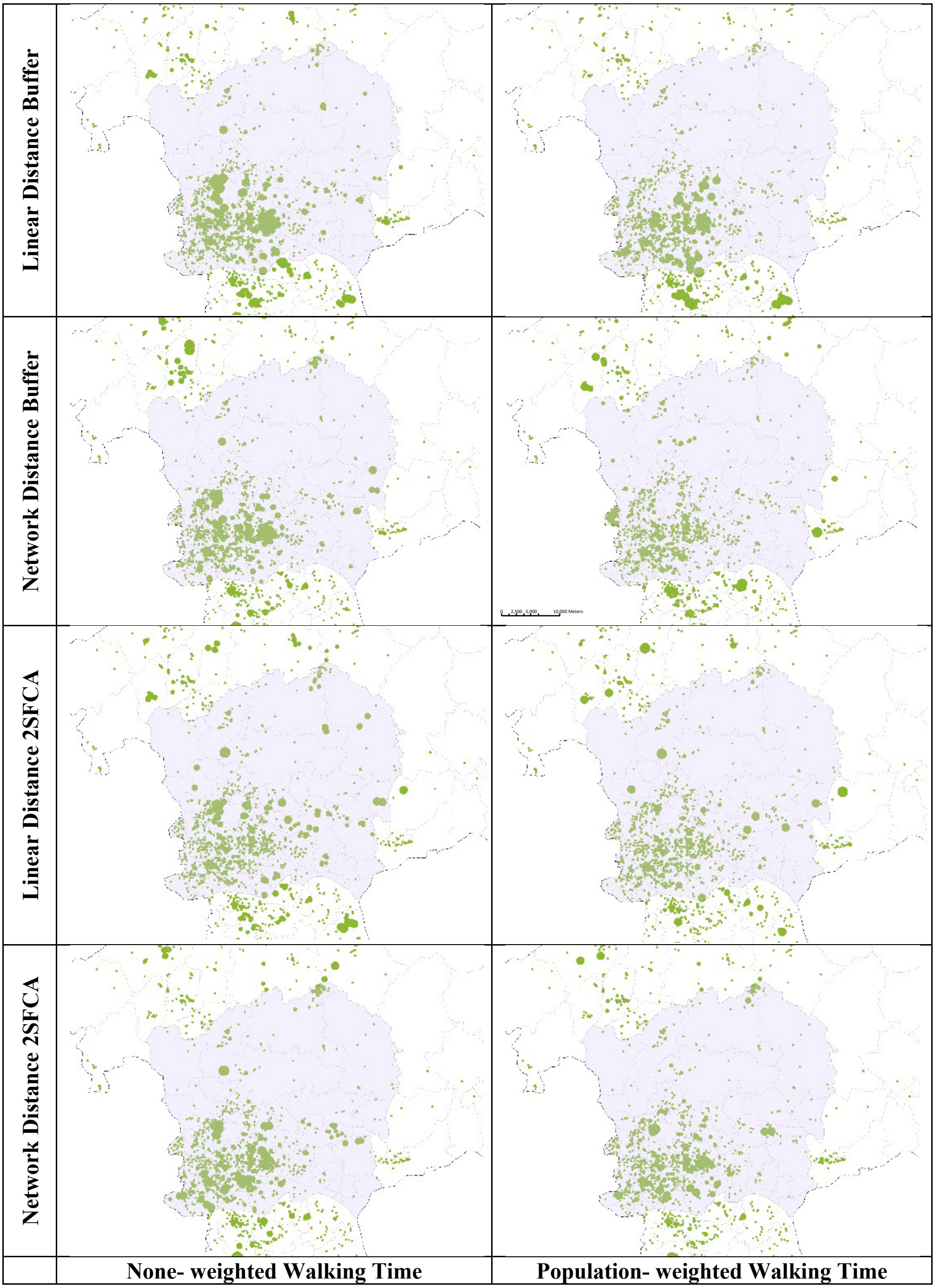

Fig. 2: Distribution of park accessibility levels (green area) with different methods in the central city area (purple area) of Guangzhou. The bigger the size of the green dot, the higher accessibility level of these residential points.

Table 6: Comparison of Park Accessibility with Linear Distance (PALD) and Park Accessibility with Network Distance (PAND)

Cases	None-weighted traveling time	Population weighted traveling time	2SFCA and none-weighted traveling time	2SFCA and population weighted traveling time
PALD > PAND Percentage (%)	74.71	32.35	54.12	27.06
PALD < PAND Percentage (%)	13.53	50.59	35.29	52.35
PALD = PAND Percentage (%)	11.76	17.06	10.59	20.59

Table 6 shows that the none-weighted time buffer method has the most overestimation of park accessibility considering the effect of the difference between using linear distance and network distance on accessibility measurement, with the highest percentage of 'PALD > PAND' at 74.71%. Meanwhile, such instabilities of accessibility measurement caused by the effect of difference between using linear distance and network distance could be somehow reduced by introducing population-weighted traveling time buffer method, 2SFCA with none weighted traveling time method or 2SFCA with population-weighted traveling time method. Among these three methods, using the method of 2SFCA with population-weighted traveling time could reduce the impact of the different types of distance on park accessibility measures to the most extent, with the most proportion of 'PALD = PAND' at 20.59%.

When exploring the influence of the none-weighted and the population-weighted traveling time on the assessment of park accessibility, Table 7 shows that using linear distance would overestimate of accessibility grades of none-weighted traveling time at a highest level, either with 2SFCA or with general buffer, whose proportions of 'PANTT > PAPTT' are both over 85%. The least difference and most stability of using different traveling time for park accessibility measures have a higher 'PANTT = PARTT' proportion, 20.59%, with the assistance of 2SFCA network distance method regardless of 79.41% accessibility grades varying with different traveling time. It also indicates that none-weighted traveling time for park accessibility measure usually overestimate the accessibility levels (compared to population-weighted traveling time for park accessibility measures), regardless of the types of distance and the analysis models (general buffer, 2SFCA).

Table 7: Comparison of Park Accessibility with None-weighted Traveling Time (PANTT) and Park Accessibility with Population-weighted Traveling Time (PAPTT)

Cases	Linear distance	Network distance	2SFCA and linear distance	2SFCA and network distance
PANTT > PAPTT Percentage (%)	85.29	59.41	87.06	55.29
PANTT < PAPTT Percentage (%)	3.53	28.82	1.18	24.12
PANTT = PAPTT Percentage (%)	11.18	11.76	11.76	20.59

We also explored the effect of different models on accessibility evaluation. The measuring results of park accessibility using general buffer model are always higher than those using the 2SFCA model, even if the types of distance are changed and/or the traveling time is weighted (Table 8). The severest and the lightest overestimation that the general buffer model conducts for park accessibility levels respectively exist in the employment of none- weighted traveling time and linear distance method, and the employment of population-weighted traveling time and linear distance. Moreover, the effect of using general buffer and 2SFCA methods on park accessibility measure's differences can be reduced by utilizing the combination of population-weighted traveling time and linear distance.

Table 8: Comparison of Park Accessibility with Buffer (PAB) and Park Accessibility with 2SFCA (PA2SFCA)

Cases	None-weighted traveling time and linear distance	None-weighted traveling time and network distance	Population-weighted traveling time and linear distance	Population-weighted traveling time and network distance
PAB > PA2SFCA Percentage (%)	86.47	77.06	47.65	52.35
PAB < PA2SFCA Percentage (%)	0	1.76	24.71	35.88
PAB = PA2SFCA Percentage (%)	13.53	21.18	27.65	11.76

4 Discussion and Outlook

Whilst there remains a need for further research, this paper demonstrates the influence of demographics on park accessibility, which are usually oversimplified through setting the traveling time based on literature or according to the park design principle such as 500-meter walking distance (CETIN 2015), 800-meter walking distance (LIANG & ZHANG 2018, RAHMAN & ZHANG 2018) and so on. Our study, using empirical data from questionnaires, offered a verification that people’s preferred walking time to the park correlated to their age. Most importantly, we verified and applied the effect of population age characteristics on walking time, which was quantified as the weights of traveling time for modelling park accessibility, making accessibility analysis more scientific and closer to the reality.

Another finding reflected that using different types of distance measure (straight-linear/ network), traveling time (mean/ population-weighted) and modelling methods (buffer/ 2SFCA) could affect the park accessibility model analysis results to varying degrees. Notably, weighting the traveling time with the demographic characteristic of age group, reduced the impacts of the differences caused by either type of model or type of distance on park accessibility measure. In summary, various combinations of traveling time’s weight, model’s type and traveling distance have been proved to all have differences in measuring the park accessibility, which is not simply a question of which combination is more accurate but rather depends on the purpose of the accessibility analysis. For instance, when linear distance and network distance cannot be used at the same time, it was concluded from this study that using population-weighted walking time and 2SFCA model can minimize the instability of accessibility analysis results caused by different distance measures. Therefore, the parameters of different methods for assessing park walking accessibility should be decided scientifically and comparatively.

Certain limitations should be noted that affect the accuracy of our analysis. For example, the lack of high precision data, lacking exhaustive study on the diversity and updating of accessibility analysis models like introducing distance decay, Three Step Floating Catchment Area (3SFCA) and so on. We will adapt more modelling methods of park accessibility analysis for future work. Another flaw could be that we cannot robustly analysis data at an individual park scale. Therefore, on average with 2254 respondents and 494 parks, on average there would only be 4 samples for each park. However, our main goal was not to study people's visiting preferences based on individual park differences, but to explore the relationship between the length of travel to parks and population characteristics. Our further research will further explore the relationship between people's visit preference and demographic characteristics based on features of individual parks.

Nonetheless, this study has provided an innovative methodology for a more accurate and public-perceived park accessibility measurement by discussing the comparison of different types of park accessibility under different scenarios. It could offer scientific clues and park accessibility modelling principles based on the public perception.

References

CETIN, M. (2015), Using GIS analysis to assess urban green space in terms of accessibility: case study in Kutahya. International Journal of Sustainable Development & World Ecology, 1-5. doi: 10.1080/13504509.2015.1061066.

CLARKE, P. & NIEUWENHUIJSEN, E. R. (2009), Environments for healthy ageing: A critical review. Maturitas, 64, 14-19.

CHUM, A. & O'CAMPO, P. (2015), Cross-sectional associations between residential environmental exposures and cardiovascular diseases. BMC Public Health, 15, 438.

DAHMANN, N., WOLCH, J., JOASSART-MARCELLI, P., REYNOLDS, K. & JERRETT, M. (2010), The active city? Disparities in provision of urban public recreation resources. Health and Place, 16(3), 431-445. https://doi.org/10.1016/j.healthplace.2009.11.005.

DATZMANN, T., MARKEVYCH, I., TRAUTMANN, F., HEINRICH, J., SCHMITT, J. & TESCH, F. (2018), Outdoor air pollution, green space, and cancer incidence in Saxony: a semi-individual cohort study. BMC Public Health, 18 (1).

DE SOUSA SILVA, C., VIEGAS, I., PANAGOPOULOS, T. & BELL, S. (2018), Environmental Justice in Accessibility to Green Infrastructure in Two European Cities. Land, 7(4), 134. doi: 10.3390/land7040134.

GHIMIRE, R., FERREIRA, S., GREEN, G., POUDYAL, N., CORDELL, H. & THAPA, J. (2017), Green Space and Adult Obesity in the United States. Ecological Economics, 136 (C), 201-212. doi: 10.1016/j.ecolecon.2017.02.002.

LIANG, H. & ZHANG, Q. (2018), Assessing the public transport service to urban parks on the basis of spatial accessibility for citizens in the compact megacity of Shanghai, China. Urban Studies, 55 (9), 1983-1999.

LUO, W. & QI, Y. (2009), An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. Health & place, 15 (4), 1100-1107.

MANANDHAR, S., SUKSAROJ, T. & RATTANAPAN, C. (2019), The Association between Green Space and the Prevalence of Overweight/ Obesity among Primary School Children. The International Journal of Occupational and Environmental Medicine, 10 (1), 1-10.

MEARS, M. & BRINDLEY, P. (2019), Measuring Urban Greenspace Distribution Equity: The Importance of Appropriate Methodological Approaches. ISPRS International Journal of Geo-Information, 8 (6), 286. doi: 10.3390/ijgi8060286.

OH, K. & JEONG, S. (2007), Assessing the spatial distribution of urban parks using GIS. Landsc. Urban Plann, 82, 25-32.

RADKE, J. & MU, L. (2000), Spatial decompositions, modelling and mapping service regions to predict access to social programs. Ann. GIS, 6, 105-112. https://doi.org/10.1080/ 10824000009480538.

RAHMAN, K. & ZHANG, D. (2018), Analyzing the Level of Accessibility of Public Urban Green Spaces to Different Socially Vulnerable Groups of People. Sustainability, 10 (11), 3917. doi: 10.3390/su10113917.

SPACES TO DIFFERENT SOCIALLY VULNERABLE GROUPS OF PEOPLE. Sustainability, 10 (11), 3917. doi: 10.3390/su10113917.

WAN, N., ZOU, B. & STERNBERG, T. (2012), A three-step floating catchment area method for analyzing spatial access to health services. International Journal of Geographical Information Science, 26(6), 1073-1089.

WANG, D., BROWN, G. & LIU, Y. (2015), The physical and non-physical factors that in- fluence perceived access to urban parks. Landscape and Urban Planning, 133, 53-66.

YE, C., ZHU, Y., YANG, J. & FU, Q. (2018), Spatial equity in accessing secondary education: Evidence from a gravity-based model. Canadian Geographer, 62(4), 452-469. https://doi.org/10.1111/cag.12482.

[1] https://ghsl.jrc.ec.europa.eu/download.php?ds=pop (December 14, 2021).

[2] https://www.openstreetmap.org/ (December 10, 2021).

[3] http://tjj.gz.gov.cn/pchb/dlcrkpc/ (December 10, 2021).