THE ACCESSIBILITY AND SPATIAL PATTERNS OF GREEN OPEN SPACE BASED ON GIS

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ABSTRACT:

Studies show that the green open space (GOS) is beneficial to visitors' mental and physical health and has positive social values. This study took four global cities as examples, namely Shanghai, Tokyo, New York and London. The per capita area, the coverage rate and the availability of GOS were calculated in this study. Then the GOS was classified according to the scales and morphological features. And the author analyzed the relations between availability and spatial patterns. The results showed that the four cities could be classified into two classes. Shanghai and Tokyo are high-population-density cities with medium GOS coverage and availability, and New York and London are medium-population-density cities with high GOS coverage and availability. It was found that the high GOS coverage rate did not necessarily lead to a higher availability. Shanghai and London could increase the amount of small GOS to ease the shortage of availability. And London and Tokyo could consider adding linear GOS to improve the connectivity of GOS.

1. INTRODUCTION

The GOS is one of the important elements of a city. It provides venues to citizens for entertainment and leisure and has certain social function. Frequent visits to GOS are beneficial to mental and physical health. Moreover, it possesses great ecological service values.

People are more likely to benefit from the GOS with high quality. The remote-assessment method is able to evaluate the quality of a large number of open space without direct observation (Taylor et al., 2011). It is found that the quality of open space in deprived urban areas cannot satisfy the residents, and the inequality exists in some areas (Hoffimann et al., 2017; Abbasi et al., 2016). For one thing, the higher quality and percentage of open space probably lead to better quality of life (Ambrey and Fleming, 2013; Douglas et al., 2018); for another, the area of open space and the distance to open space will influence the price of a house (Wu et al., 2015; Cho et al., 2010). There is a study demonstrating that the abundant vegetation in open space relates to the lower crime rate (Wolfe and Mennis, 2012). Furthermore, urban green infrastructure is beneficial to the urban sustainability and ecological health (Lovell and Taylor, 2013).

Kabisch et al. (2016) calculated the availability of urban green space based on the land cover data and population data grid. Xu et al. (2018) assessed the impact of urban dynamics on the availability of green space under different scenarios at both regional and sub-regional level. Cetin (2015) found that the distance and the accessibility of green space were closely related to the provision of recreational needs in Kutahya. Wu et al. (2017) used gravity-based accessibility by park type and then explored the relationships between accessibility to parks and housing prices using a hedonic price model. Kim and Nicholls (2017) explored the accessibility and equity of open space by using the geographically weighted regression in Detroit Metropolitan Area. Kang (2015) investigated the impact of accessibility to land use on walking in Seoul by using four newly developed accessibility indices.

Thus far, there is no research to study the relationship between availabilities and spatial patterns of GOS. This study calculated the availabilities and analysed the spatial patterns of four cities, and then investigated the correlation between them. The remainder of the paper is organized as follows. The first section introduces the background information of the study areas. The second section presents the data sources and the research methods. The third section explains the results of GOS indices, the availability and the spatial patterns. The fourth section discusses the relations between the availability and the distribution of GOS and assesses the impacts of spatial pattern of GOS. In the final section, the study summarizes the results and suggests policy implications.

2. STUDY AREAS: SHANGHAI, TOKYO, NEW YORK AND LONDON

This study selected the four global cities Shanghai, Tokyo, New York and London as examples for the following reasons. According to the world city ranking 2018 (published by GaWC), London and New York are the Top 2 world cities and classified as Alpha ++. Shanghai and Tokyo which are in Alpha+ level, are two of the most competitive metropolises in Asia. While Shanghai and Tokyo are high-density cities, which is different from New York and London. We can make the comparison of the GOS distribution in different global cities by conducting analysis in the foregoing four cities.

The study areas of the four cities are the central city of Shanghai, the special wards of Tokyo, New York City and London postal district (They are called Shanghai, Tokyo, New York and London below). These four study areas are central areas of their respective metropolitan areas. And they have similar land areas, which makes the four global cities more comparable. The unit of analysis of the central city of Shanghai is subdistrict. In this study, the subdistricts whose governments are within the Shanghai outer ring expressway constituted the study region. The London postal district is comprised of the E, EC, N, NW, SE, SW, W and WC postcode areas. The unit of analysis of London postal district is

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wards. If more than half of one ward's land area is within the London postal district, it was included in the study area. The unit of analysis of the special wards of Tokyo and New York City are district (chome) and neighborhood. The study areas of Shanghai, Tokyo, New York and London comprise 104, 3184, 359 and 194 units respectively. The populations and areas of the four cities are shown in table 1.

City	Population	Area (km^2)	Unit of Analysis
Shanghai	11061971	683.88	104
Tokyo	9272740	628.54	3184
New York	8175133	783.12	359
London	4874271	624.54	194

Table 1. Basic information of the study areas

3. DATA AND METHODS

The three indices which are per capita area, coverage rate and availability of GOS were calculated in this research. The availability is the proportion of citizens who can access the GOS, and it was calculated on the basis of the methods proposed by Kabisch et al. (2016).

3.1 Data Sources and Pre-processing

The research data in this study includes the spatial data of population (Figure 1) and GOS of the four study areas. The demographic data of the four cities was acquired from their official census data. And the data sources of their GOS data are different. The vector data of GOS of Shanghai was outlined by the author based on the digital map of tianditu. To be specific, the author added the Tianditu from WMS (Web Map Service) and a new polygon shapefile in QGIS, and then outlined the GOS in the shapefile by adding new features. The data of Tokyo and London is the vector data of open street map which is exported from Hotosm. The data of New York City is downloaded from the website of NYC OpenData. The detailed information of the data sources is described in the table 2.

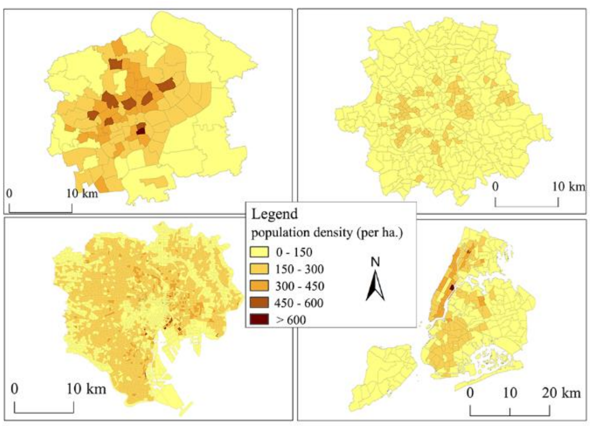

Figure 1. The population density of the four study areas

3.2 The per capita area and coverage rate of GOS

The two GOS indices including per capita area and coverage rate were calculated in this study. The per capita area is the quotient of dividing the total area by the population. And the coverage rate is the ratio of the area of GOS to the area of the study region.

City	Data Sources
Shanghai	Demographic data: Sixth National Population Census of China (year 2010) GOS data: Tianditu (year 2019, http://www.tianditu.gov.cn/)
Tokyo	Demographic data: National Population Census of Japan 2015 GOS data: open street map exported from Hotosm (year 2019, https://export.hotosm.org/en/v3/)
New York	Demographic data: New York City Population By Neighborhood Tabulation Areas (year 2010,https://data.cityofnewyork.us/City-Government/New-York-City-Population-By-Neighborhood-Tabulatio/swpk-hqdp) GOS data: the data provided by NYC Open Data (year 2018, https://data.cityofnewyork.us/Recreation/Open-Space-Parks-/g84h-jbjm)
London	Demographic data: 2011 Census Demography (https://data.london.gov.uk/dataset/981e9136-a06a-44ec-a067-10f3d786cd3f) GOS data: open street map exported from Hotosm (year 2019, https://export.hotosm.org/en/v3/)

Table 2. Data sources of demographic and GOS data

3.3 The availability of GOS

Firstly, this paper determined the accessibility standard. The four cities in this study have different accessibility standards (table 3). This study synthesized the four cities' accessibility standards and developed a new standard to compare the accessibility of the four cities. In Europe, the European Environment Agency (EEA) recommends that people should have access to green space within 15 min walking distance (Barbosa et al., 2007). People's walking velocity is 1.3m/s to 1.4m/s (Ji and Pachi, 2005), so the upper limit set for the service distance is 1200 meters. In addition, the smallest GOS in the four cities' accessibility standard is 0.25 hectares, so 0.25 hectares is the minimum land area which has the shortest service distance 250 meters. And the availability of GOS smaller than 0.25 hectares is not calculated.

Secondly, the author created the buffer zones for the GOS in QGIS. In order to determine the region having access to the GOS, the author created the buffer zones for the GOS according to the accessibility standard. This work was done in QGIS by using the "buffer" function in processing toolbox.

Thirdly, this paper calculated the availability. The availability is calculated based on the buffer zones and the population data. In QGIS, the population data intersected with buffer zones of GOS using the "intersection" in the vector geoprocessing tools and then the buffer zones in each unit of analysis are obtained. Supposing one study urban area C have n units of analysis, the number of citizens in one unit of analysis that have access to the GOS is given by:

$$Q_i = P_i \frac{B_i}{A_i} \quad i = 1, 2, ..., n \tag{1}$$

where P_i = citizen number of the analysis unit i
B_i = intersection land area of the analysis unit i with the buffer zones
A_i = land area of the analysis unit i.

The availability of the study urban area C is given by:

$$R(C) = \frac{\sum_1^n Q_i}{\sum_1^n P_i} \quad i = 1, 2, ..., n \tag{2}$$

City	Reference Standard	Size of Open Space and Service Distance
Shanghai	Technical criteria for regulatory planning of Shanghai (amended version 2016)	0.04 hectares, 300-500 meters; 0.3 hectares, 500-1000 meters; 4 hectares, 2000 meters; 10 hectares, 5000 meters
Tokyo	City planning park · the improvement policy of green space (amended version)	2500 square meters, 250 meters; 10 hectares, 2 kilometers
New York	National recreation & park association (NPRA) parks and open space guidelines	1 arce, 1/4 mile; 5-10 arces, 1/4-1/2 mile; 30-50 arces, 1/2-3 miles; > 50 arces, services the entire community.
London	The London Plan March 2016	2 hectares, 400 meters; 20 hectares, 1.2 kilometers; 60 hectares, 3.2 kilometers; 400 hectares, 3.2-8kilometers

Table 3. The availability standards of the four cities

4. RESULTS

4.1 The per capita area and coverage rate of GOS

The total area and per capita area of GOS are shown in table 4. For New York, it has the highest area and coverage rate and the second-highest per capita area of GOS. The coverage rate and per capita area of New York is 12.18% and 11.65 m^2. London is next to New York in area and coverage rate, and ranks first in per capita area. London's per capita area is 15.21 m^2 and its coverage rate is 10.83%. The values of Shanghai and Tokyo are inferior to those of New York and London. The per capita area and coverage rate of Shanghai and Tokyo are less than half of London's and New York's.

4.2 The availability of GOS

Figure 2 and Figure 3 show the area and number of GOS based on the classification standard (table 5) in 3.3.1. There are numerous GOS less than 0.25 ha or larger than 20 ha in New York. Tokyo has the maximum total area of the GOS less than 0.25 ha among the four cities, while the area and number of GOS larger than 20 ha in Tokyo are less than other three cities. London performs better than Shanghai and Tokyo in the GOS larger than 20 ha, while the area and number of GOS less than 0.25 ha in London is less than New York's and Tokyo's. Shanghai needs to improve on the GOS less than 0.25 ha and larger than 20 ha. There is no significant difference in the other three classes of GOS for the four cities.

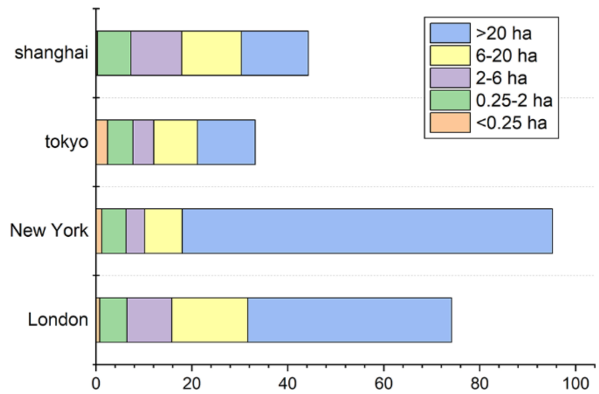

Figure 2. The area of green open space

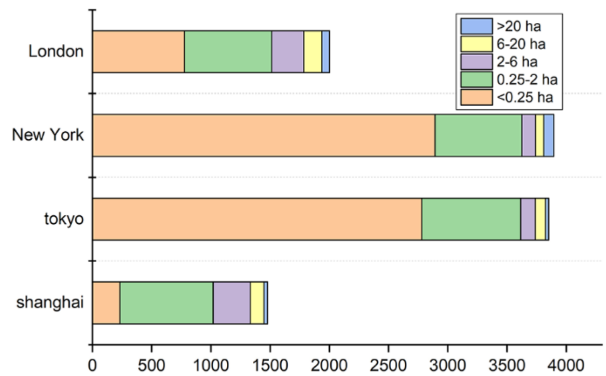

Figure 3. The number of green open space

City	Area of GOS (km^2)	Per Capita Area of GOS(m^2)	Coverage Rate
Shanghai	44.45	4.02	6.50 %
Tokyo	33.19	3.58	5.28 %
New York	95.21	11.65	12.16 %
London	74.12	15.21	11.87 %

Table 4. The per capita area and coverage rate of GOS

The Figure 4 shows the buffer zones which were created based on the methods in 3.3.2. The buffer zones of London form continuous area. In New York, the buffer zones in Manhattan, The Bronx and Staten Island are continuous, while there are both continuous areas and scattered small areas in Queens and Brooklyn. For Shanghai and Tokyo, the spatial feature of the buffer zone is circle distribution. The large buffer zones form the continuous circular areas and the small ones scatter between the two neighboring circles.

Size of Open Space	Service Distance
> 20 hectares	1200 meters
6-20 hectares	800 meters
2-6 hectares	400 meters
0.25-2 hectares	250 meters

Table 5. The accessibility standard

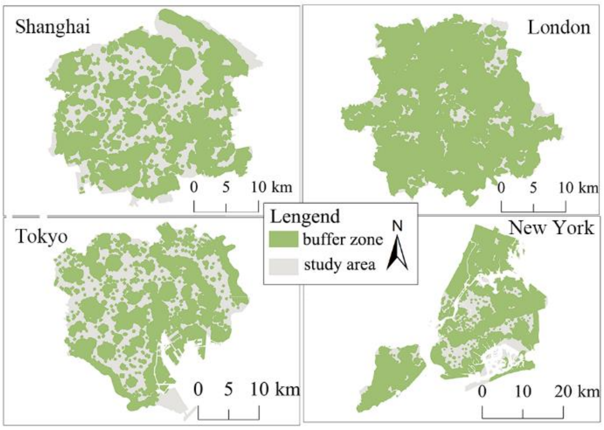

Figure 4. The buffer zones of the four study areas

The table 6 shows the availability of GOS. Among the four cities, London has the highest availability of 91.73%, and the availability of New York is 80.45% which is next to London's. While Shanghai and Tokyo have wide gaps with London and New York. The availability of Shanghai and Tokyo are 64.64% and 61.63%, which means that less than two-thirds of their citizens have access to the GOS larger than 0.25 ha.

City	Availability (%)
Shanghai	64.64
Tokyo	61.63
New York	80.45
London	91.73

Table 6. The availabilities of the study areas

4.3 The spatial pattern of GOS

According to the population density, GOS coverage and availability, we classified the four cities into two classes: Shanghai and Tokyo are the high-population-density cities with medium GOS coverage and availability, and New York and London are the medium-population-density cities with high GOS coverage and availability. Besides, based on the scales we classified the GOS into three classes: small (< 0.25 ha), medium (0.25 ha – 20 ha) and large (> 20 ha). In the aspect of small GOS, Shanghai is the worst among the four cities and London is slightly better than Shanghai. In contrast, Tokyo and New York have great mount of small GOS. In terms of large GOS, New York and London have adequate large GOS. While Shanghai and Tokyo are short of them. There is no significant difference in medium GOS. Meanwhile, based on the morphological features, we generalized four types of GOS which were normal GOS, riverside linear GOS and roadside linear GOS. For coastal GOS, only New York has great amount of them. Those of Shanghai and Tokyo are significantly fewer than those of New York. And there is no coastal GOS in London because the study area is not near the ocean. For the riverside linear GOS, except London which has only few amount, all the other three cities have certain amount of them. For roadside linear GOS, the four cities are different. Shanghai has masses of roadside GOS because of developing green belt encircling the city and the green way. Those of London are fewer than those of Shanghai and New York. Tokyo has hardly no roadside linear GOS.

5. DISCUSSION

5.1 Relations between availability and the distribution of GOS

From table 4 and table 6, we find that the high GOS coverage rate does not necessarily lead to a higher availability. London's coverage rate is lower than New York's, while it has a higher availability because of its great amount of large GOS. Besides, there are numerous small GOS in Tokyo and New York. On account of omitting the availability of GOS smaller than 0.25 ha, the availability of Tokyo and New York were probably underestimated. In addition, although the availability is not directly related to the population density, that the large population occupies copious urban space leads to a lower coverage rate. Hence the high-population-density cities have relatively lower availabilities.

5.2 Assessing the impacts of spatial pattern of GOS

In the aspect of small GOS, there are numerous this kind of GOS in Tokyo and New York. The small GOS has its unique characteristics. It has excellent convenience despite the shortage of functionality. For one thing, the small GOS can compensate for the deficiency of availability in part of the urban area; for another, it is pedestrian-friendly and convenient for the pedestrians to have a temporary rest. Thus, the small open space is a decent choice for the high-density cities Shanghai and Tokyo which do not have sufficient urban space. For the large GOS, Shanghai and Tokyo are obviously insufficient comparing with London and New York. Large GOS is applicable for diverse activities and can provide the visitors a wild perspective and rehabilitative experience (Lau et al., 2014; Giles-Corti et al., 2005). Shanghai and Tokyo are supposed to narrow the gaps with the two other cities.

The four cities are different in types of GOS. Firstly, the four cities have different amount of coastal GOS as a result of the limits of the study areas. The study area of London is not next to the sea and there is only a small part of the boarders of the study areas of Shanghai and Tokyo next to the sea. The coastal GOS will provide the visitors opportunities to enjoy the blue space which benefits the visitors' social activities and their mental health (De Bell et al., 2017; Völker et al., 2018). Shanghai and Tokyo can make a reasonable increase in the coastal GOS. Secondly, London has a disadvantage of riverside linear GOS. This type of GOS owns positive landscape values and can provide cultural services (Garcia et al., 2017; Vollmer et al., 2015). Thirdly, Shanghai and New York have more roadside linear open space than Tokyo and London. The roadside linear

GOS can enhance urban structural connectivity and improve citizen life satisfaction. In a word, the three types of GOS have diverse merits and are essential for an ecological city.

6. CONCLUSION

This study calculated the GOS indices and availability by using the spatial data of population and GOS of Shanghai, Tokyo, New York and London, and then analyzed the spatial patterns of GOS and its relation to availability. It was found that the four cities can be classified into two classes. Shanghai and Tokyo are high-population-density cities with medium GOS coverage and availability, and New York and London are medium-population-density cities with high GOS coverage and availability. Shanghai and London could increase the amount of small GOS. Because of developing green belt encircling the city and the green way, Shanghai has plenty of riverside and roadside linear GOS. London and Tokyo could consider adding linear GOS to improve the connectivity of GOS. In terms of future research directions, further study could explore the correlation between the spatial pattern of GOS and other urban issues such as ecosystem services and housing price.

REFERENCES

Abbasi, A., Alalouch, C., Bramley, G., 2016. Open Space Quality in Deprived Urban Areas: User Perspective and Use Pattern. *Procedia - Social and Behavioral Sciences* 216, 194-205.

Ambrey, C., Fleming, C., 2013. Public Greenspace and Life Satisfaction in Urban Australia. *Urban Studies* 51(6), 1290-1321.

Barbosa, O., Tratalos, J.A., Armsworth, P.R., Davies, R.G., Fuller, R.A., Johnson, P., Gaston, K.J., 2007. Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning* 83(2-3), 187-195.

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.

Cho, S.-H., Lambert, D.M., Kim, S.G., Roberts, R.K., Park, W.M., 2010. Relationship between value of open space and distance from housing locations within a community. *Journal of Geographical Systems* 13(4), 393-414.

De Bell, S., Graham, H., Jarvis, S., White, P., 2017. The importance of nature in mediating social and psychological benefits associated with visits to freshwater blue space. *Landscape and Urban Planning* 167, 118-127.

Douglas, O., Russell, P., Scott, M., 2018. Positive perceptions of green and open space as predictors of neighbourhood quality of life: implications for urban planning across the city region. *Journal of Environmental Planning and Management* 62(4), 626-646.

Garcia, X., Benages-Albert, M., Pavón, D., Ribas, A., Garcia-Aymerich, J., Vall-Casas, P., 2017. Public participation GIS for assessing landscape values and improvement preferences in urban stream corridors. *Applied Geography* 87, 184-196.

Giles-Corti, B., Broomhall, M.H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., Donovan, R.J., 2005. Increasing walking: how important is distance to, attractiveness, and size of public open space? *American journal of preventive medicine* 28(2 Suppl 2), 169-176.

Hoffimann, E., Barros, H., Ribeiro, A.I., 2017. Socioeconomic Inequalities in Green Space Quality and Accessibility-Evidence from a Southern European City. *International journal of environmental research and public health* 14(8).

Ji, T., Pachi, A., 2005. Frequency and velocity of people walking. *Structural Engineer* 84(3), 36-40.

Kabisch, N., Strohbach, M., Haase, D., Kronenberg, J., 2016. Urban green space availability in European cities. *Ecological Indicators* 70, 586-596.

Kang, C.-D., 2015. The effects of spatial accessibility and centrality to land use on walking in Seoul, Korea. *Cities* 46, 94-103.

Kim, J., Nicholls, S., 2017. Using Geographically Weighted Regression to Explore the Equity of Public Open Space Distributions. *Journal of Leisure Research* 48(2), 105-133.

Lau, S.S.Y., Gou, Z., Liu, Y., 2014. Healthy campus by open space design: Approaches and guidelines. *Frontiers of Architectural Research* 3(4), 452-467.

Lovell, S.T., Taylor, J.R., 2013. Supplying urban ecosystem services through multifunctional green infrastructure in the United States. *Landscape Ecology* 28(8), 1447-1463.

Taylor, B.T., Fernando, P., Bauman, A.E., Williamson, A., Craig, J.C., Redman, S., 2011. Measuring the quality of public open space using Google Earth. *American journal of preventive medicine* 40(2), 105-112.

Völker, S., Heiler, A., Pollmann, T., Claßen, T., Hornberg, C., Kistemann, T., 2018. Do perceived walking distance to and use of urban blue spaces affect self-reported physical and mental health? *Urban Forestry & Urban Greening* 29, 1-9.

Vollmer, D., Prescott, M.F., Padawangi, R., Girot, C., Gret-Regamey, A., 2015. Understanding the value of urban riparian corridors: Considerations in planning for cultural services along an Indonesian river. *Landscape And Urban Planning* 138, 144-154.

Wolfe, M.K., Mennis, J., 2012. Does vegetation encourage or suppress urban crime? Evidence from Philadelphia, PA. *Landscape and Urban Planning* 108(2-4), 112-122.

Wu, C., Ye, X., Du, Q., Luo, P., 2017. Spatial effects of accessibility to parks on housing prices in Shenzhen, China. *Habitat International* 63, 45-54.

Wu, J., Wang, M., Li, W., Peng, J., Huang, L., 2015. Impact of Urban Green Space on Residential Housing Prices: Case Study in Shenzhen. *Journal of Urban Planning and Development* 141(4), 05014023.

Xu, C., Haase, D., Pauleit, S., 2018. The impact of different urban dynamics on green space availability: A multiple scenario modeling approach for the region of Munich, Germany. *Ecological Indicators* 93, 1-12.