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Original article

Public green spaces and human wellbeing: Mapping the spatial inequity and mismatching status of public green space in the Central City of Shanghai

Yanan Shen[a,c], Fengyun Sun[a,c], Yue Che[b,c,*]

[a] School of Geographic Sciences, East China Normal University, Shanghai 200241, China
[b] School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China
[c] Shanghai Key Lab for Urban Ecological Processes and Eco-Restoration, East China Normal University, Shanghai 200241, China

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ABSTRACT

Public green spaces are fundamental and indispensable to urban settlements, given the diverse social, economic and environmental benefits that they can provide. However, the absence of knowledge regarding the allocation and access status quo consistently hinders the suitability and rationality of follow-up green space planning, which could eventually impair the livability and sustainability of cities. This study evaluates disparities in access to public green space for urban residents and the spatial mismatches among public green space provision, residents' visits and the demands of socially vulnerable groups within the Central City of Shanghai. The results show that disparities in public green space accessibility exist pertaining to social status and household composition status. Sub-districts with higher social status or larger proportions of family households composed by children and married inhabitants tend to have better public green space access. In contrast, sub-districts with larger proportions of aged or unemployed populations unexpectedly show worse public green space access. To a certain degree, this reduced access can be considered to be an environmental injustice. Additionally, the mismatches among public green space provision, residents' visits and the demands of socially vulnerable groups are observed to vary in space, indicating potential problems of resource shortage, supply-demand mismatch, underuse and congestion. The findings could offer urban planners and policy-makers insights into optimizing public green space resources and equitably providing proximal public green space to urban residents, especially vulnerable groups, such as children, the elderly and the unemployed.

1. Introduction

It is reported that 54% of the world's population resided in urban areas in 2014, and most of the growing urban population will be concentrated in Asia and Africa in the forthcoming decades (United Nations, 2014). Taking this statement into consideration, the progress of contemporary urbanization has become a challenge calling for joint attention and efforts (Godschalk, 2004; UN-Habitat, 2008). How can we make cities more sustainable and livable with the advancement of urbanization? As the remnant of natural areas in compact cities, urban green spaces have been demonstrated to provide various environmental, social and economic benefits (Heckert, 2013; Tian et al., 2014). These are seen as crucial for contributing to the imminent challenge of urbanization.

Based on ownership, urban green spaces can generally be divided into private and public green spaces (You, 2016). Private green spaces refer to outdoor amenities with restricted accessibility unless otherwise permitted by the owners (e.g., domestic gardens, backyards, and home gardens) (You, 2016). Public green spaces are deemed as public goods that can be accessed freely by all citizens and mainly encompass vegetated natural spaces (e.g., parks, gardens, forests and woods) and human-modified places (e.g., riverside greenbelts, institutional green spaces, greening squares and plazas) (Shan, 2014; Wende et al., 2012; You, 2016). Despite differing in ownership, public green spaces and private green spaces both play a critical role in maintaining biodiversity and providing various ecosystem services in urban districts (Barbosa et al., 2007; Bolund and Hunhammar, 1999). However, in terms of places that can offer a shared focus to diverse neighborhoods and communities (Barbosa et al., 2007; Hughey et al., 2016), public green spaces provide broader social significance. Thus, in this study, we focus on green spaces that are publicly accessible.

Although studies on environmental justice have broadened to include research on disparities in access to green spaces across different neighborhoods, most of them employ only a basic indicator of socioeconomic status or racial/ethnic minority composition as a moderator between neighborhood socioeconomic status and green space

* Corresponding author at: School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China.
E-mail address: yche@des.ecnu.edu.cn (Y. Che).

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accessibility (Hughey et al., 2016; Kamel et al., 2014). Moreover, previous studies have often found variable and contradictory results. For example, whereas some have reported worse accessibility in socioeconomically deprived and high-minority neighborhoods (Boone et al., 2009; Dai, 2011; Heckert, 2013), others have observed no remarkable difference (Gilliland et al., 2006; Nicholls, 2001). The simple indicators applied and mixed results found require further advancements in research on public green space equity.

Knowledge on access to public green space for socially vulnerable groups, such as children, the elderly and the unemployed, remains scarce. Children and the elderly are potentially more vulnerable to equity and environmental justice issues because of limitations based on age and ability (Boone et al., 2009; Reyes et al., 2014). Among the limited research, several studies have found inequities in park access for children/youth (Cutts et al., 2009; Reyes et al., 2014), and a few have detected unequal public green space provision to aged populations (Kabisch and Haase, 2014; Yung et al., 2016). In contrast, growing evidence in recent studies underlines the importance of accessible green spaces for the health of children and the elderly. For example, children with high exposure to green spaces are more likely to be physically active and obesity free (Sanders et al., 2015; Wolch et al., 2011), and older adults living in greener neighborhoods will enjoy more physical activities, fewer mental disorders and greater longevity (Gong et al., 2014; Takano et al., 2002). For the unemployed, they are also liable to encounter more social and environmental injustice (Chakraborty et al., 2016; Schwarz et al., 2015). Unemployment leads to a loss of income, an increased risk of poverty, a weakening of social relations, a feeling of social isolation, an absence of daily structure, as well as a deterioration of health (Frasquilho et al., 2016; Giatti et al., 2010). Compared to people who are employed full time, the unemployed tend to spend more time in their community and to rely more on and thus be more vulnerable to the provision of local infrastructure and social resources (Cummins et al., 2007; Giatti et al., 2010). In China's megacities, the populations of children, the elderly and the unemployed are much larger than those of ethnic minorities. In addition, issues on population aging, family downsizing under the enforcement of the one-child policy and employment difficulties have caused significant social concerns (Duckett and Hussain, 2008; Wang, 2014). Given the above discussion, it is necessary to analyze whether public green spaces can be equally accessed by those socially vulnerable groups.

As a theoretical evaluation, public green space accessibility offers useful reference and guidance for urban green space planning, yet real-world public green space visits or utilization may diverge from the planned goals. The utilization of public green space can be affected by various factors besides public green space accessibility (Hughey et al., 2016; Wang et al., 2015). With particular concerns to socially vulnerable groups, we should also question whether their public green space demands can be satisfied based on the status quo of public green space provision and utilization. However, previous studies have mainly focused on one specific dimension, seldom synthetically analyzing potential incoordination among public green space accessibility, residents' visits and the demands of socially vulnerable groups.

To depict real-world public green space visits, new data sources are expected. Recently, the ubiquitous big data shed new lights on social science practices for the self-contained abundant information and the enriched analysis methods (Liu et al., 2015). Many social media platforms (e.g., Twitter, Foursquare, Jiepang and Sina) support check-in option, which allows users to share their location-based information on the internet (Bao et al., 2013). To date, check-in records have already been used to study what is related with geographic spatial distribution or user behavior (Cheng et al., 2011; Li et al., 2013). Particularly, Bao et al. (2013) suggests that the distribution of check-ins closely relates to the real spatial pattern, which helps to support business and city construction planning. Given all of the above arguments, it would be prospective to use check-in records as an alternative to explore public green space visits. Targeted intervention strategies can be drawn up efficiently after discerning spatial mismatches among public green space accessibility, residents' visits and demands of socially vulnerable groups.

In aiming to close the aforementioned knowledge gaps in public green space research, this study selects the Central City of Shanghai as the study area, and the overall objectives are (1) to identify spatial inequities of public green space provision among different resident groups by analyzing disparities in public green space accessibility based on local socioeconomic status and demographic characteristics; (2) to identify spatial mismatches and potential problems among public green space provision, residents' visits and the demands of socially vulnerable groups (namely, children, the elderly and the unemployed) by comparatively analyzing the values of public green space accessibility, the visit density and the demand index of the vulnerable groups.

2. Data and methods

2.1. Study area and data sources

Shanghai Municipality, located in the middle of China's mainland coastline, is considered the economic, financial, trade and shipping center of China. In addition, following Tokyo and Delhi, Shanghai is the world's third largest city with approximately 23 million inhabitants (United Nations, 2014). Shanghai's Central City, referring to the domain within the Outer Ring Road, covers an area of approximately 660 km^2 (Xiao et al., 2017). The population density in the Central City is extremely high since nearly half of the municipality's population is concentrated in this area (Fig. 1). According to the Shanghai Statistical Yearbook, the per-capita public green space area of Shanghai Municipality was approximately 7.6 m^2 in 2015 (Shanghai Bureau of Statistics, 2016), which is lower than the World Health Organization's recommendation of a minimum of 9 m^2 (World Health Organization, 2010). At this stage, large public green spaces are under construction in the outlying suburbs; nevertheless, the public green space is still in short supply within the congested Central City (Chinese Society for Urban Studies, 2002). Given these circumstances, research on the current allocation status of public green space resources and the prompt identification of potential public green space problems is of primary importance for future green space planning and management.

The units of analysis for this study are township-level subdivisions (n = 116), including 84 sub-districts, 28 towns, and 4 special areas. Based on China's three-tier administrative division system, township-level (similar to the US census tracts level) subdivisions are the smallest administrative units. Like many extant urban China studies, this study relies on administrative boundary data and national census data available at the township level (Xiao et al., 2017). In the following sections, we use "sub-district" to represent township-level subdivision for simplicity and clarity.

The data used in this study came from several sources. First, digitalized layers of the road network, public green spaces and residential parcels were originally obtained from the Shanghai Municipal Bureau of Planning. In total, 1213 public green spaces were distinguished within (n = 1213) the study area, including parks, street gardens, greening forests, greening squares and plazas, greenways, and sports grounds, as shown in Fig. 2(a). Second, demographic data at sub-district level were extracted from the sixth Shanghai Census of 2010. Third, the Jiepang check-in records employed in this research have already been used in prior studies on inter-urban trip and spatial interactions (Liu et al., 2014; Wu et al., 2014). Specifically, as one of the largest location-based social network platforms in China, Jiepang was widely used during the time on which this study focused (Lian et al., 2014; Yang et al., 2017). Users can 'check-in' to online places as they visit offline places to win prizes (Sun et al., 2015; Yang et al., 2017). Check-in data were examined and used as an indicator of residents' visits to public green spaces since the number of check-ins positioned within public green space can reflect the magnitude of residents' visits to a certain

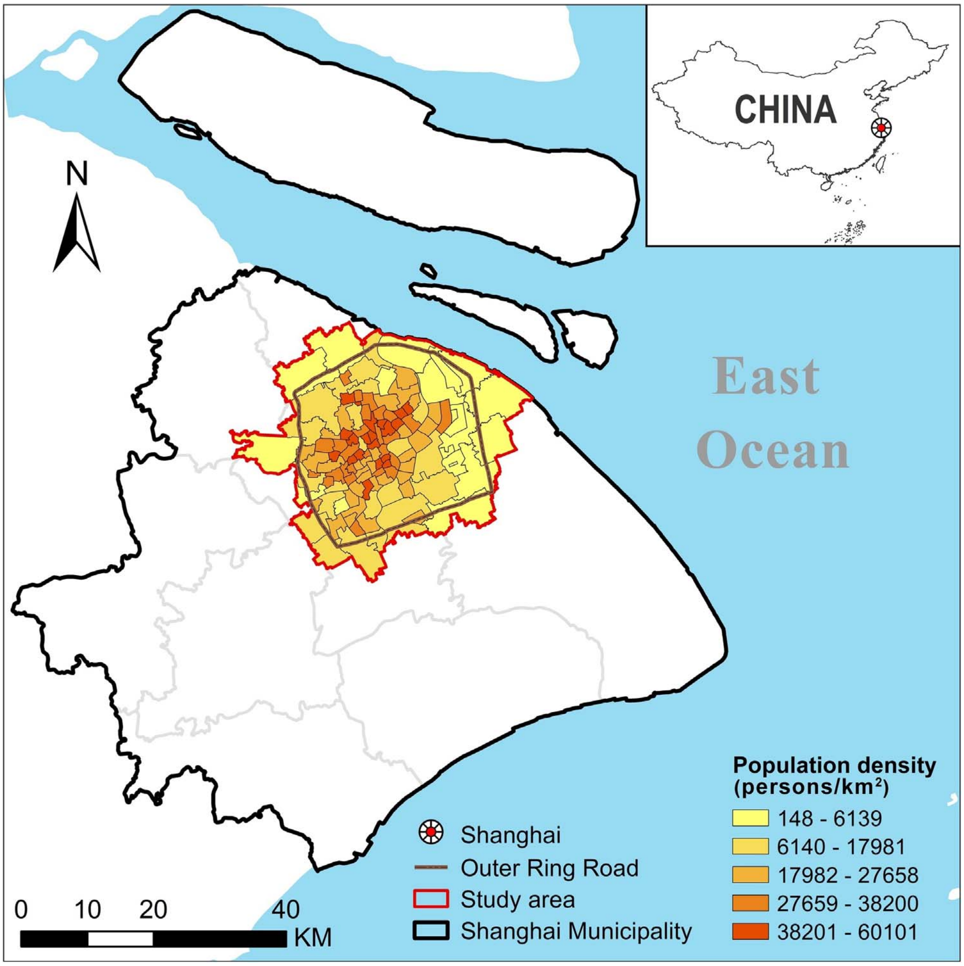

Fig. 1. Overview map of the study area.

degree. Exact data of public green space visits were difficult to obtain due to the absence of integral official statistics and the impracticability of field statistics within the broad city area. Fig. 2(b) presents the distribution of more than 800,000 Jiepang check-in records collected from September 1, 2011 to September 20, 2011.

2.2. Calculation of public green space accessibility

The evaluation of public green space accessibility for each sub-district was the fundamental step to accomplish the first objective. The Gaussian-based two-step floating catchment area (2SFCA) method was used to calculate the public green space accessibility of residential parcels based on a 1.2 km threshold distance. This method was first

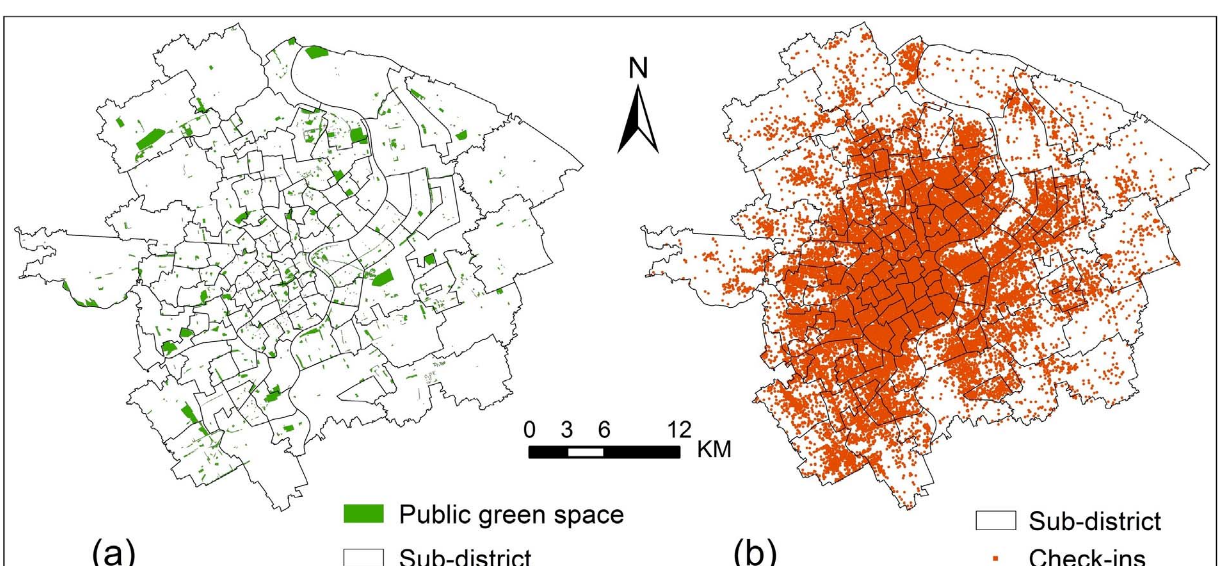

Fig. 2. (a) Distribution of public green spaces; (b) Distribution of Jiepang check-ins.

introduced by Dai to continuously differentiate access through integrating the Gaussian function with the 2SFCA method (Dai, 2010; Dai, 2011). A distance threshold of 1.2 km was determined for three reasons. First, as reported in the case of Guangzhou, a 20-min walking distance was a critical divide in determining whether residents would walk to public green spaces (Shan, 2014). 1200 m was within the acceptable time cost, corresponding to a 15–20 min walking trip for the general public (Kaczynski et al., 2014; Reyes et al., 2014). In addition, the Gaussian-based 2SFCA method itself accounted for travel-friction effect. Lastly, a 1.2 km buffer distance covered approximately 97% of all residents in the study area, which prevented otherwise zero values of accessibility for some sub-districts.

A few details are worth noting in the calculation of accessibility. First, the sub-district population was reassigned to residential parcels according to the residential area proportions to improve the calculation accuracy (Yao et al., 2014). Second, geographic centroids were used to represent residential parcels and public green spaces in the calculation of the distance between them along the road network. One may think the entrances or access points to public green spaces are more accurate than geographic centroids, but detailed location data of entrances are often difficult to obtain even by manual digitalization. Moreover, for some public green spaces (e.g., riverside greenways), any point along the perimeter can be deemed as the access point. In addition, it is often problematic to assign attributes (e.g., area) to points representing multiple entrances of a same public green space in the network analysis (Sevtsuk and Mekonnen, 2012). Therefore, geographic centroids were used in this study, as in many prior studies (La Rosa, 2014). Third, public green space accessibility for each sub-district was derived using the population-weighted average method.

2.3. Equity analysis for different resident groups

To date, studies on environmental injustice have developed a series of socioeconomic indicators and discussed their impacts on the provision of urban green spaces (Shrestha et al., 2016). Based on the related literature, the specific background of the study area and data availability, twelve social characteristic variables were employed to depict neighborhood profiles from the aspects of socioeconomic status, demographic characteristics and the urban spatial structure (Xiao et al., 2017), including aged population, non-agricultural population, unemployed population, family household, married population, children, older dwellings, population with high-degree education, population with senior occupations, population density, average housing price and distance to the city center (see Table 1). Note that it is widely accepted that in China, aged population refers to those who are 60 years old and above. Meanwhile, unemployed population in this paper refers to unemployed individuals aged 16 years or above and did not do any work to earn income during the census period. Average income was not available for sub-district units; instead, unemployment rate was used to depict the neighborhood socioeconomic disadvantage (Li and Liu, 2016; Xiao et al., 2017). The proportion of older dwellings can reflect the neighborhood socioeconomic status and was found to be relevant to public green space provision (Jim and Shan, 2013; Zhang et al., 2015). The variables regarding marital status and family household were selected given their relative significance to the distribution of and residents' visits to public green spaces reported in some previous studies (Jim and Chen, 2006; Sanesi and Chiarello, 2006; Xiao et al., 2017).

To explore whether spatial inequity of public green space provision exists across sub-districts, a bivariate correlation was employed to detect associations between public green space accessibility and the social characteristic variables. Then, factor analysis (FA) was conducted using varimax rotation to facilitate the interpretation of the resulting factors. In the next step, sub-districts were classified into four quartile groups according to the value of the selected factors or variables, and the average public green space accessibility in each quartile group was calculated. Further, a ratio graph was drawn to more obviously reveal gradients in public green space access by comparing the accessibility of each quartile group with that of the first quartile group.

Table 1
Bivariate correlation analysis between social characteristic variables and public green space accessibility.

Variable	Public green space access
Aged population (%) [a]	−0.331**
Non-agricultural population (%)	−0.210*
Population density (persons per square kilometer)	−0.445**
Unemployed population (%)[b]	−0.251**
Average housing price (USD)[c]	−0.122
Distance to the city center (meter)	0.269**
Family household (%)	−0.214*
Married population (%)	−0.123
Children (%)[d]	0.110
Older dwellings (%)	−0.126
Population with high-degree education (%)[e]	0.124
Population with senior occupations (%)[f]	−0.036

[a] Population aged 60 or above.
[b] Population aged 16 or above and without job.
[c] The average housing price was obtained by interpolating housing price samples of common residence.
[d] Population aged 16 or under.
[e] Population with a bachelor's degree or above.
[f] Population engaged in lead positions or professional & technical positions.
* Significant at the 0.05 level (2-tailed).
** Significant at the 0.01 level (2-tailed).

2.4. Mismatches among public green space provision, residents' visits and demands of socially vulnerable groups

To achieve the second research objective, public green space buffers of 20 m were created in view of inevitable positioning errors, and the check-ins located within the buffered public green space were selected. A bivariate correlation analysis between the check-in data and the official visitor statistics of 87 charge-free urban parks within the Central City was conducted initially to validate the capability of the check-in data in representing the actual visits to public green spaces. The Pearson correlation coefficient of 0.712 indicates that a significant correlation exist between the check-in data and the official visitor statistics. We therefore assume that the check-in data can be used to estimate public green space visits. Public green space visit density was calculated as the check-in number divided by the public green space area of each sub-district. Next, the demand index of vulnerable groups (DIVG) was developed to evaluate the general public green space demands of children, the elderly and the unemployed. DIVG was defined as follows:

DIVG = (norm. (*children* + *aged population*) + norm. (*unemployed population*))/2.

The variables in the formula were all in percentage form. Normalization, equal weighting and additive function were carried out to obtain the value of DIVG.

Potential mismatches among public green space provision, residents' visits and the demands of socially vulnerable groups were analyzed using clustering analysis based on values of public green space accessibility, the visit density and DIVG. Because the number of clusters was unknown, the two-step cluster analysis was first applied to determine the optimal number of clusters. Next, a hierarchical cluster analysis using Ward's method and Squared Euclidean Distance was adopted to complete the final clustering. ANOVA was conducted and descriptive statistics were calculated to examine the validity of the clustering result.

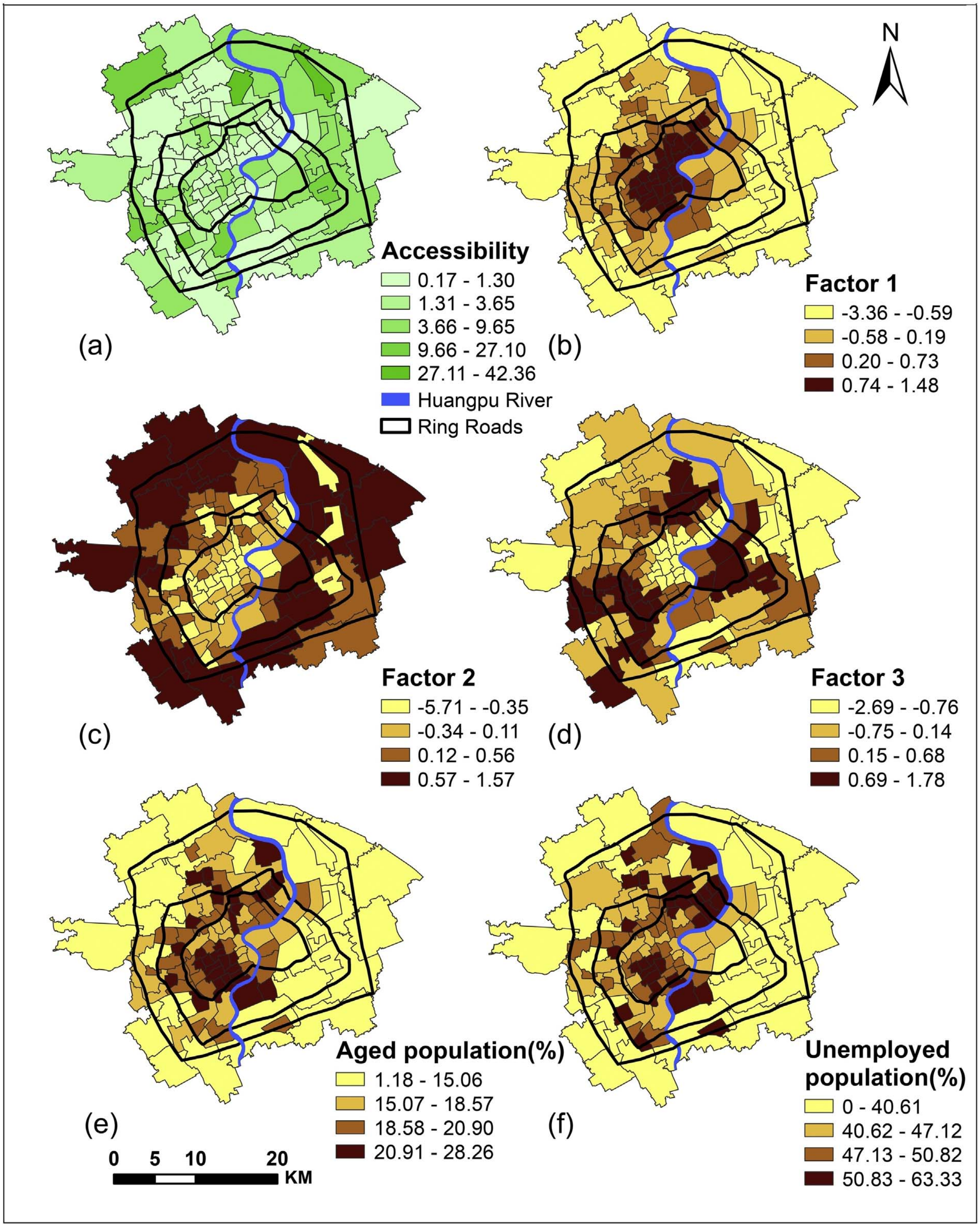

Fig. 3. (a) Public green space accessibility; (b) Factor 1 (general urbanization status); (c) Factor 2 (household composition status); (d) Factor 3 (social status); (e) Distribution of aged population; (f) Distribution of unemployed population.

3. Results

3.1. Inequities on public green space access among different resident groups

The pattern of public green space accessibility across the study area is shown in Fig. 3(a). Overall, the high-accessibility sub-districts were mainly located near the north Outer Ring Road, as well as in the eastern and southwestern sections, whereas most of the low-accessibility sub-districts were located in the Puxi area (west of the Huangpu River).

Table 1 shows that public green space accessibility was significantly negatively correlated with population density, percentages of aged population, non-agricultural population, unemployed population and family households, but was significantly positively associated with distance to the city center. The correlation between public green space accessibility and the remaining six variables was insignificant.

The KMO test reached 0.708, signifying a generally acceptable level

Table 2
Social characteristic variables and the three rotated factors after the factor analysis. Note: The variables mainly loaded into the corresponding factor are shaded.

Variable	Factor 1	Factor 2	Factor 3
Aged population (%)	0.91	0.08	0.21
Non-agricultural population (%)	0.80	0.10	0.54
Population density (persons per square kilometer)	0.79	0.02	-0.04
Unemployed population (%)	0.83	-0.11	0.24
Average housing price (USD)	0.72	-0.39	-0.01
Distance to the city center (meter)	-0.84	0.31	0.13
Family household (%)	0.55	0.79	0.00
Married population (%)	-0.14	0.90	-0.12
Children (%)	-0.28	0.82	0.15
Older dwellings (%)	0.44	-0.28	-0.71
Population with high-degree education (%)	0.15	-0.45	0.77
Population with senior occupations (%)	0.38	0.08	0.84

for the implementation of FA. The results of FA are shown in Table 2. Three rotated factors were extracted, capturing 80.7% of the total variance in the original data. Factor 1 accounted for 42.5% of the original variation and represented six variables, suggesting “general urbanization status” because it was positively correlated with five variables except the last one. Factor 2 indicated “household composition status” because it was positively associated with the proportions of family households, the married population and children. Factor 3 denoted “social status” because it was related to educational attainment, residential condition and occupation status.

The spatial distribution of factor scores and two vulnerable groups are mapped in Fig. 3(b–f) by quartile classification. Fig. 3(b) delineates the general urbanization status from the city center to city edge. Sub-districts in the central area showed high values of the population density, housing price, unemployed population, non-agricultural population and aged population. Fig. 3(c) shows that the proportions of family households, married people and children gradually increased away from the city center. Fig. 3(d) reveals that sub-districts with superior social status were mainly located in four directions outside the centermost area. In contrast, sub-districts with low social status were mainly located in the centermost and peripheral areas. As seen from Fig. 3(e) and (f), the distribution pattern of the aged population was similar to that of the unemployed population. Sub-districts with a high level of population aging or unemployment were mainly located in the Puxi area, within the Outer Ring Road.

Table 3 lists the average value of public green space accessibility, as well as the value range of the selected factors and variables in each quartile group. As a supplement to Table 3, the ratio graph (Fig. 4) more obviously depicted gradients in public green space accessibility pertaining to sub-district socioeconomic characteristics. From the aspect of the general urbanization status (factor 1), public green space accessibility decreased approximately 68% in the most urbanized sub-districts (4th quartile) compared to the least urbanized sub-districts (1st quartile). For household composition status (factor 2), public green space accessibility increased approximately 18% in sub-districts with large proportions of family households composed by married couples and children (4th quartile). In terms of social status (factor 3), the accessibility in sub-districts with high social status (4th quartile) increased approximately 70% compared to sub-districts with low social status (1st quartile). The ratio curves also indicate the declining public green space access in sub-districts with a high degree of population aging or unemployment, given that the accessibility in the 4th quartile decreased approximately 60% compared to the 1st quartile.

3.2. Mismatching status among public green space provision, residents’ visits and demands of socially vulnerable groups

As shown in Fig. 5(a), despite the intensive public green space visits in the southern area, the visit density gradually decreased away from the city center. Fig. 5(b) shows that the sub-districts with a high value of DIVG were mainly located in the central and northern areas. In particular, the value of DIVG was obviously lower in Waigaoqiao Free Trade Zone, Jinqiao Export Processing Zone and Zhangjiang Hi-tech Park than other sub-districts.

Two-step cluster analysis identified an optimal number of three clusters. The results of hierarchical clustering revealed the discrepant matching modes among public green space provision, residents’ visits and demands of socially vulnerable groups (Fig. 6). Table 4 lists the

Table 3
Quartile statistics for social characteristics and public green space accessibility at the sub-district level. Note: Bracketed is the range of each quartile. Bolded is the average public green space accessibility of each quartile.

	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
Factor 1	(−3.4, −0.6)**5.15**	(−0.5, 0.2)**2.57**	(0.3, 0.7)**1.71**	(0.8, 1.5)**1.65**
Factor 2	(−5.7, −0.4)**2.75**	(−0.3, 0.1)**2.02**	(0.2, 0.6)**3.07**	(0.7, 1.6)**3.24**
Factor 3	(−2.7, −0.8)**2.51**	(−0.7, 0.1)**2.39**	(0.2, 0.7)**1.88**	(0.8, 1.8)**4.3**
Unemployed population	(0,40.6%)**5.18**	(40.7%,47.1%)**2.26**	(47.2%,50.8%)**1.66**	(50.9%,63.3%)**1.98**
Aged population	(1.2%,15.1%)**4.84**	(15.2%,18.6%)**2.49**	(18.7%,20.9%)**1.73**	(21%,28.3%)**2.03**

cluster size and the mean values of the variables for each cluster. The resulting clusters were in a concentric-circle mode. Cluster 1 was comprised of 30 sub-districts mainly located in the city periphery. The mean public green space accessibility of cluster 1 was the highest of the three clusters, but both the average visit density and the average DIVG were the lowest. For these sub-districts, abundant public green space provision was accompanied by insufficient utilization by residents and low demands of socially vulnerable groups. Sub-districts in cluster 2 formed the middle tier of the clustering pattern, which extended in the north-south direction. The low accessibility and the medium-high DIVG of cluster 2 indicated that public green spaces in these sub-districts were in short supply, especially for the vulnerable groups. Cluster 3, comprised of 19 sub-districts, was mainly located within the Inner Ring Road. Though the average public green space accessibility of cluster 3 was the median among the three clusters, it was still below the city average. In addition, the values of the visit density and DIVG were conspicuously high in this cluster.

4. Discussion

4.1. Findings and implications for public green space studies

Studies on public green space access have been continuously conducted around the world. These studies often attempt to identify potential inequities on public green space access among different socioeconomic groups (Heckert, 2013; Hughey et al., 2016; Ibes, 2015; You, 2016). However, so far there is little evidence available to verify whether public green spaces are equally provided in China's megacities. Taking Shanghai as the case study, one merit of this study is that we discovered underlying inequities of public green space access among neighborhoods characterized by different socioeconomic and demographic characteristics, with particular attention to the environmental justice of the socially vulnerable groups.

Our study shows that public green spaces are unequally distributed throughout the Central City. The west of Huangpu River has been the city center since the nineteenth century (Fan et al., 2017), and public green spaces in this area are relatively in shortage mainly because of the dense population, historical city planning and land scarcity. In contrast, public green space accessibility is better in the newly developed Pudong area (east of the Huangpu River). Public green space accessibility seems to be related with the development history and the degree of development of the district. In some other Chinese cities, e.g., Hong Kong and Guangzhou, the old districts are also beset by a cramped living environment with poor public green space access (Jim and Shan, 2013; Tian et al., 2014).

Discrepancies in public green space access have been observed pertaining to specific neighborhood socioeconomic and demographic characteristics. Sub-districts with high social status are favored in public green space provision, which is coincident with the findings of some prior studies (Dai, 2011; Ibes, 2015; Li and Liu, 2016). High-social-status groups have better access to public green spaces partly because they have greater ability to choose residences with high quality living environments and to be involved in planning decisions relevant to their benefits (Shrestha et al., 2016). In addition, this study finds that public green space access also varies in the household composition status, given that access is better in sub-districts with a higher percentage of family households, married couples and children. Some previous studies have found that married people or families with young children value the proximity to public green spaces more and visit public green spaces more frequently because of children's needs (Sanesi and Chiarello, 2006; Shan, 2014; Xiao et al., 2016). Then, there is a possibility that families intentionally move their homes to places near public green spaces to create a better living environment for children. Moreover, this study discloses the low public green space access in sub-districts with a high level of population aging and unemployment. Population aging and unemployment would exist for a certain period in Shanghai, which could therefore greatly increase the demands for social infrastructures, including public green space resources (Wang and Liu, 2012). Under these circumstances, poor public green space access for the elderly and the unemployed may stir environmental injustice issues, calling for pre-awareness and effective response measures.

Another merit of this study is that it explores the spatial mismatching modes among public green space provision, residents' visits and demands of socially vulnerable groups. Using check-ins to estimate

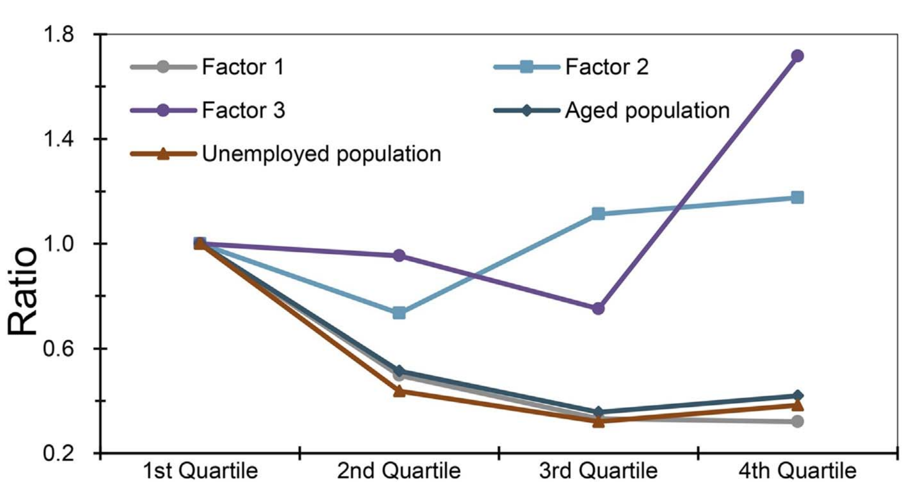

Fig. 4. Variation of public green space access based on the selected factors and demographic variables using the average public green space accessibility of the first quartile group as the reference.

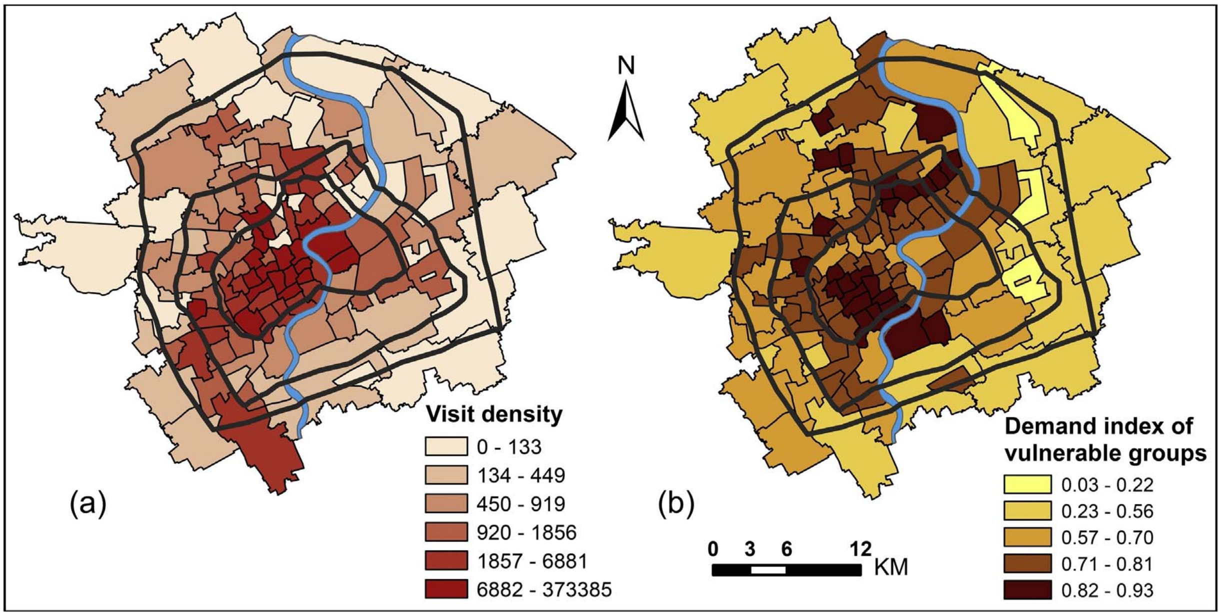

Fig. 5. (a) Public green space visit density (check-ins per km^2); (b) Demand index of vulnerable groups (DIVG).

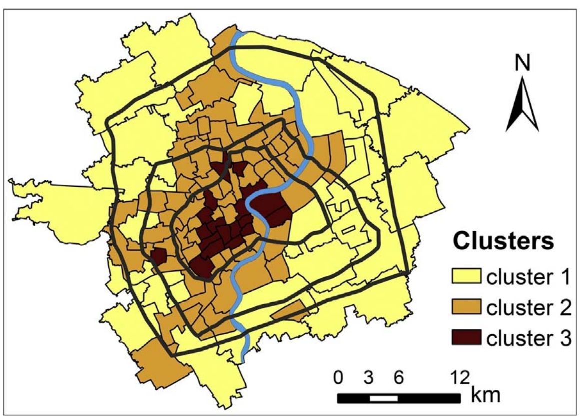

Fig. 6. Clustering pattern of sub-districts according to public green space accessibility, the visit density and the demand index of vulnerable groups (DIVG).

Table 4
Mean values of public green space accessibility, the visit density and the demand index of vulnerable groups (DIVG) for three clusters of sub-districts.

	Cluster 1 (n = 30)	Cluster 2 (n = 67)	Cluster 3 (n = 19)	Total city
Public green space accessibility	5.30	1.84	2.04	2.77
Visit density	6.33	17.28	230.73	49.41
DIVG	0.50	0.77	0.79	0.71

the public green space visit density, dense public green space visits have been distinguished within the Inner Ring Road and in the southern area. The results of residents' visits to public green spaces may be partly explained by the spatial distribution of population, because the public green space visit density is positively correlated with population density. In addition, many public green spaces in the inner city are located in the hybrid area of commerce and residence, with extra visitors passing by. Moreover, prior studies have found that apart from the travel distance and green space size, many quality features, such as facilities, amenities, maintenance, aesthetic design and safety conditions, also influence individuals' use of public green space (Hughey et al., 2016; Wang et al., 2015; Wende et al., 2012). Therefore, a deep survey is recommended in the following work to explore the visit characteristics and preferences of public green space users.

In general, the demand distribution pattern of socially vulnerable groups is similar to residents' visit pattern, but it is rather different from the distribution pattern of public green spaces, indicating potential conflicts between demand, provision and utilization. For example, vulnerable social groups who live in neighborhoods with meager public green spaces have to use overcrowded public green spaces. Specifically, for some sub-districts in the peripheral area, the high value of public green space accessibility indicates a relatively sufficient supply of public green spaces, whereas the low visit density reflects inefficient public green space utilization. For these sub-districts, future greening programs should place more emphasis on improving the quality of public green spaces to increase residents' use. For some sub-districts located around the inner-ring area, the low average public green space accessibility indicates the deficiency of proximal public green spaces. Efforts should be made to increase the quantity of public green spaces in these sub-districts. Both residents' visit density and the demands of socially vulnerable groups are rather large in some sub-districts within the Inner Ring Road, whereas the public green space accessibility is below the city average, arousing concerns about public green space overuse and congestion (Brander and Koetse, 2011). Currently, it may be difficult to build large public green spaces in the compact central area due to the long term land-use pattern, intense land demand and other restrictions (Chen and Hu, 2015). If so, other greening strategies, such as vertical greening, parkways and greenways, are recommended to create better green space access and more opportunities for residents' daily recreation (Haaland and van den Bosch, 2015).

4.2. Potential limitations

Several limitations to this study are worthy of particular attention and future improvements. First, although the check-in data are verified by their significant correlation to the official visitor statistics, estimation error could still exist in the calculation of residents' visit density because some social groups are less active cellphone users. Improvements in data precision and deviation filtering are expected in big data analysis. Second, the way of reassigning the population to local residential parcels according to residential area proportions may introduce a certain calculation error to public green space accessibility. Other improvements on data precision and calculation method of accessibility are expected. Third, only the quantity of public green space is considered in the assessment of accessibility and equity. In future studies, the evaluation method could be improved by analyzing the quantity and quality of public green space jointly.

5. Conclusions

This study evaluates the spatial inequity of public green spaces within the Central City of Shanghai. In addition, the study explores the potential mismatches among public green space provision, residents' visits and the demands of socially vulnerable groups. In spite of the intricate patterns, disparities in public green space accessibility have been observed based on household composition and social status. Moreover, inferior access has been found in the sub-districts inhabited by a large number of older adults or unemployed residents. The disadvantageous access to public green spaces among low-social-status groups, the elderly and the unemployed, to some extent, can be deemed as environmental injustice. In this regard, intervention programs should take priorities to make up the shortfall in neighborhoods lacking public green spaces and to eliminate the inequities in public green space provision. Furthermore, the spatial mismatches among public green space provision, residents' visits and the demands of socially vulnerable groups indicate some potential problems (e.g., a public green space shortage, underuse, congestion and supply-demand mismatch) in local areas. In-depth surveys on the quantity, quality and equality of public green space are recommended to deal with the local mismatching. Relevant departments and city planners should pay extra attention to the above issues and spare no efforts in optimizing the allocation of public green spaces to better serve the welfare of the whole society.

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