Spatial Equity of Public Open Space Accessibility in Dense Urban Areas: Evidence from Kowloon, Hong Kong

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Abstract. In global high-density cities, the contradiction between supply and demand of public open space is prominent, and the issue of fairness has attracted much attention. This paper takes Kowloon City District of Hong Kong as the research object, adopts the Gaussian two-step floating catchment area method to calculate public open space accessibility at building group population points, evaluates spatial social equity via the Lorenz curve, Gini coefficient and Theil index, and applies the Geodetector model to identify the driving mechanism of spatial differentiation. The following main conclusions are obtained. Firstly, accessibility exhibits a spatial differentiation pattern with higher values in the northeast and central-west and lower values in the southern coastal areas. Secondly, the Gini coefficient is 0.2404, indicating mild inequality. The Theil index shows that the unfairness mainly stems from spatial location differences within the same group. Thirdly, road network density is the core driving factor. Factor interaction enhances explanatory power, with the strongest synergy between road network density and income. This article enriches the empirical application of spatial justice theory in high-density urban areas and provides reference for green space planning and stock renewal in similar old urban areas.

Keywords: Public open space, high-density cities, Hong Kong.

1. Introduction

With the acceleration of global urbanization, high-density cities are facing the contradiction between the supply of public open space and the growing demand of citizens on limited land resources. As one of the world's most densely populated metropolises, Hong Kong has long suffered from low per capita public open space area and uneven spatial resource distribution. At the same time, the issue of social equity in space allocation has become increasingly prominent, and there are differences in residents' access to public open space services. Accordingly, this paper proposes the following research questions: What are the spatial differentiation characteristics of public open space accessibility in Kowloon, Hong Kong? What are the differences in accessibility and fairness among different social groups? What drives this unfair pattern?

Based on the theory of spatial justice as the main analytical framework, combined with the theory of public service equalization and the theory of demand hierarchy, this paper discusses the impact of the equitable distribution of urban public resources, the equal supply of public facilities, and the accessibility of public open space on residents' life equity. In terms of accessibility measurement, the Gaussian two-step floating catchment area method has been widely used in the accessibility evaluation of public service facilities, and the introduction of a Gaussian distance-decay function is more in line with the actual law of distance attenuation [1]. In terms of fairness evaluation, the Gini coefficient is often used to quantify the fairness of space allocation [2]. Theil index can quantify the spatial differences and dynamic changes of urban human settlements quality [3]. In terms of driving mechanism, Geodetector is a statistical method to detect spatial differentiation and its driving forces [4]. It has been applied to the analysis of factors affecting the accessibility of park green space and the driving mechanism of spatial distribution of public cultural places [5]. Geodetector has advantages in revealing non-linear relationships and factor interactions [6]. Nevertheless, systematic research on the driving mechanism of public open space accessibility equity in high-density cities using the Geodetector model remains insufficient [7].

The existing literature has been analyzed from the aspects of accessibility measurement and fairness evaluation, and there are still research gaps in the spatial hierarchical heterogeneity of driving factors and the interaction effect of factors [8]. Taking Kowloon of Hong Kong as the case area, this paper adopts the Gaussian two-step floating catchment area (G2SFCA) method to compute the public open space accessibility index of each population demand point, applies the Lorenz curve, Gini coefficient and Theil index to quantify equity levels, and employs the Geodetector model to reveal corresponding driving mechanisms. Theoretically, it enriches the empirical application of spatial justice theory in high-density cities and expands the methodological practice of Geodetector in the research of public resource allocation. Practically, the research provides references for public open space planning and policy formulation in Hong Kong and other comparable high-density cities.

2. Research designs

2.1. Data sources

This study's datasets derive from the Common Spatial Data Infrastructure and OpenStreetMap, and all spatial layers are unified into the Hong Kong 1980 Grid coordinate system to eliminate multi-source spatial inconsistencies. Building group centroids serve as the basic analytical units, extracted from building group and housing market boundary datasets of the 2021 Population Census. Each centroid represents the smallest demographic unit defined by Hong Kong's Census and Statistics Department. These centroids act as population demand points for the G2SFCA accessibility calculation. In Geodetector analysis, centroid-based accessibility indices are adopted as dependent variables, with six spatial socioeconomic and built-environment indicators selected as independent variables to construct analysis datasets. Compared with regular grids, point units avoid null-value issues of uninhabited grids and artificial bias from grid scale selection, while fully retaining the original census spatial precision and socioeconomic attributes.

2.2. Variable definition

The first is about the accessibility calculation of public open space. This study uses the G2SFCA method to measure the accessibility level of spatial units in Kowloon district. In view of the fact that the census data are provided in the form of building group centroids, this study directly takes the centroids of each building group as the population demand point and the public open space as the supply point [9]. The specific calculation is divided into two steps. The first step is to take each public open space as the supply point j, take its 15-minute walking service range as the search domain, where d_0 is 15 minutes, corresponding to about 1.25 km. The walking speed is set as 5 km/h. All population demand points k within the search threshold is extracted to calculate the supply-demand ratio. The second step is to take each population demand point i as the center, summarize the supply and demand ratio of all supply points in its 15-minute search domain, and obtain the accessibility index Ai of the grid, as in model (1).

$$A_i = \sum_{j\in\{d_{ij}\le d_0\}} \left[\frac{S_j}{\sum_{k\in\{d_{kj}\le d_0\}} D_k \cdot \frac{e^{-\frac{1}{2}\left(d_{kj}/d_0\right)^2} - e^{-\frac{1}{2}}}{1-e^{-\frac{1}{2}}}} \cdot \frac{e^{-\frac{1}{2}\left(d_{ij}/d_0\right)^2} - e^{-\frac{1}{2}}}{1-e^{-\frac{1}{2}}} \right] \tag{1}$$

S_j is the area of public open space at supply point j, Dk is the population at demand point k, dk_j is the shortest walking distance of the road network, and the higher the A_i value, the more adequate the public open space services available to residents in the unit within 15 minutes of walking. The above calculation is based on the network analysis module of ArcGIS.

The second is about the evaluation of spatial fairness. The accessibility index of each demand point is linked to its corresponding population, and the Gini coefficient and Lorenz curve are introduced to evaluate the overall equity of space distribution in Kowloon district [10]. The demand points are

arranged in ascending order of the accessibility index, and the Lorenz curve is drawn with the cumulative population ratio as the horizontal axis and the cumulative accessibility ratio as the vertical axis to calculate the Gini coefficient. Further, the Theil index is used to decompose the group differences. Demand points are grouped according to the monthly income level and age structure of households, and the proportion of people aged 65 and over. The overall inequality is divided into intergroup differences and intra-group differences, and the contribution of social dimensions to inequality is quantified.

The third is the analysis of influencing factors based on Geodetector. This study uses two modules, factor detector and interaction detector, to reveal the driving mechanism of spatial differentiation of accessibility in public open space in Kowloon district. The accessibility index Ai of building groups at each demand point is taken as the dependent variable (Y). Six driving factors (X) are selected from three aspects of physical geography, socioeconomy, and built environment. The selected factors are terrain slope, population density, monthly household income, proportion of population aged 65 and over, road density, and point of interest density. The factor detector quantifies the explanatory power of each factor on the spatial differentiation of accessibility through the q value (0-1), as in Model (2).

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \tag{2}$$

Among them, N and N_h are the total sample size of the study area and the sample size of class h factor, respectively. L value is the number of driver types, and represent the total variance and class h total variance of the study area, respectively. The closer the q value is to 1, the stronger the explanatory power of the factor to the spatial differentiation of accessibility. Factors that passed the significance test were identified as the dominant drivers.

Fourth, the interaction detector is used to assess whether the combination of the two factors will enhance or weaken the explanatory power of the dependent variable Y. The principle is to compare the sum of q values when the two factors act alone with the size of q values when interacting, so as to judge the type of interaction. This module helps to reveal the complex combination of causes of the unfair pattern of accessibility.

3. Empirical results

3.1. Spatial differentiation

As shown in Fig. 1, according to Getis-Ord Gi* hotspot analysis, public open space accessibility within the study area presents obvious spatial agglomeration. High-value hotspots gather in central-western and northeastern zones, where dense populations are supported by sufficient surrounding public open spaces, while low-value cold spots concentrate in southern coastal areas and form accessibility depressions. Spatial matching results reveal supply-demand spatial dislocation, as some public open spaces cannot effectively serve nearby residents. It should be noted that partial coastal open spaces are excluded from this research's dataset due to screening boundaries, which to some extent underestimates the actual service capacity of southern coastal regions. Overall, accessibility shows an unbalanced pattern: high in the northeast and central-west, yet relatively low across southern coastal zones with prominent spatial differentiation.

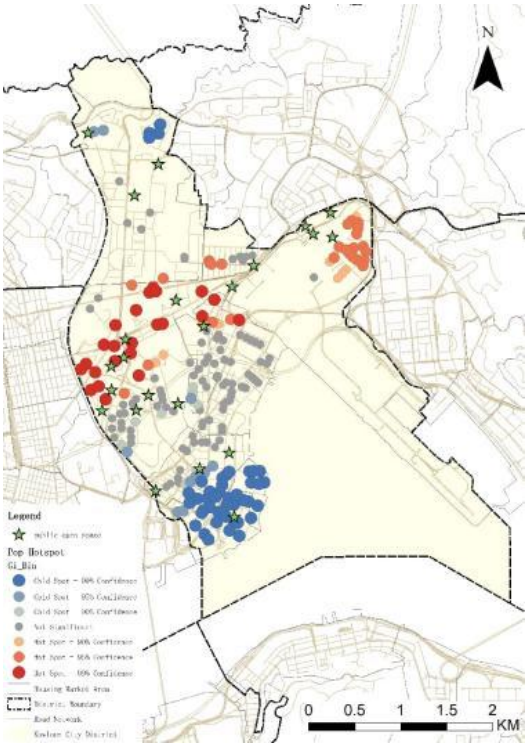


Fig. 1 Spatial hot and cold spot patterns of public open space accessibility (Picture credit: Original).

3.2. Social space equity differences

As Fig. 2, this study uses a population-weighted Gini coefficient and Lorenz curve to characterize the overall distribution equilibrium level of public open space accessibility. With the help of the Theil index decomposition method, the sources of accessibility inequality are identified from the perspectives of family income and the proportion of the elderly population. The results of the Lorenz curve show that the distribution curve as a whole is below the 45-degree full fair line, which deviates slightly from the fair line. The Gini coefficient is 0.2404, indicating that the accessibility of public open space in the study area is slightly unbalanced. The overall allocation of resources is relatively balanced, but local spatial differences exist objectively. The results of the Theil index decomposition show that the total Theil index is 0.1153. When grouped by income and the proportion of the elderly, the contribution of intergroup differences was only 0.30% and 1.58%, respectively. The vast majority of inequality came from intra-group differences.

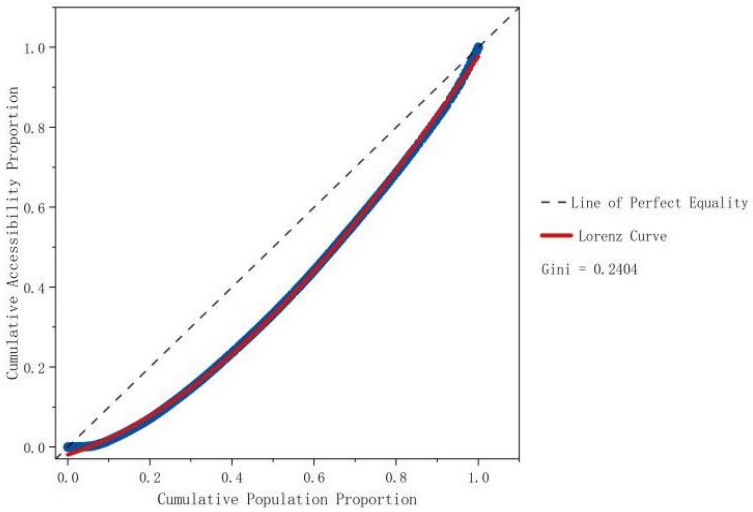


Fig. 2 Lorenz curve of population-weighted public open space accessibility (Picture credit: Original).

3.3. Analysis of driving mechanism based on Geodetector

This paper uses the geodetector model to identify the driving factors of spatial differentiation of accessibility in public open space. The results of factor detection showed that there were significant differences in the explanatory power of each factor. Road network density has the highest explanatory power, q=0.078, p<0.01. It is the core factor affecting the reachable personality pattern. Population density followed, q=0.078, p<0.01. Slope, monthly household income, proportion of elderly population, and point of interest density did not pass the significance test, and a single factor was difficult to explain the spatial difference of accessibility independently. The regional built environment tends to be mature, and socioeconomic factors such as income, aging, and commercial supporting facilities cannot lead to significant differentiation in the accessibility of public open space alone.

The results of Fig. 3 show that the explanatory power of any two factors after interaction is higher than that of a single factor, showing the characteristics of double-factor enhancement. This indicates that the uneven pattern of accessibility is the result of the joint action of many factors. The combination of road network density generally has high interactive explanatory power, among which the interaction between road network density and household monthly income is the strongest, q=0.547. The density of the road network and the proportion of the elderly population follow closely, q=0.526. The interactive q value of road network density and population density reached 0.427, which also showed a strong synergistic effect. This indicates that road network accessibility is the basic driving condition, and the superposition of population distribution, socioeconomic characteristics of residents, and road network conditions jointly shapes the spatial differences in the accessibility of public open space in the study area.

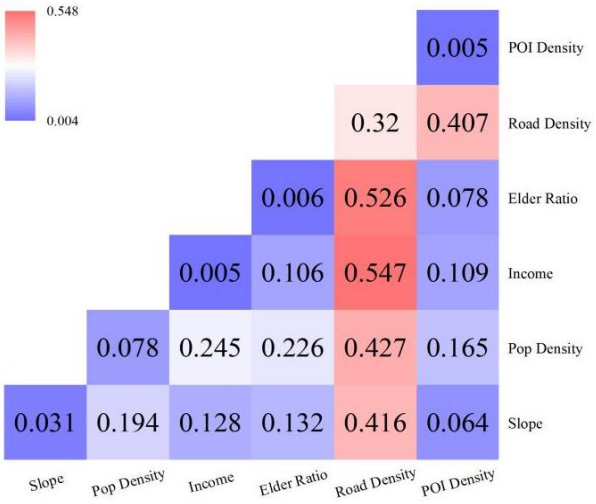


Fig. 3 Heatmap of interaction detection for driving factors (Picture credit: Original).

4. Discussions and optimization strategies

Empirical results reveal Kowloon City's public open space accessibility imbalance is dominated by regional spatial location gaps. No systematic accessibility disparities exist across income and elderly groups, while road network connectivity constitutes the core factor shaping service levels. Combined with high-value hotspots and southern coastal low-value depressions identified via hotspot analysis, zoned differentiated spatial optimization paths are proposed. Central-western and northeastern hotspots prioritize stock quality improvement instead of large-scale new green space construction: planners can adjust park entrance layouts, develop pocket parks from street corners and building gaps, and ease green space crowding in dense residential blocks. Southern coastal cold spots suffer calculation bias from incomplete datasets, so authorities should improve slow-traffic connectivity and space supply, build pedestrian corridors linking coasts and inland communities, and

incorporate coastal leisure venues into evaluation systems to eliminate accessibility depressions. Urban renewal can also revitalize fragmented idle land to offset local service shortages at low cost.

Geodetector outputs prove single socioeconomic indicators poorly explain accessibility patterns, yet the joint superposition of road network density, household income and elderly ratio exacerbates spatial inequity, and pedestrian networks form the fundamental constraint for equal green resource distribution. Current planning overemphasizes green space expansion and ignores pedestrian connectivity. Accordingly, a road network-prioritized equal allocation strategy is presented. First, upgrade continuous graded pedestrian systems in cold-spot zones, reconstruct dead-end roads and narrow sidewalks, and install barrier-free facilities to weaken road-induced accessibility stratification. Second, establish coordinated site selection for roads and green spaces, prioritizing micro leisure facilities in populous areas with poor road networks to boost green space radiation efficiency. Third, construct age-friendly pedestrian corridors with ramps and rest stops in heavily ageing regions to mitigate unfair effects amplified by factor interactions.

5. Conclusion

This paper takes high-density Kowloon of Hong Kong as the research object, adopts the Gaussian two-step floating catchment area method to calculate public open space accessibility at building group points, and uses the Lorenz curve, Gini coefficient, Theil index and Geodetector to explore equity and differentiation drivers. Three key conclusions are obtained. First, accessibility presents distinct spatial agglomeration, high in the northeast and central-west while low in southern coastal zones. Second, public open space distribution bears mild inequity, and almost all disparities derive from intra-group spatial gaps. Low-income and ageing areas have no systematic green space undersupply. Third, road network density acts as the core driver, followed by population density. It generates the strongest synergy with household income and elderly ratio, and pedestrian network conditions enlarge disparities from demographic and socioeconomic factors. Corresponding optimization paths for old high-density urban districts are proposed in three dimensions: zoned differentiated supply, road network-led equal allocation and multi-subject collaborative governance.

At the theoretical level, this paper enriches the empirical cases of spatial justice theory in the high-density urban areas of Guangdong, Hong Kong and Macao. At the practical level, the calculation conclusions and optimization strategies can provide reference for the renewal of the Old Kowloon district and the integrated planning of the waterfront promenade in Hong Kong. However, there are still some limitations in this study, such as the screening boundary of the public open space data set; some small coastal leisure venues are not included in the calculation, and the actual supply level in the southern area is underestimated to a certain extent. Future research can improve the data collection of coastal small and micro-open space, set differentiated travel thresholds for different groups of people, and carry out multi-scenario accessibility calculation. Panel data can also be introduced to track the long-term dynamic evolution of green space accessibility and fairness after the implementation of the old area renewal project, so as to further improve the fair governance system of public open space in high-density cities.

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