

深圳市城市居住单元绿化水平与空间差异研究

Research on the Greening Rate and Spatial Differences of Urban Residential Neighborhoods in Shenzhen

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摘要

居住区绿地是城市居民使用最多的城市绿地类型之一。鉴于既有绿化指标无法准确衡量城市居住区绿化水平的空间差异，本文提出居住单元绿化覆盖率、绿视率、500m范围内的公园绿地率三项居住单元绿化指标，旨在探讨城市绿地服务的公平性问题。研究以2017年的深圳市建成区居住单元为例，利用土地覆被图、街景图片等建立了包含14 196个居住单元的绿化数据库，并测算了每个居住单元的三项绿化指标值，衡量了居住单元绿化水平及其空间差异的影响因素。研究表明：1) 三项指标均可独立反映居住单元内部或周边绿化水平；2) 居住单元的绿化覆盖率、500m范围内的公园绿地率均较低，绿视率较高；3) 不同居住单元内部、500m范围内的公园绿地，以及不同房屋产权类型的居住单元的绿化水平存在较大空间差异，绿地服务的公平性不足；4) 居住单元绿化水平受开发强度、房屋产权类型、海拔和区位等地理空间因素影响。研究建议城市绿地布局应考虑与居住单元的空间关系，关注弱势群体的绿地服务质量，并重视居住区绿化指标的多维化，尤其可将500m范围内的公园绿地率作为现有居住区绿化指标体系的补充指标。

关键词

居住单元；居住单元绿化覆盖率；绿视率；500m范围内的公园绿地率；绿化水平；空间差异；深圳

ABSTRACT

Residential green spaces are one of the most frequently used urban green space types. Aiming at filling a gap in the existing greening indicators with considerations on the spatial differences of residential green spaces, as well as to inform the improvement of urban green space service, three greening indicators, i.e. residential unit's green coverage rate, green view index, and park ratio within a 500 m service radius, are proposed in this paper. This study selects 14,196 residential units in built area of Shenzhen City in 2017 to measure the greening rate and the geographic spatial factors of the units upon multi-sourced geographic databases such as land cover maps and street view images. The research reveals that: 1) the three indicators can all independently measure the greening rate within or around residential units; 2) the studied residential units are low in residential unit's green coverage rate and park ratio within a 500 m service radius, but high in green view index; 3) there are significant disparities of the greening rate and the surrounding parks in 500 m service radius among the studied units, and among different housing property rights, showing a disequilibrium in green space service; and 4) the greening rate of residential units is mainly impacted by factors such as development intensity, types of housing property right, altitude, and location. In conclusion, it is suggested that urban green space layout should prioritize improving the spatial distribution and layout of residential green spaces, especially for the socially vulnerable population. Finally, the study points out that the park ratio within a 500 m service radius can be adopted as a supplement to existing greening indicators for residential areas.

KEYWORDS

Residential Neighborhoods; Residential Unit's Green Coverage Rate; Green View Index; Park Ratio Within a 500 m Service Radius; Greening Rate; Spatial Difference; Shenzhen

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1 引言

城市绿地是城市中以植被为主要形态,并对生态、游憩、景观、防护具有积极作用的各类绿地的总称^[1]。城市绿地所发挥的生态作用包括固碳、净化空气、缓解热岛效应、过滤和减少雨水径流等^{[2][3]}。作为城市景观的重要组成部分,城市绿地对城市居民的身体、生理、社交等方面重要性也已得到广泛证实^{[4][5]}。居住区内部及周围绿地是城市居民访问率较高的绿地,为社会融合和市民体育锻炼提供了机会,也有利于提升居民心理健康、缓解压力,减少肥胖、暴力和犯罪^{[6][7]}。因此,作为提升民生福祉的重要途径,居住区绿地服务的公平性尤应受到重视。

多年来,中国的规划管理体系一直将城市绿地率、城市绿化覆盖率和人均公园绿地面积等作为主要的城市绿化评价指标^[8]。这些指标虽然可以对城市绿地总量进行直观的量化评价,却难以评价绿地与居住区之间的空间关系,尤其忽视了弱势群体所面临的居住区绿地服务不足的问题^{[9]-[14]}。随着城市房屋产权类型多元化发展——包括不同密度的商品房、集体宿舍、保障房、城中村等——城市绿地供给也开始呈现多元化格局。此外,尽管这些指标可对二维平面绿化效果进行一定评价,却无法指征三维空间的绿化分布和景观效果。而实际上,人在环境中所接收到的信息约80%~90%来源于视觉^[15],街道绿化与居住区内部树木是大部分居民日常接触最多的绿色景观之一^[16]。建设小微绿地与立体绿化能够提高街区绿化可视性与空间绿量^[17]。因此,对于视觉层面绿化(包括街道绿化、居住区内部树木、草坪和其他绿化)的评价可以反映城市空间绿化水平。但少有研究系统分析城市居住区的相关绿化的三维分布情况^[18],而“绿视率”^[19]这一概念的出现补充了现有绿化评价指标在居住区的街道绿化与居住区内部树木等绿化在可视性方面的不足,且近年数据可获取性和计算机图片处理技术的发展亦为深入研究绿视率提供了可能^{[20][21]}。因此,如何更准确地衡量城市居住空间中绿化水平的空间差异,以提升绿地服务的公平性还有待探讨。

基于此,本研究以深圳市建成区居住单元为对象,利用土地覆被图、街景图片等构建多源地理数据集成的绿化数据库,在现有城市绿化评价指标基础上补充针对居住单元的三项绿化指标——居住单元绿化覆盖率、绿视率、500m范围内的公园绿地率,并借助统计学分析,探讨衡量城市居住单元绿化水平与空间差异的方法,评估绿地服务的公平性情况。

1 Introduction

Collectively, urban green space refers to all kinds of individual green spaces that are mostly covered by vegetation and contribute to local ecology, recreation, landscape, and protection^[1], wherein the ecological benefits include carbon sequestration, air purification, Urban Heat Island Effect mitigation, and filtration and reduction of stormwater runoff^{[2][3]}. As a critical component to the urban landscape, urban green spaces have proven their benefits to people's physical and mental health, as well as social activities^{[4][5]}. Green spaces within and around residential areas could encourage residents to visit for the opportunities of social cohesion and physical exercise, so as to alleviate residents' psychological pressure and reduce obesity, violence, and crimes^{[6][7]}. To facilitate the promotion of people's well-being, research on the equality of residential green space service is expected.

Existing indicators, e.g. urban green rate, urban green coverage rate, and the per capita green area of the park, are primarily used to quantitatively assess the overall amount of urban green spaces^[8] with little consideration on the spatial pattern relationship between green spaces and residential areas—especially to the vulnerable groups who live in the areas lacking green spaces^{[9]-[14]}. China's increase in urban property rights of houses—including commercial housing with varied living densities, dormitories, affordable housing, and urban villages—have resulted in the diversity of urban green space creation. However, no corresponding changes do the two-dimensional indicators bring to assesses three-dimensional spatial morphology and landscape effect. Given that visual perception contributes to about 80% ~ 90% of the information a person receives from the environment^[15], streetscapes and the trees within residential areas are the mostly frequent objects of visual perception^[16]. The visibility and Living Vegetation Volume of residential green spaces can be improved by adding more small-scale green spaces and vertical greenery^[17]. Therefore, the evaluation of visual greening (including street greening, and trees, lawn, and other greenery within residential areas) can indicate the greening rate of urban spaces. However, systematic research on the three-dimensional distribution of the greening of urban residential areas is still absent^[18]. Green view index^[19], an indicator of the greening rate of urban spaces, can be used in such research, which is also promoted by the increase of data availability as well as the advance of computer image-processing capability^{[20][21]}. A further exploration on how to increase the accuracy in measuring the spatial differences of residential green spaces can inform the improvement of the city's green space service.

In response, the study is carried out in the residential neighborhoods (residential unit hereafter) in built areas of Shenzhen City, to verify the research method that measures the greening rate and spatial difference of residential units to inform the improvement of the city's green space service via three greening indicators, i.e. residential unit's green coverage rate, green view index, and park ratio within a 500 m service radius, through statistical analyses upon multi-source geographic databases such as land cover maps and street view images.

2 数据来源与研究方法

2.1 研究对象及样本选择

本文选取中国园林城市深圳市作为研究案例。2016年,深圳市建成区园林绿地面积362.67km²^[22],建成区绿地率39.2%;建成区绿化覆盖率为45.1%,人均公园绿地面积为16.45m²^[23]。而同年,中国城市建成区绿地率为36.34%,建成区绿化覆盖率约为40%,人均公园绿地面积为13.16m²^{[24][25]}。可见,相较全国数据而言,深圳市建成区的各项绿化指标均达到较高水平。

研究将深圳市建成区的居住单元作为分析样本——居住单元指城市用地现状普查图中涵盖居住建筑的宗地^①^{[26]-[28]}。依据深圳市规划和自然资源局2015年的土地调查资料《土地利用现状调查》^②,深圳市共有居住单元19 575个。2014年《深圳市建筑普查》^③资料显示,深圳市居住建筑的房屋产权类型主要为商品房(含保障房)、农民房(含城中村、小产权房)、集体宿舍(含部分小产权房)、其他产权房。本研究分别统计了每个居住单元的用地面积、所有建筑的基底面积、总建筑面积,并测算了居住单元容积率、建筑密度等指标。由于商品房居住单元数量最多,为进一步区分不同密度商品房的绿化特点,研究以样本居住单元容积率的中位数值(2.0),将商品房分为高密度商品房(容积率≥2.0)和低密度商品房(容积率<2.0)两类。

2.2 三项绿化指标测算

综合已有的衡量城市绿化的相关方法,研究提出居住单元绿化覆盖率(后文简称“绿覆率”)、绿视率、500m范围内的公园绿地率三项指标,用于衡量居住单元的绿化水平与空间差异。

(1) 绿覆率

基于2017年高分辨率多光谱全色SPOT-5影像所获得的深圳市土地覆被图^[29],借助ArcGIS工具获得居住单元用地范围内所有植被垂直投影的面积(VPA)。计算时,居住单元绿覆率为居住单元用地范围内所有植被垂直投影的面积与该居住单元总面积(RUA)的比值。^[28]计算公式为:

$$GCR = VPA/RUA \times 100\% \quad (1)$$

(2) 绿视率

绿视率通过街景图片进行计算。国内推出了百度、高德、腾讯等多家街景地图,研究采用覆盖范围最广、更新更为及时迅速的腾讯街景地图^[21]。本文作者于2017年5~6月,利用腾讯街景地图抓取了深圳市所有

① 宗地是城镇地籍的最小单元,具有确定权属主和利用类别(参见参考文献[25])。

② 数据来源:深圳市规划和自然资源局。

③ Land plot is the basic unit in urban land management with clear ownership and land use category [Source: Ref. [25]].

④ Data source: Shenzhen Municipal Bureau of Planning and Natural Resources.

2 Data Source and Research Method

2.1 Study Object and Sample Selection

This paper focuses on Shenzhen, a Chinese Garden City, where the built area boasted 362.67 km² green space^[22] with a green rate of 39.2%, a green coverage rate of 45.1%, and 16.45 m² per capita green area of the park^[23], according to the statistics of 2016. Compared with the nationwide data at that time, the last three indicators were 36.34%, 40%, and 13.16 m², respectively^{[24][25]}. Apparently, the greening level of built areas in Shenzhen has been relatively high.

The research selected all kinds of residential units—which refer to the land plot^① covering residential buildings in the general survey map of urban land use—in built area of Shenzhen as study samples^{[26]-[28]}. According to the Land Use Survey^② offered by Shenzhen Municipal Bureau of Planning and Natural Resources in 2015, the city accommodated 19,575 residential units. Shenzhen Building Survey^③ in 2014 reported that the property rights of residential buildings were commercial housing (affordable housing included), farmer housing (urban village and housing with limited property right included), dormitories (part of housing with limited property right included), and other housing. This research measures the land area, building covering area of all buildings, total floor area of each residential unit, and calculates indicators such as Floor Area Ratio (FAR) and Building Density (BD). The research identifies the building density levels of the residential units by FAR median (2.0), and divides commercial housing into high-density ones (FAR ≥ 2.0) and low-density ones (FAR < 2.0).

2.2 Calculation of Greening Indicators

According to the existing evaluation methods, this paper puts forward three greening indicators to measure the greening rate and spatial difference of the residential units, namely green coverage rate (GCR), green view index (GVI), and park ratio within a 500 m service radius (PRS).

(1) Green coverage rate

Based on the land cover map of Shenzhen from 2017 high-resolution multispectral panchromatic SPOT-5 image^[29], GCR is the ratio of the vertical projection area of all vegetation (VPA) within the residential unit (RUA) by ArcGIS.^[28] The calculation formula is:

$$GCR = VPA/RUA \times 100\% \quad (1)$$

(2) Green view index

GVI is generated via Tencent Street View, which covers the most comprehensive streetscape data of Chinese cities in an immediate update compared with other street view providers such as Baidu and AutoNavi^[21]. During May to June 2017, the authors fetched all the street data of Shenzhen (captured from January 2013 to May 2017) and gained 1,167,200 street view images from 291,800 sampling points in total. The GVI of a sampling point is the mean greenery ratio in street view images

道路的街景数据（数据本身抓取时间分布在2013年1月~2017年5月），获得29.18万个采样点总计116.72万张街景图片。计算时，采样点绿视率为该点沿道路前进方向的前、后、左、右4个方向街景图片中绿色植物所占的面积（GA）与图片总面积（IA）的比重均值^[21]。居住单元的绿视率取值为该单元内部及周边主要道路（居住单元用地边界100m缓冲区内）^③所有采样点的绿视率均值。若相邻两个居住区缓冲区相交，不重复计算叠加部分的采样点。计算公式为：

$$GVI = GA/IA \times 100\% \quad (2)$$

（3）500m范围内的公园绿地率

为定量比较不同居住单元周围公园绿地服务的水平，本研究结合绿地可达性和城市绿地率^[30]，提出居住单元500m范围内的公园绿地率指标。计算方法为：居住单元边界外500m缓冲区范围内的各类公园绿地（PA）^④（含城市公园、社区公园）占缓冲区总面积（BA）的比例。计算公式为：

$$PRS = PA/BA \times 100\% \quad (3)$$

2.3 数据库建立及统计学分析

研究运用ArcGIS工具，对全市19 575个建成区居住单元绿化建立数据库。为减少居住单元占地面积或建筑规模较少和绿视率采样点不足带来的误差，研究先剔除了居住单元占地面积小于2 000m²或居住建筑总面积小于1 000m²的居住单元，后剔除了绿视率采样点数量少于10个的居住单元^[31]。最终纳入统计分析的居住单元样本数为14 196个。研究分别测算了每个居住单元的三项指标，并计算各个指标的均值与标准差。同时，本文参考相关研究^{[21][31]}及数据可获取性，最终选取了14个自变量，分别建立线性回归分析模型，试图寻找与居住单元绿化水平相关的地理空间因素。其中，自变量的类型为居住单元本身特征、居住单元区位条件和居住单元周边环境，二分类变量进行了哑变量处理，分为了用地面积、建筑数量、建筑密度、容积率、是否商品房、是否集体宿舍、是否农产房、是否其他产权房、是否关内^⑤、与CBD距离、公交线数、是否临山、是否临水和海拔。因变量为绿覆率、绿视率、500m范围内的公园绿地率。

③ 据《深圳市城市规划标准与准则（2013版）》，深圳市城市道路宽度为12~80m。因此，100m缓冲区基本可覆盖居住单元邻接道路两侧的采样点。

④ 本研究的公园绿地包括《深圳市城市规划标准与准则（2013版）》所提及全部绿地类型。该标准依据深圳市用地实际情况，将绿地与广场用地分为公园绿地和广场用地，公园绿地按服务级别分为城市公园（包括综合公园和专类公园）和社区公园（包括集中绿地、带状公园）。

⑤ “关内”是指深圳市的原经济特区，即福田区、罗湖区、南山区、盐田区。

taken from 4 directions, i.e. front, back, left, and right along the road (GA) to the total area of the images (IA)^[21]. The GVI of a residential unit adopts the mean value of all sampling points within the unit and main surrounding roads/paths (in the 100 m buffer zone around the unit)^③. Particularly, if the buffer zones of two adjacent residential units intersect, the sampling points in the overlapping areas will not be calculated repeatedly. The formula shows below:

$$GVI = GA/IA \times 100\% \quad (2)$$

(3) Park ratio within a 500 m service radius

Combining the green space accessibility and urban green rate^[30], this study employs PRS to quantify the park service of each residential unit. It is the ratio of the area of all kinds of parks (including urban parks and community parks)^④ within a 500 m buffer zone around the unit (PA) to the total area of the buffer zone (BA). The calculation formula is as follow:

$$PRS = PA/BA \times 100\% \quad (3)$$

2.3 Database Establishment and Statistical Analysis

This research establishes a database about the 19,575 studied residential units via ArcGIS. To avoid the deviation caused by the residential units of a smaller size or of inadequate GVI sampling points, the research eliminates the ones of a land area less than 2,000 m², or total floor area less than 1,000 m², or GVI sampling points less than 10^[31]. 14,196 residential units are obtained for statistical analysis, and the three indicators of each unit as well as the corresponding mean value and standard deviation (SD) are calculated. For examining the geographic spatial factors influencing the greening rate of units, a total of 14 independent variables are adopted for the linear regression analysis in accordance with relevant studies^{[21][32]} and data availability. The types of independent variables (including properties, locations, and surrounding environments of residential units) are taken as dichotomous variables encoded by dummy variables, and classified into 14 categories, namely land area, building quantity, BD, FAR, commercial housing (yes/no), dormitory (yes/no), farmer housing (yes/no), other housing (yes/no), within Shenzhen Pass^⑤ (yes/no), distance from CBD, amount of bus lines, on mountain foot (yes/no), in waterfront (yes/no), and altitude. The dependent variables are GCR, GVI, and PRS.

③ According to Shenzhen Urban Planning Standards and Guidelines [2013], the width of urban roads in Shenzhen is 12 ~ 80 m, which can be fully covered by the 100 m buffer zones in the research.

④ The parks in this research include all the green space types defined in Shenzhen Urban Planning Standard and Guidelines [2013]. Considering the local conditions of land use reality, Park Land and Square is subcategorized into Parks and Squares, wherein the former is divided into Urban Parks (including general parks and special parks) and Community Parks (including commons and belt parks).

⑤ "Within Shenzhen Pass" refers to the former special economic zones of Shenzhen, namely District of Futian, Luohu, Nanshan, and Yantian.

3 居住单元绿化水平与空间差异分析

3.1 绿化水平与空间差异分析

结果表明,三个绿化指标之间弱正相关($p < 0.01$)。绿覆率与绿视率、500m范围内的公园绿地率相关系数分别为0.24、0.02,绿视率与500m范围内的公园绿地率相关系数为0.19。

根据表1,居住单元平均绿覆率仅为32.7%,大幅低于全市建成区绿化覆盖率(45.1%)^[23]。500m范围内的公园绿地率均值8.6%,也远低于全市建成区公园绿地率(18.6%)^⑥。而平均绿视率为30.5%,与全市建成区道路绿视率均值相当(31.5%)^⑦,也大大高于相关文献推荐的25%的水平标准——在此标准上,人将获得舒适的视觉感知与精神状态^{[19][33]}。上述结果表明深圳市建成区居住单元内部和500m范围内的绿化水平总体均偏低,但内部道路和周边道路绿化水平较高。

相较之下,绿覆率(13.7%)、500m范围内的公园绿地率(11.8%)的标准差较大,绿视率(8.4%)的标准差较小。表明不同居住单元的绿覆率与500m范围内的公园绿地率和各自的平均值相差较大,即数值离散程度大,因此,不同居住单位的内部绿化水平、500m范围内的公园绿地水平的空间分布不均衡;而不同居住单元的绿视率都接近平均值,表明不同居住单元内部及周边道路绿化景观的空间分布较均衡。研究采用自然间断点分级法,利用ArcGIS工具将绿覆率、绿视率、500m范围内的公园绿地率空间分布可视化^⑧(图1~3)。

3.2 不同房屋产权类型居住单元的绿化水平比较

经方差分析,表明不同房屋产权类型居住单元绿化水平差异较大($p < 0.05$)。低密度商品房、其他产权房的三项指标均较高,即这两种房屋产权类型居住单元的绿化水平最高。值得注意的是,高密度商品房的500m范围内的公园绿地率较低密度商品房低。而农民房和集体宿舍的绿化水平最低(图4)。社会正义理念强调基本公共服务应当向特定的社会弱势群体倾斜^{[34][35]}。农民房、集体宿舍的租户主要为城市中的弱势群体,而其绿覆率与500m范围内公园绿地率较低,可见深圳市建成区绿地空间分布的公平性与社会正义性存在不足。

⑥ 全市建成区公园绿地率由作者基于2015年的《土地利用现状调查》数据自行计算,取值为公园绿地面积与建成区用地面积的比值。

⑦ 全市建成区道路绿视率均值由作者计算,等于城市道路上所有取样点绿视率的平均值。

⑧ 由于某一居住单元的缓冲区可能同时是周边其他几个居住单元缓冲区的一部分,因此三张空间分布图的数据根据每个居住单元的绿覆率、绿视率和500m范围内的公园绿地率的数值进行可视化。

⑥ The green rate in built area of Shenzhen is calculated as the ratio of the park area to the build-up area, according to the data of Land Use Survey in 2015.

⑦ The average GVI of the roads in built area adopts the average GVI of all the sampling points on roads.

⑧ As the buffer zone of one residential unit which may be also a part of another neighboring unit, the data of the three spatial distribution maps visualize the units themselves only.

3 Analysis on Greening Rate and Spatial Difference of Residential Units

3.1 Analysis on Greening Rate and Spatial Difference

The results show that there are slight positive correlations between the three greening indicators ($p < 0.01$). The correlation coefficient between GCR and GVI, GCR and PRS, and GVI and PRS is 0.24, 0.02, and 0.19, respectively.

Showing in Table 1, the average GCR of the studied residential units is only 32.7%, sharply lower than the green coverage rate (45.1%)^[23]; the average PRS is just 8.6%, also lower than the green rate (18.6%)^⑥ in built areas of Shenzhen; the average GVI (30.5%) is roughly equal to that of the roads in built areas of Shenzhen (31.5%)^⑦, which is much higher than 25%, a standard for pleasant visual perception and mental status suggested by related studies^{[19][33]}. The results indicate that the general greening rate of the residential units and the 500 m service radius are relatively low, but the roads within and around the units relatively high.

In contrast, GCR (13.7%) and PRS (11.8%) have a relatively large SD, while GVI (8.4%) owns a relatively small one. The high mean absolute deviation value of GCR and PRS of each unit indicate a disequilibrium distribution of the greening among varied units, as the same as the surrounding parks in 500 m service radius; and the low mean absolute deviation value of GVI see a slight difference among the roads within and around the units. This study quantifies and visualizes the spatial distribution of GCR, GVI, and PRS by the natural breaks in ArcGIS[®] (Fig. 1 ~ 3).

3.2 Comparison on the Greening Rate of Different Housing Property Rights in the Residential Units

Variance analysis evidences the significant differences in the greening rate of different property rights of houses ($p < 0.05$). The three indicators of low-density commercial housing and other housing are relatively higher, suggesting that the two types of housings have the highest greening rate. Remarkably, the PRS of high-density commercial housing is lower than the low-density one. The greening rate of farmer housing and dormitory, where a large number of vulnerable population live, is the lowest (Fig. 4). Social justice emphasizes that basic public services of socially vulnerable groups should be guaranteed^{[34][35]}. The poor GCR and PRS indicate the deficiency in the spatial equality and social justice of green space distribution in built areas of Shenzhen.

3.3 The Impact Factors of Greening Rate

In SPSS 17.0, three linear regression models are established. The Q-Q plot test results show the dependent variables conform to normal distribution. Since the values of variance inflation factors (VIF) of all the variables are smaller than 3, multi-collinearity does not exist. The R^2 values of GCR, GVI, and PRS are 0.318, 0.195, and 0.152 respectively, proving the explanatory effectiveness of the models, whereas GCR the strongest.

The results show that most variables are in a same positive/negative correlation with each other (Table 2). Among the high significance ($\text{sig.} < 0.001$), regression

表1: 居住单元基本属性表
Table 1: Basic attribute of residential units

变量 Variable	均值 Mean	标准差 SD
用地面积 (m ²) Land area (m ²)	24,786.75	34,286.35
总建筑数量 (栋) Total building number	35	84
建筑密度 BD	0.473	0.165
容积率 FAR	2.66	2.28
绿覆率 (%) GCR (%)	32.7	13.7
绿视率 (%) GVI (%)	30.5	8.4
500m范围内的公园绿地率 (%) PRS (%)	8.6	11.8

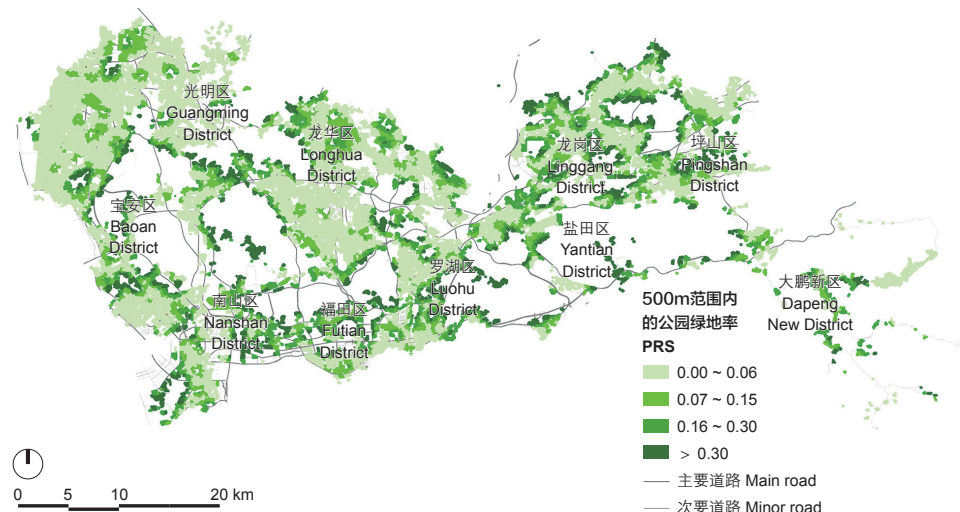
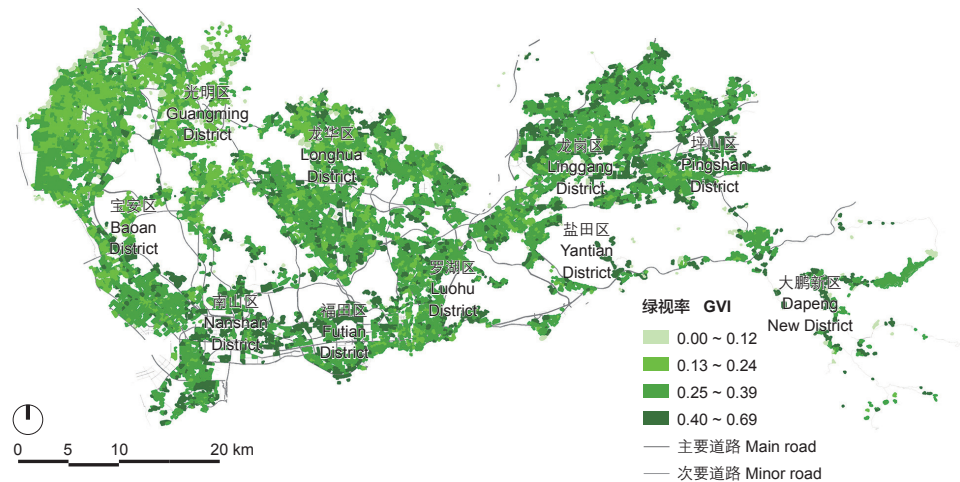
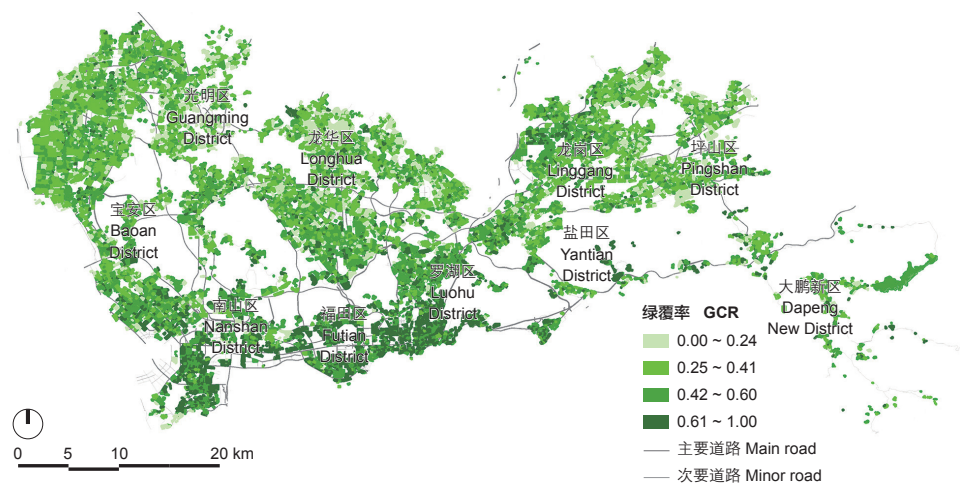
1. 绿覆率空间分布
2. 绿视率空间分布
3. 500m范围内的公园绿地率的空间分布

1. The spatial distribution of GCR in residential units
2. The spatial distribution of GVI for residential units
3. The spatial distribution of PRS for residential units

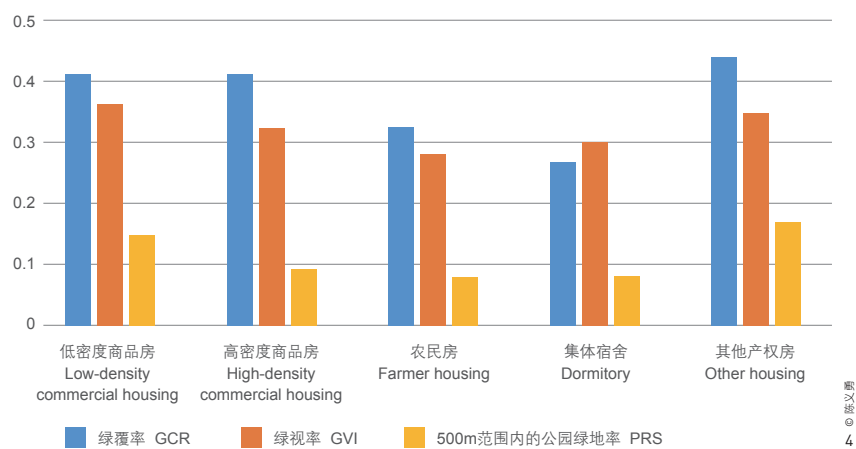
3.3 绿化水平的影响因素

在SPSS 17.0中,建立了三个线性回归分析模型。Q-Q图检验显示,因变量均符合正态分布。模型中所有变量的方差膨胀因子(VIF)均小于3,表明变量之间不存在明显共线性。绿覆率、绿视率和500m范围内的公园绿地率的校正决定系数(R²)分别为0.318、0.195、0.152,表明模型对绿化水平有一定的解释力度,其中,对绿覆率的解释力度最大。

三个模型中(表2),大部分变量的方向(正、负相关)一致。其中,建筑密度、容积率的回归系数(a)均为负且显著性水平高(sig.<0.001),是否关内、海拔的回归系数均为正且显著性水平高(sig.<0.001),表明开发强度小(即建筑密度小、容积率小)、位于关内、海拔高的居住单元具有较高的绿化水平。针对每个指标而言,显著影响绿覆率且回归系数为正的因子还包括是否商品房(a=0.127),显著影响绿覆率但回归系数为负的因素还包括用地面积(a=-0.053)、与CBD距离(a=-0.067);显著影响绿视率但回归系数为负的因素还包括建筑数量(a=-0.073)、是否集体宿舍(a=-0.088)等。表明非商品房、用地面积越大、与CBD距离越远的居住单元绿覆率越低,建筑数量越多、是集体宿舍的居住单元绿视率越低。显著影响500m范围内的公园绿地率的因素还包括地块面积(a=0.049)



coefficients (a) of BD and FAR are negative, and those of within Shenzhen Pass (yes/no) and altitude are positive, suggesting the residential units with low development intensity (i.e. low BD and FAR), located within Shenzhen Pass, and with high altitude have a higher greening rate. GCR also strongly correlates with commercial housing (a = 0.127), land area (a = -0.053), and distance from CBD



4. 不同房屋产权类型居住单元的三项绿化指标的均值
4. The mean value of the three indicators of residential units with different property rights of houses

和与CBD距离 ($a=0.188$), 表明地块面积越大、与CBD距离越远的居住单元周边拥有更多的公园绿地。可见, 居住单元绿化水平主要受到居住单元的开发强度、房屋产权类型、海拔和区位等多种因素的影响。

4 讨论

4.1 居住单元的绿化水平与空间差异原因分析

研究提出的居住单元三项绿化指标中, 绿覆盖率和500m范围内的公园绿地率总体水平均较低, 绿视率较高; 另外, 绿覆盖率和500m范围内的公园绿地的空间差异较大, 绿视率差异较小。

其中, 居住单元绿覆盖率均值仅为32.7%, 大幅低于全市建成区绿化覆盖率; 另外, 绿覆盖率计算中还包含了乔木投影、屋顶花园、植草砖等用地, 这也可能导致最终数值比《城市居住区规划设计标准》中的街坊用地的绿地率(该指标未将这些用地纳入计算)更高。根据回归分析结果, 绿覆盖率的差异大的原因主要在于居住单元的开发强度、是否位于关内、是否商品房、海拔高度、用地面积, 和与CBD距离等。其中, 商品房规划设计中依据《城市居住区规划设计标准》控制街坊用地绿地率最小值, 农民房、集体宿舍则无此规定^[36]。深圳关内地区发展建设较早且成熟度较高, 商品房居住区占多数, 关外地区则以农民房、集体宿舍居多^[37]。

($a = -0.067$); and GVI strongly correlates with building quantity ($a = -0.073$) and dormitory (yes/no) ($a = -0.088$)—The data prove that the residential units of non-commercial housing, larger land area, or farther away from CBD have a lower GCR; and the ones of larger building quantity or in type of dormitory have a lower GVI. Moreover, land area ($a = 0.049$) and distance from CBD ($a = 0.188$) both are verified significant impact on PRS, revealing that the residential units of larger land area and farther distance from CBD are surrounded with more parks. Overall, the greening rate of residential units is influenced by many factors such as development intensity, property rights of houses, altitude, and location.

4 Discussions

4.1 Analysis on the Factors Influencing the Greening Rate and Spatial Difference of Residential Units

In sum, research results demonstrate that GCR and PRS of the studied residential units are both relatively low while higher in GVI, and GCL and PRS are in greater disequilibrium distribution as well.

The mean GCR is only 32.7%, greatly lower than the green coverage rate in built areas of Shenzhen. A possible reason might be that the land of arbor projection, roof garden, and grass planting tiles were counted as part of green coverage area, leading to a higher result than the stipulated green space ratio of neighborhoods by the Standard for Urban Residential Area Planning and Design which excludes such land uses. According to regression analysis results, the significant spatial difference of GCR is mainly caused by factors such as development intensity, within Shenzhen Pass (yes/no), commercial housing (yes/no), altitude, land area, and distance from CBD. This is maybe because of the green space ratio of neighborhoods required by the Standard for Urban Residential Area Planning and Design which merely cover the minimum GCR of commercial housing^[36]. Another reason might be that there are more commercial housings within Shenzhen Pass built during the earlier urbanization, but farmer housings and dormitories are more built in other districts of the city^[37].

表2: 回归模型标准化系数及显著性水平
Table 2: Regression model results on variables and significance

自变量 Independent variables		因变量 Dependent variables			自变量 Independent variables		因变量 Dependent variables		
类型 Type	二分类 Dichotomous variable	绿覆率 GCR	绿视率 GVI	500m范围内的 公园绿地率 PRS	类型 Type	二分类 Dichotomous variable	绿覆率 GCR	绿视率 GVI	500m范围内的 公园绿地率 PRS
居住单元 本身特征 Property	用地面积 Land area	-0.053**	0.018	0.049**	居住单元 区位条件 Location	是否关内 (是 = 1, 否 = 0) Within Shenzhen Pass (Yes = 1, No = 0)	0.273**	0.363**	0.435**
	建筑数量 Building quantity	-0.030*	-0.073**	0.001		与CBD距离 Distance from CBD	-0.067**	-0.195**	0.188**
	建筑密度 BD	-0.151**	-0.179**	-0.056**		公交线数 Bus lines	0.018	-0.016	-0.202*
	容积率 FAR	-0.071**	-0.043**	-0.048**	居住单元 周边环境 Surrounding environment	是否临山 (是 = 1, 否 = 0) On mountain foot (Yes = 1, No = 0)	0.011	0.032	0.001
	是否商品房 (是 = 1, 否 = 0) Commercial housing (Yes = 1, No = 0)	0.127**	-0.089**	0.049**		是否临水 (是 = 1, 否 = 0) In waterfront (Yes = 1, No = 0)	-0.008	-0.061*	-0.020*
	是否集体宿舍 (是 = 1, 否 = 0) Dormitory (Yes = 1, No = 0)	-0.154*	-0.088**	-0.011		海拔 Altitude	0.053**	0.274**	0.255**
	是否农民房 (是 = 1, 否 = 0) Farmer housing (Yes = 1, No = 0)	0.127*	-0.072**	0.009	样本量 Sample quantity	14196	14196	14196	
	是否其他产权房 (是 = 1, 否 = 0) Other housing (Yes = 1, No = 0)	0.370	-0.002	0.015	调整后R ² adj. R ²	0.318	0.195	0.152	
				F值 F-value	510.7	265.5	196.2		

注
*代表 $p < 0.01$; **代表 $p < 0.001$ 。

NOTE
* means $p < 0.01$; ** means $p < 0.001$.

至于绿视率, 本研究中的绿视率旨在反映居住单元道路绿化水平, 绿视率越高, 说明城市道路绿化的建设及维护水平越高^[33]。而城市道路绿化一般由市、区政府以统一标准投资建设与维护, 这可以解释为何绿视率水平较高且空间差异较小。此外, 研究也发现, 绿视率结果显示居住单元内部道路绿化水平较高且不同单元之间差异较小, 而绿覆率结果显示居住单元内部绿化水平总体偏低且不同单元之间差异巨大, 即存在居住单元内部道路绿化水平高而居住区内部总体绿化水平低的情况, 其原因可能在于不同居住单元总体绿化受多种绿地空间影响。如在商品房、其他产权房类型的居住单元中, 除道路绿化水平较高外, 宅旁绿

The GVI indicator used in this study aims at measuring the road greening rate of residential units. Generally, the higher the GVI value, the higher the construction and maintenance level of urban road greening^[33]. Road greening is usually invested, constructed, and maintained at a unified standard by municipal or district governments—This could somehow explain why GVI is of a higher yet less spatial disequilibrium distribution. The GVI findings suggest that the studied residential units have a higher road greening rate, and the differences across them are small. Meanwhile, GCR results evidence that the greening rate of residential units is generally low, yet the difference between each other is significant. In other words, the research findings imply that some residential units may have a high greening rate of roads but of a low greening level in general, which is possibly resulted from the diversity of green space patterns: For example, the green space beside residential building, sub-community green space, and roof garden within commercial housing and other housing largely contribute to the high overall greening rate, together with

地、组团绿地、屋顶花园等较为普遍，共同作用形成了较高的总体绿化水平^{[38][39]}；而在集体宿舍、农民房类型的居住单元中，不少居住单元内部并没有专门的绿地，但是路旁、周边等空间栽种了长势良好的独立树木^[28]，共同作用形成较高道路绿化但较低总体绿化水平。

对于500m范围内的公园绿地率而言，可能是由于既有的规划标准主要是对城市公园绿地的总量进行控制，因此，尽管深圳市建成区公园绿地率达18.6%，公园绿地500m服务半径覆盖的居住单元数量、面积比率分别达97.3%、90.9%^⑨，但居住单元500m范围内的公园绿地率的均值却仅为8.6%，且标准差大，表明公园绿地空间分布差异大，缺乏有效管控（尤其是与居住单元的关系）^[40]。具体体现在社区层面绿地建设不完善，缺乏居住邻里间小微绿地的建设。同时，公园绿地布局可能并未进一步考虑向弱势群体的居住空间适当倾斜。

4.2 不同房屋产权类型居住单元的绿化水平差异原因分析

研究发现，低密度商品房、其他产权房的绿化水平最高，可能是因为低密度商品房开发建设一般较早，占据着良好地段，而其他产权房是依托于墓地、陵园等非农业用地开发建设，一般有着良好的生态环境区位。高密度商品房500m范围内的公园绿地率较低密度商品房低，原因可能在于商品房开发定位中考虑了不同消费群体的住房支付能力与使用需求差异。高密度商品房面向住房支付能力一般的居民，优先满足交通等基本服务需求；低密度商品房则面向住房支付能力较好、有生态休憩需求且愿意为公园绿地高可达性而承担高房价的消费群体^{[41]-[43]}。相比之下，农民房和集体宿舍的绿化水平（尤其是绿覆率）最低，可能是由于农民房和集体宿舍的建筑密度普遍高于商品房，一般不具备绿化用地^[44]。绿视率较低可能是由于农民房和集体宿舍建筑及其周围用地产权多由散户持有，难以形成公共绿地系统^[45]。周边500m的公园绿地也较少，是由于农民房和集体宿舍居民以住房支付能力低的弱势群体为主，环境与休闲场所需求往往次于基础设施与公共服务设施需求^[46]，所在的村集体对绿化投入也就比较少。因此，为提升居住单元绿化水平，未来全市的人居环境建设应重点关注开发强度大（如高密度商品房）和弱势群体居住单元（如农民房、集体宿舍）的绿化建设。

⑨ 公园绿地500m半径覆盖的居住单元数量占比为公园绿地500m缓冲区覆盖的居住单元数量与总居住单元数量之比；居住单元面积500m半径覆盖的居住单元面积比率为公园绿地500m缓冲区覆盖范围内居住单元用地面积与居住单元总用地面积之比。

high greening rate of road^{[38][39]}. Although dormitory and farmer housing have a higher road greening rate due to the well growth of trees, they often lack of other types of green spaces that lead to a low overall greening rate^[28].

Compared with that the green rate of built areas in Shenzhen is 18.6% and the 500 m service radius of park green space covers 97.3% of residential units and 90.9% of total residential area^⑨, the mean PRS of the studied residential units is only 8.6% with a large SD, indicating a considerable disequilibrium in green scape distribution that lacks effective regulation (especially that closely related with residential units)^[40]. This is probably because existing planning standards mainly focus on the control of the total amount of urban green spaces. This finding reveals that the construction of community-scale green spaces is insufficient in the creation of smaller green spaces in residential units, and for socially vulnerable groups less benefited from the park space distribution.

4.2 Causalities of Greening Rate Differences of Residential Units Among Varied Housing Property Rights

The research finds out that low-density commercial housing and other housing enjoy the highest greening rate. It may be because that the former was built in the city's earlier urbanization and often have superior location conditions, and the latter was built on non-agricultural land (e.g. public cemeteris) where often sit in sound ecological environment. The lower PRS of high-density commercial housing than that of low-density one may attribute to the disparity in real estate development upon the affordability and usage demands of consumer groups. The consumers for high-density commercial housing are mainly the ones with a medium affordability, and their basic service demands such a traffic accessibility should be guaranteed; the low-density one serves those with a relatively high affordability and needs for quality living environment and recreational opportunities^{[41]-[43]}. In contrast, the greening rate of farmer housing and dormitory is unsatisfactory, especially in GCR. It probably because the two types of housings are often densely built with few green spaces^[44]. The lower GVI may be due to that the land property right of both housings and surrounding land plots are owned by different investors that is difficult to form public green space systems in the residential units^[45]. Besides, such housings often accommodate vulnerable groups, and developers invest more in infrastructure and public service facilities, rather than environmental and recreational uses^[46]. According to the research findings, future residential construction of Shenzhen should prioritize improving the greening of high-density commercial housing (such as high-density commercial housing) and residential areas for vulnerable groups (such as farmer housing and dormitory).

⑨ The proportion of the residential units covered by the 500 m service radius of park is calculated as the ratio of the unit number within the 500 m buffer zone around parks to the total amount of units. The residential unit area ratio is the ratio of unit land area within 500 m buffer zone around parks to total land area of units.

4.3 居住单元周边公园绿地供给水平指标创新与建议

以往研究多以城市绿地率或人均公园绿地面积为指标^{[47]-[49]}来衡量公园绿地的供给情况；《城市园林绿化评价标准（GB/T 50563-2010）》中也提出了公园绿地服务半径（500m）覆盖率指标，并指出公园绿地的布局应尽可能使公园绿地500m服务半径内实现居住用地全覆盖。事实上，这三个指标都旨在评价城市绿地的整体服务水平，无法衡量特定居住单元的绿地可达水平，即难以反映居住单元与周边绿地的空间关系^{[12][50][51]}。

本研究结合城市绿地率和绿地可达性，提出并测算了居住单元500m范围内的公园绿地率。研究证明该指标可以衡量居住单元周边公园绿地的比例，比较不同居住单元周边公园绿地的空间分布差异情况，并且可以结合居住单元绿覆率、绿视率等指标，综合评估居住单元绿化情况。研究建议基于不同房屋产权类型居住空间的绿化特征，针对性地调整影响因素。如在500m范围内的公园绿地率相对较低的高密度商品房居住单元空间内建设街头绿地，利用低层裙房建设空中花园等。农民房、集体宿舍类型居住单元空间内，可考虑依托道路基础设施建设，沿街适当增添乔木种植、立体绿化等来提高绿视率。

4.4 研究不足

本研究所使用的研究数据年份不同，对实验结果可能有一定影响。研究数据涉及2014年建筑普查、2015年土地利用数据与2017年深圳市街景数据等，在统计居住单元容积率、建筑密度、绿视率等相关指标时存在一定误差。

5 结论

研究以深圳市建成区居住单元为例，建立了多源地理数据集成的城市居住单元绿化数据库。综合已有的衡量城市绿化的相关方法，提出了绿覆率、绿视率、500m范围内的公园绿地率三项绿化指标，分析了居住单元绿化水平与空间差异，探讨了绿地服务的公平性问题。

1) 本研究提出的绿覆率、绿视率、500m范围内的公园绿地率三项绿化指标之间呈弱正相关，均可独立反映居住单元内部或周边的绿化水平。整体上，深圳市居住单元的绿覆率和500m范围内的公园绿地率均较低，绿视率则较高。

2) 深圳市居住单元绿化水平存在空间差异，绿地服务的公平性不足。其中，不同居住单元内部及周边主要道路绿化空间差异不大，居住

4.3 Innovation on the Supply Level Index of Parks Around Residential Units and Related Suggestions

Existing studies evaluate park supply by indicators such as urban green rate and per capita green area of the park^{[47]-[49]}. The Evaluation Standard for Urban Landscaping and Greening (GB/T 50563-2010) also includes the indicator coverage ratio of park service radius (500 m), and expects a full coverage of residential land in the 500 m service radius of parks. In fact, the three indicators are used to measure the overall service level of urban green space, but failed to assess the green space accessibility to specific residential areas, i.e. the spatial relations between residential units and surrounding green spaces^{[12][50][51]}.

Combining with urban green rate and green space accessibility, this research proposes and calculates PRS, which measures the spatial distribution difference of parks around residential units, and also the overall green rate of residential units together with GCR and GVI. In addition, this research suggests that the greening level of different housing types should be improved upon their specific spatial characteristics and housing property rights. For instance, the PRS of high-density commercial housing can be improved by adding small-scale green spaces and increasing roof gardens on low-rise podium buildings; For farmer housing and dormitory, it can be taken into account to plant more arbors and increase vertical greening based on existing infrastructure such as streets, so as to improve GVI.

4.4 Research Limitation

The findings of this research need to be further verified because the data used were collected in different years (such as Building Survey in 2014, Land Use Survey in 2015, and street view of Shenzhen in 2017), which would cause unavoidable inaccuracy in the calculation of FAR, BD, GVI, etc.

5 Conclusions

This research examines the residential units of built areas in Shenzhen to establish a greening database integrating multi-source geographic data. According to existing evaluation methods, this research proposes three greening indicators, i.e. residential unit's green coverage rate, green view index, and park ratio within a 500 m service radius, to delve into the greening rate and spatial difference among the studied residential units, as well as the service justice of the city's green spaces.

1) There are slight positive correlations between residential unit's green coverage rate, green view index, and park ratio within a 500 m service radius, meaning that they can all independently measure the greening rate within or around residential units. Overall, the studied residential units in Shenzhen are low in green coverage rate, and park ratio within a 500 m service radius but high in green view index.

2) There are spatial disparities in greening rate of residential units, showing the disequilibrium in green space service. There are slight differences among the roads within and around the units, while a significant disparity in spatial distribution

区内部绿化和500m范围内的公园绿地的空间分布差异较大；不同房屋产权类型居住单元绿化水平也存在较大差异，其中低密度商品房和其他产权房绿化水平最高，农民房和集体宿舍的绿化水平最低。反映出公园绿地这一公共产品未能向居住在农民房和集体宿舍的弱势群体倾斜，绿地服务的公平性与正义性有待提升。

3) 影响居住单元绿化水平的地理空间因素主要包括开发强度、房屋产权类型、海拔和区位等。

4) 研究提出的居住单元500m范围内的公园绿地率指标具有实践意义，可作为现有居住区绿化指标体系的补充，尤其建议将其作为衡量城市公园绿地率及空间分布情况的补充指标。LAF

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among varied units, as the same as the surrounding parks in 500 m service radius; The greening rate varies largely between different housing property rights, wherein low-density commercial housing and other housing see the highest rate while farmer housing and dormitory the lowest. The conclusions explain that the improvement in the fairness and justice of green space service—as a public goods—is expected, particularly for the socially vulnerable groups living in farmer housing and dormitory.

3) Geographic spatial factors influencing residential unit greening rate mainly include development intensity, types of housing property right, altitude, and location.

And 4) park ratio within a 500 m service radius, proposed in this research as a supplement to existing greening indicator system for measuring the quality of residential areas, may provide more targeted guidance to future planning and design of parks and for the spatial optimization of urban green spaces. LAF

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