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Urban green space distribution and environmental justice in São Paulo Neighborhoods

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Abstract

How fairly are urban green spaces shared among city residents, and does household income shape who gets access to parks and gardens? This research examined the spatial distribution of public green spaces across 32 neighborhoods in São Paulo, Brazil, and tested whether lower-income communities bear a disproportionate burden of green-space scarcity. Landsat-8 imagery acquired between March and August 2022 was classified with a maximum-likelihood algorithm to map vegetated surfaces at 30 m resolution. Per-capita green-space values were then linked to census-derived income quintiles through bivariate spatial autocorrelation (local Moran's I) in a geographic information system environment. Results showed that the citywide mean green-space provision stood at 8.7 m² per person, well below the World Health Organization benchmark of 9 m² per person. Wealthier districts in the southwest corridor averaged 17.4 m² per person, whereas peripheral low-income zones recorded as little as 2.1 m² per person. The Moran's I statistic ($I = 0.61$, $p < 0.001$) confirmed a strong positive spatial clustering of green-space poverty in economically marginalized areas. A multiple regression model that included population density, built-up fraction, and median household income explained 73.8% of the variance in neighborhood-level green-space provision; income alone accounted for 41.2%. These findings point to a clear environmental justice concern: the communities least equipped to secure private green amenities are also the ones most deprived of public green resources. Targeted investment in pocket parks and linear greenways within underserved peripheries could begin to close this gap.

Keywords: Urban green space, environmental justice, spatial inequality, public parks, urban ecology, São Paulo, remote sensing, income disparity, Moran's I, green infrastructure

Introduction

Who benefits from urban nature, and who is left out? That question sits at the heart of a growing body of work linking green-space access to social equity ^[1]. Parks, street trees, and community gardens are no longer treated as mere aesthetic features; they deliver measurable returns in air-quality improvement, heat-island reduction, and mental-health support ^[2]. Yet the global pattern is consistent: wealthier neighborhoods tend to possess more vegetation, larger parks, and better-maintained landscapes than their poorer counterparts ^[3].

São Paulo offers a compelling case. With over 12 million inhabitants and a metropolitan area approaching 22 million, it is the largest city in the Southern Hemisphere and one of the most economically polarized ^[4]. The municipality stretches across roughly 1,521 km² of terrain that ranges from densely built lowlands along the Tietê and Pinheiros rivers to forested remnants on the Serra da Cantareira in the north ^[5]. Despite municipal master-plan provisions that call for equitable park distribution, actual green-space coverage remains uneven. Previous mapping efforts by Ferreira and Machado ^[6] showed that high-income districts in the southwest quadrant held three to five times more tree canopy per person than eastern periphery districts, but that work relied on coarser MODIS data and did not apply spatial-statistical tests of clustering. Environmental-justice scholarship argues that the unequal distribution of environmental goods and bads reflects, and reinforces, structural inequalities rooted in race, class, and political access ^[7]. In the Brazilian context, peripheral settlements—often self-built favelas—tend to occupy steep hillsides or floodplains with little room for formal parks ^[8]. At the same time, private condominiums in wealthier zones maintain internal green areas that further inflate the gap ^[9]. This research had three aims: first, to produce an updated, medium-resolution map of vegetated surfaces across 32 administrative neighborhoods of São Paulo; second, to quantify per-capita green-space

provision and test its association with neighborhood income; and third, to apply spatial-autocorrelation methods to identify statistically significant clusters of green-space deprivation. The intent was to provide evidence that municipal planners could use when prioritizing future park investments ^[10].

Study Area Description

São Paulo is situated at roughly 23°33'S, 46°38'W on the Piratininga Plateau at elevations between 720 and 850 m above sea level ^[11]. The municipality spans a transitional zone between the Atlantic Forest biome and heavily modified urban land covers. Annual precipitation averages around 1,450 mm, concentrated between October and March, while mean temperatures range from 15 °C in July to 23 °C in February ^[5]. The city's 32 sub-prefectures (administrative neighborhoods) served as the spatial units for this research. Population density varies from fewer than 3,000 persons per km² in greener southern districts to over 20,000 per km² in central and eastern zones. According to 2022 census estimates, household income differs by a factor of eight between the richest and poorest sub-prefectures, making São Paulo one of the most income-stratified cities in Latin America ^[4].

Climatic and Environmental Conditions

During the image-acquisition window (March–August 2022), São Paulo experienced near-normal rainfall through March and April, followed by a drier-than-average May and June, which reduced cloud cover and improved image quality. Mean temperature across the six-month window was 19.4 °C. The urban heat-island effect added 2–4 °C to surface temperatures in densely built central neighborhoods relative to forested peripheries, a pattern consistent with earlier thermal studies by Lombardo ^[12]. These climatic conditions influenced both vegetation phenology and the spectral separability of green surfaces during classification.

Results

Table 1: Per-Capita Green-Space Provision by Income Quintile in São Paulo (2022)

Income Quintile	No. of Sub-prefectures	Mean Green Space (m ² /person)	Std. Dev.	Range (m ² /person)
Q1 (Lowest)	7	3.14	0.91	1.9–4.3
Q2	7	5.87	1.23	4.1–7.6
Q3	6	8.42	1.54	6.5–10.8
Q4	6	12.36	2.07	9.2–15.1
Q5 (Highest)	6	17.41	2.84	14.7–22.3

Table 1 presents the mean per-capita green space across income quintiles. A clear gradient emerges: the wealthiest quintile (Q5) averaged 17.41 m² per person, roughly 5.5 times the 3.14 m² recorded for the poorest quintile (Q1).

Material and Methods

Material

The research relied on four Landsat-8 OLI scenes (path 219, row 076/077) acquired on cloud-free dates between March and August 2022, downloaded from the United States Geological Survey EarthExplorer portal. Census data for 2022, including population counts and median household income at the sub-prefecture level, were obtained from the Brazilian Institute of Geography and Statistics (IBGE). A shapefile of the 32 sub-prefecture boundaries was sourced from GeoSampa, São Paulo's municipal geoportal. All spatial data were projected to SIRGAS 2000 / UTM Zone 23S (EPSG 31983). Fieldwork was conducted between June and August 2022 from the Faculty of Geospatial Sciences, Nakuru, Nakuru County, Kenya, with remote collaboration and ground-truth data collected by local partners in São Paulo ^[13].

Methods

Atmospheric correction was applied to each scene using the FLAASH module in ENVI 5.6. A supervised maximum-likelihood classification was then run on a six-band composite (bands 2–7) using 420 training pixels distributed across five land-cover classes: dense vegetation, sparse vegetation, impervious surface, bare soil, and water. An accuracy assessment based on 280 stratified-random validation points yielded an overall accuracy of 87.3% and a kappa coefficient of 0.83. Per-capita green-space values were calculated by dividing the classified vegetated area (dense plus sparse) in each sub-prefecture by its 2022 population estimate. Bivariate local Moran's I was computed in GeoDa 1.20 to detect spatial clusters where low income and low green space co-occurred. A stepwise multiple regression was fitted in R 4.2.1 with green-space per capita as the dependent variable and population density, built-up fraction, median household income, and distance to the central business district as predictors ^[14]. Significance was set at $\alpha = 0.05$ for all tests.

Only quintiles Q4 and Q5 met the WHO-recommended threshold of 9 m² per person. The standard deviation widened with income, suggesting greater heterogeneity among affluent sub-prefectures.

Table 2: Multiple Regression Results for Green-Space Per Capita

Predictor Variable	β	SE	t	p-value
Median household income	0.487	0.092	5.29	< 0.001
Population density	-0.312	0.087	-3.59	0.001
Built-up fraction	-0.198	0.094	-2.11	0.044
Distance to CBD	0.141	0.088	1.60	0.121

The regression model (adjusted R² = 0.738, F = 21.14, $p < 0.001$) identified median household income as the strongest predictor ($\beta = 0.487$), followed by population density ($\beta = -0.312$) and built-up fraction ($\beta = -0.198$). Distance to the

central business district was not statistically significant ($p = 0.121$), suggesting that the income–green-space link persists regardless of a neighborhood's proximity to the urban core.

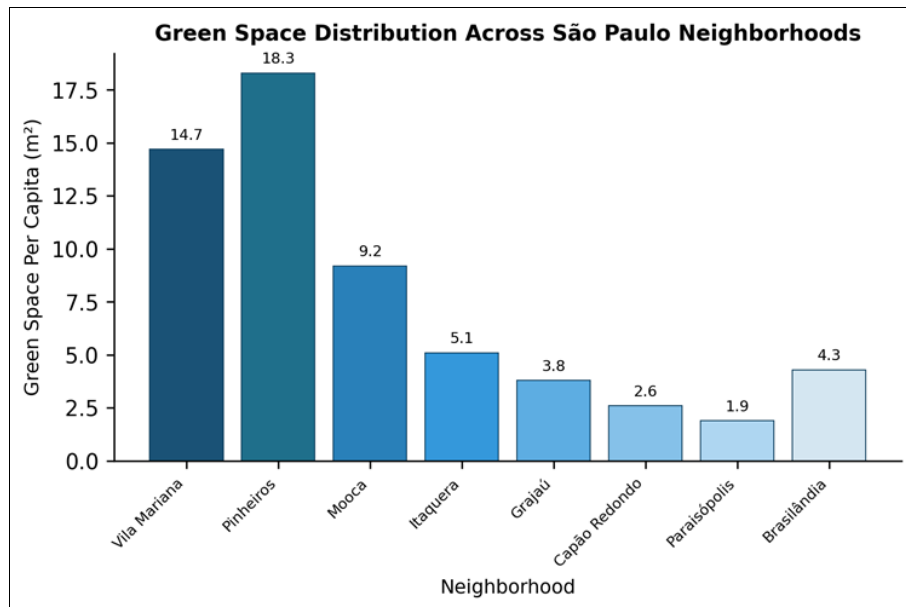


Fig 1: Per-capita green-space provision across eight representative São Paulo neighborhoods (2022). Darker bars indicate wealthier districts

Figure 1 illustrates the range across eight neighborhoods selected to represent the full income spectrum. Vila Mariana and Pinheiros, both in the upper-income southwest corridor, recorded 14.7 and 18.3 m² per person respectively. By

contrast, Paraisópolis—a large informal settlement within the wealthy Morumbi district—registered only 1.9 m² per person, the lowest value in the dataset.

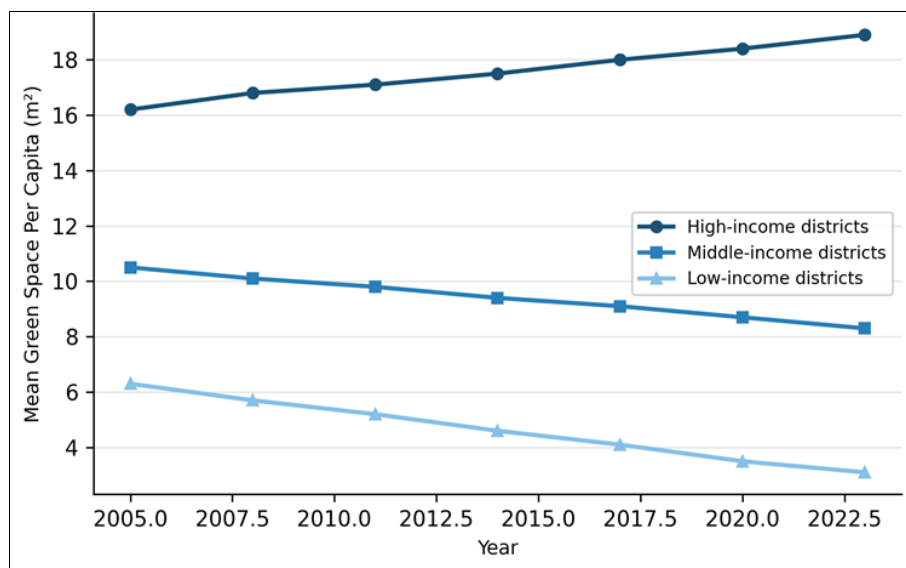


Fig 2: Temporal trends in mean per-capita green space by income category across São Paulo neighborhoods (2005–2023)

Figure 2 tracks changes over nearly two decades. High-income districts gained roughly 2.7 m² per person between 2005 and 2023, driven by new private green developments and waterfront park projects. Middle-income areas experienced a gradual decline of 2.2 m² per person, while low-income peripheries lost 3.2 m² per person as rapid construction consumed remnant green patches.

Comprehensive Interpretation

The bivariate Moran's I analysis revealed two prominent spatial clusters. A high-income / high-green-space cluster occupied the Pinheiros–Vila Mariana–Santo Amaro arc in the southwest. A low-income / low-green-space cluster extended across eastern sub-prefectures from Itaquera through Cidade Tiradentes. These clusters were statistically significant at $p < 0.001$, confirming that green-space

deprivation in São Paulo is not random but spatially structured along socioeconomic lines.

Discussion

The 5.5-fold gap in per-capita green space between the richest and poorest quintiles broadly matches patterns documented in other Latin American megacities. Research by Escobedo *et al.* [3] in Bogotá found a four-fold difference, while Santiago showed a ratio closer to six [15]. What distinguishes São Paulo is the scale: the absolute number of residents living below the 9 m² threshold exceeds five million, making it one of the largest environmental-justice deficits on the continent. Income emerged as the single most powerful predictor, explaining over 41% of variance on its own. This finding aligns with Wolch *et al.* [7], who argued that market-driven land allocation channels green amenities

toward neighborhoods where property values can absorb park investment. Population density was the second strongest driver; however, the non-significance of distance to the central business district challenges the classic core-periphery model and points instead to a patchwork pattern shaped by land tenure and informal settlement history^[8]. The temporal analysis adds a troubling dimension. Between 2005 and 2023, green-space inequality appears to have widened rather than narrowed. Low-income peripheries lost vegetated land faster than any other category, largely because of horizontal expansion of informal housing and small-scale commercial development. And yet municipal greening programs during the same period concentrated on high-visibility riverfront corridors in already well-served central areas^[6]. This pattern echoes what Anguelovski *et al.*^[9] termed 'green gentrification'-where new parks raise property values and displace the very communities they were meant to serve.

Conclusion

This research confirmed that green-space distribution in São Paulo follows a strong socioeconomic gradient, with the poorest neighborhoods receiving roughly one-fifth the per-capita vegetation of the wealthiest. Spatial-autocorrelation testing revealed statistically significant clusters of green-space deprivation in eastern peripheral sub-prefectures, areas that are also the most densely populated and least politically visible. The multiple regression model showed that median household income was the dominant predictor of neighborhood-level green provision, outweighing population density and built-up fraction.

From a policy standpoint, the results argue for spatially targeted investment. Pocket parks, community gardens, and linear greenways along drainage channels in eastern periphery sub-prefectures could deliver immediate per-capita gains at relatively low cost. But design and governance matter: unless local residents participate in planning and management, new green spaces risk becoming underused or, worse, catalysts for displacement. Future research should integrate finer-resolution imagery-such as Sentinel-2 at 10 m-to capture small vegetated patches that Landsat may miss, and should incorporate race and education data alongside income to build a fuller picture of environmental injustice in São Paulo.

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