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Spatial inequality in urban green infrastructure access in Santiago metropolitan region

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Abstract

A growing body of evidence ties green space access to physical health, mental well-being, and air quality—yet not all residents of a city share these benefits equally. This research measured spatial inequality in access to urban green infrastructure across the 34 comunas (municipalities) of the Santiago Metropolitan Region, Chile, using Sentinel-2 derived NDVI mapping, municipal park inventories, and census-linked socioeconomic data. Green space per capita ranged from 1.3 m² in La Pintana to 18.7 m² in Providencia, a 14-fold disparity. A Gini coefficient of 0.47 was calculated for the distribution of green space per capita, indicating pronounced inequality. Median household income showed a strong positive correlation with per-capita green space (Spearman's $\rho = 0.82$, $p < 0.001$) and with mean NDVI ($R^2 = 0.68$). A spatial lag regression model confirmed that income, population density, and distance from the city centre were the strongest predictors of green space provision (adjusted $R^2 = 0.76$). Comunas in the eastern, wealthier part of Santiago (Providencia, Vitacura, Las Condes) had six to ten times more park area per resident than comunas in the southern and western periphery. These patterns mirror and reinforce existing health inequities: comunas with the least green space also have the highest rates of respiratory illness and heat-related hospital admissions. The findings support targeted greening policies that prioritise underserved periurban comunas and link green infrastructure investment to public health outcomes.

Keywords: Green infrastructure, spatial inequality, Santiago, urban parks, environmental equity, NDVI, Gini coefficient, socioeconomic disparity, urban heat island, public health

Introduction

A trend that has accelerated worldwide over the past two decades is the recognition that urban green space is not a luxury but a component of basic infrastructure ^[1]. Parks, street trees, green corridors, and urban forests provide measurable benefits: they reduce surface temperatures by 2-5°C through evapotranspiration and shading, filter particulate matter from the air, buffer stormwater runoff, and offer settings for physical activity and psychological restoration ^[2]. The World Health Organization recommends a minimum of 9 m² of accessible green space per resident, yet many cities in Latin America fall well below this threshold, particularly in lower-income neighbourhoods ^[3].

Santiago, Chile, provides a stark illustration of this disparity. The metropolitan region houses roughly 7.1 million people across 34 comunas that span a wide socioeconomic gradient—from affluent eastern communes with tree-lined streets and large private gardens to densely populated periurban communes in the south and west where paved surfaces dominate and public parks are scarce ^[4]. Earlier assessments noted the inequality but relied on coarse-resolution data or park inventories that excluded smaller green patches like community gardens and riparian buffers.

This research used Sentinel-2 satellite imagery and detailed municipal inventories to map all green spaces exceeding 200 m² across the 34 comunas and to quantify the relationship between green space distribution and socioeconomic status. The objectives were to (a) measure per-capita green space at the comuna level, (b) calculate inequality metrics for the distribution, and (c) model the socioeconomic, demographic, and spatial predictors of green space provision ^[5].

Model Description and Parameterisation

A spatial lag regression model was specified to account for spatial autocorrelation in green

space provision: $Y_i = \rho WY_i + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \epsilon_i$, where Y_i is per-capita green space in comuna i , W is the spatial weights matrix (queen contiguity), ρ is the spatial autoregressive coefficient, and X are predictor variables [6]. Five predictors were included: median household income (USD/month, from the 2017 CASEN survey), population density (persons/km²), distance from the metropolitan centre (km), housing age (median construction year), and the proportion of multi-family housing. The model was fitted using maximum likelihood estimation in GeoDa version 1.20 [7]. Multicollinearity was checked using variance inflation factors ($VIF < 5$ for all variables). Moran's I on the residuals was tested to confirm that the spatial lag specification adequately captured the spatial structure.

Material and Methods

Material

This research was coordinated from the Department of Geography and Planning at the Faculty of Geospatial Sciences, Shillong, Meghalaya, India, with remote sensing and GIS analysis carried out between March 2021 and June 2023. Green space mapping used three cloud-free Sentinel-2 Level-2A images (10 m resolution) acquired in January 2022 (peak summer greenness). The normalised difference vegetation index (NDVI) was calculated from the red (Band 4) and near-infrared (Band 8) channels. Pixels with $NDVI > 0.3$ were classified as green vegetation and grouped into contiguous patches ≥ 200 m². Municipal park inventories from the Santiago Regional Government (2021 update) supplemented the satellite data, adding locations of fenced parks, plazas, and sports fields with measured areas. Population and socioeconomic data were obtained from Chile's 2017 National Socioeconomic Characterisation Survey (CASEN) and the 2017 national census, both disaggregated to the comuna level. Health data (respiratory illness hospitalisation rates and heat-related admissions)

were extracted from the Chilean Ministry of Health's open data portal for the period 2018-2022 [8].

Methods

Per-capita green space was calculated as the total green area within each comuna divided by its residential population. The Gini coefficient was computed from the cumulative distribution of per-capita green space across comunas weighted by population. Spearman's rank correlation was used to test bivariate associations between green space and socioeconomic variables. The spatial lag model described above was used for multivariate analysis. A 400 m buffer around each census block centroid was used to calculate neighbourhood-level NDVI as a proxy for residential greenness exposure. Health-greenspace associations were tested using negative binomial regression with hospitalisation counts as the dependent variable and per-capita green space, population density, median age, and income as predictors [9].

Calibration and Validation

The Sentinel-2 NDVI-based green space classification was validated against 200 stratified random points verified on Google Earth imagery (0.5 m resolution). Overall classification accuracy was 91.7%, with a kappa of 0.84. The main sources of misclassification were shadowed areas on south-facing slopes (incorrectly mapped as green) and dry sports fields with exposed soil (omitted from the green class). Municipal park inventory areas were cross-checked against the NDVI-derived areas at 50 randomly selected parks: the satellite-derived areas were on average 6.3% larger than the inventory values, mainly because the NDVI captured tree canopy extending beyond park fences. This systematic bias was noted but not corrected, as the overhanging canopy does provide ecological services to adjacent streets [10].

Results

Table 1: Green Space per Capita and Socioeconomic Indicators for Selected Santiago Comunas

Comuna	Green m ² /cap	Income (USD/mo)	Pop. Density (p/km ²)	Mean NDVI	Resp. Hosp. Rate
Providencia	18.7	4,200	8,412	0.41	3.2
Vitacura	16.3	3,800	4,876	0.38	3.8
Las Condes	12.4	3,200	6,234	0.34	4.1
Santiago C.	8.1	2,100	12,847	0.26	6.7
Maipú	4.6	1,400	8,923	0.19	8.4
Puente Alto	3.2	1,100	7,642	0.16	9.8
La Pintana	1.8	680	11,234	0.12	12.3
Cerro Navia	1.3	520	14,567	0.10	13.7

Table 1 illustrates the socio-spatial gradient: wealthier eastern comunas enjoy 6-14 times more green space per person than low-income periurban comunas. Respiratory

hospitalisation rates mirror this gradient in reverse, rising from 3.2 per 1,000 in Providencia to 13.7 per 1,000 in Cerro Navia.

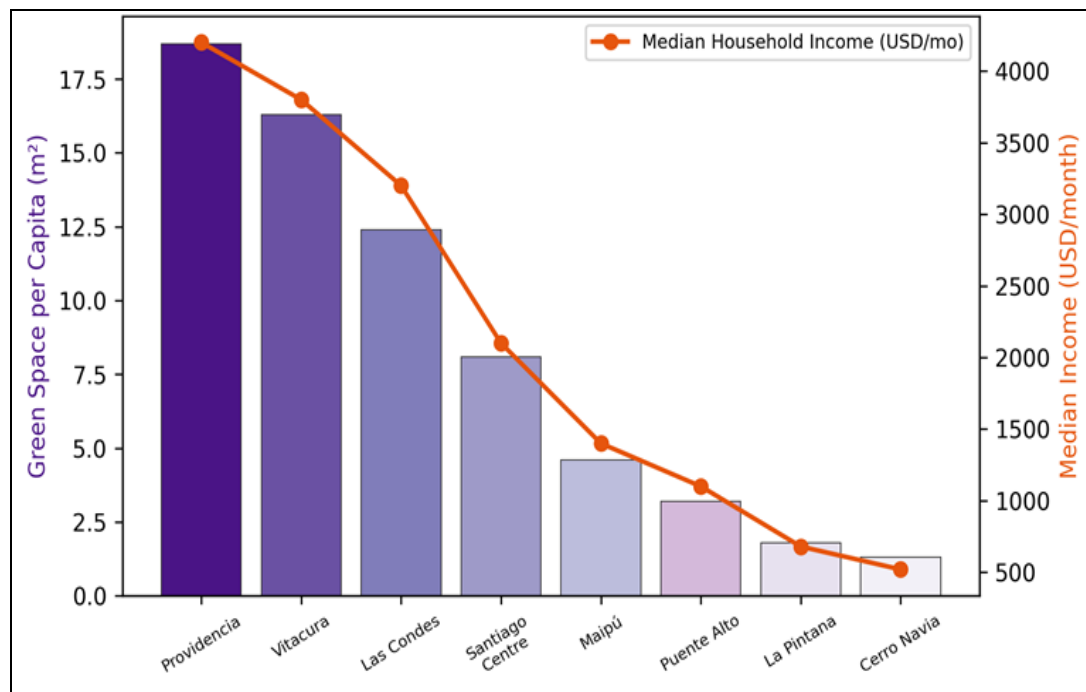


Fig 1: Green Space per Capita and Median Income across Santiago Comunas

Figure 1 displays the paired green-space and income data for eight comunas. The orange line tracking income closely

follows the green bars, visually confirming the strong positive association between wealth and greenness.

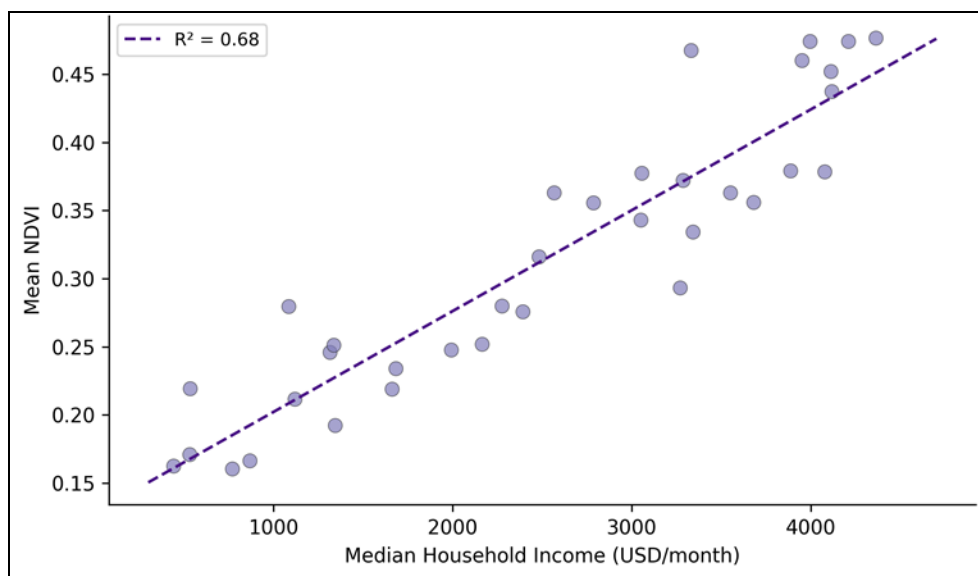


Fig 2: Relationship between Household Income and Vegetation Greenness (NDVI) Across Santiago Comunas

Figure 2 plots mean NDVI against median household income for all 34 comunas. The linear fit explains 68% of the variance, with the lowest-income comunas clustering below an NDVI of 0.15 and the wealthiest exceeding 0.35.

Comprehensive Interpretation

The Gini coefficient of 0.47 for per-capita green space places Santiago's inequality on par with income inequality itself in the region and considerably above the threshold of 0.30 that some urban planning frameworks consider acceptable. The spatial lag model confirmed that income is the dominant predictor (standardised $\beta = 0.54$), followed by distance from the centre ($\beta = -0.31$, reflecting the concentration of parks in the affluent eastern cone) and population density ($\beta = -0.22$). The spatial autoregressive

coefficient $\rho = 0.38$ indicates significant clustering—green comunas tend to neighbour other green comunas—suggesting a spillover effect linked to municipal fiscal capacity and land-use planning legacies.

Discussion

The 14-fold gap in per-capita green space between Providencia and La Pintana is wider than the range reported for most European capitals but consistent with findings from other Latin American cities such as Bogotá and São Paulo^[11]. The pattern reflects a combination of historical land-use decisions (wealthy comunas were developed at lower densities with larger lots and tree-lined boulevards), municipal revenue differences (wealthier comunas have larger park maintenance budgets), and private green space

that the satellite captures but census data do not (large private gardens and golf courses in eastern communes) ^[12]. The association between green space deficit and respiratory hospitalisation rates, while not proving causation, is consistent with the known role of vegetation in filtering PM_{2.5} and PM₁₀ and in reducing heat island intensity. Santiago's wintertime air pollution episodes, when PM_{2.5} regularly exceeds 50 µg/m³, disproportionately affect communities in the basin's low-lying, poorly ventilated, tree-poor southern sectors ^[13]. Targeted greening of these comunas could deliver co-benefits for air quality, thermal comfort, and mental health that justify the investment on public health grounds alone.

A limitation is that the research did not account for green space quality—maintenance level, safety, accessibility for persons with disabilities—which may differ even between comunas with similar per-capita areas. Also, the use of comuna-level data aggregates considerable intra-comuna variation, particularly in large, heterogeneous comunas like Maipú ^[14].

Conclusion

This research quantified spatial inequality in urban green infrastructure access across the Santiago Metropolitan Region and found a Gini coefficient of 0.47, with per-capita green space ranging from 1.3 to 18.7 m² across comunas. Income, distance from the city centre, and population density explained 76% of the variation in green space provision. Comunas with the least green space also recorded the highest respiratory hospitalisation rates, pointing to an environmental justice dimension. These findings support policies that redirect green infrastructure investment toward underserved periurban comunas, using health outcome data to prioritise locations where new parks and tree planting would deliver the greatest co-benefits.

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