



## Public garden squares and mean monthly per capita income in Curitiba, PR, Brazil: inequalities in the distribution and access of benefits generated by nature

### *Praças e rendimento médio mensal per capita em Curitiba, PR, Brasil: desigualdades na distribuição e no acesso aos benefícios gerados pela natureza*

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**ABSTRACT:** The urban forest generates diverse ecosystem services for people. Among the components of the urban forest, public garden squares are different for having a smaller area but a greater quantity and better distribution across cities, acting as small forests that provide benefits. However, these benefits may not be shared by the entire population, due to the variability in the vegetation cover of the squares and the inequality concerning areas with better or worse socioeconomic conditions. Therefore, we investigated the relationship between the squares and the mean monthly income in the 40 clustered neighborhoods of Curitiba, aiming at supporting urban planning to maintain equal distribution of benefits to the population or reduce inequalities, if any. Thus, quantitative and qualitative data from the squares were compared to the mean monthly income through descriptive and correlation statistical analysis and spatial data visualization. Results indicate that neighborhoods with lower income have fewer squares concerning the neighborhood total area and fewer tree species in total and per square. Neighborhoods with higher incomes have better indicators of quantity and quality, in general, except for the mean square area and permeability. We concluded that the benefits are not equally distributed to the entire population of Curitiba, with a loss of access to the benefits generated by the squares and their ecosystem services for the population with worse socioeconomic conditions.

*Keywords:* ecosystem services; green areas; green inequity; socioeconomic inequality; urban forest.

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**RESUMO:**

A floresta urbana gera diversos serviços ecossistêmicos para as pessoas. Dentre os componentes da floresta urbana, as praças se diferenciam por geralmente possuírem menor área, mas maior quantidade e melhor distribuição pelas cidades, agindo como pequenas florestas geradoras de benefícios. Esses benefícios, entretanto, podem não ser compartilhados por toda a população, tanto devido à variabilidade na cobertura vegetal das praças, quanto pela desigualdade de distribuição das praças em relação às áreas com melhores ou piores condições socioeconômicas. Por isso, buscou-se investigar a relação entre as praças e o rendimento médio mensal nos 40 bairros agrupados de Curitiba visando a subsidiar o planejamento urbano para manter a distribuição igualitária de benefícios à população ou diminuir desigualdades, caso existam. Assim, dados quantitativos e qualitativos das praças foram comparados ao rendimento médio mensal por meio de análises estatísticas descritivas e de correlação, e da visualização espacial dos dados. Os resultados indicam que bairros com menores rendimentos possuem menos praças em relação à área do bairro e menos espécies arbóreas no total e por praça. Bairros com maiores rendimentos têm melhores indicadores de quantidade e de qualidade, em geral, exceto quanto à área média das praças e à permeabilidade. Conclui-se que os benefícios não estão igualmente distribuídos para toda a população de Curitiba, com prejuízo no acesso aos benefícios gerados pelas praças e seus serviços ecossistêmicos pela população com pior condição socioeconômica.

*Palavras-chave:* áreas verdes; desigualdade socioeconômica; floresta urbana; iniquidade verde; serviços ecossistêmicos.

## 1. Introduction

The urban forest encompasses all vegetation cover located within urban and peri-urban areas, both public and private, including street trees, gardens, green areas and native vegetation remnants (Biondi, 2015; FAO, 2016). Through these different typologies, the urban forest is a nature-based solution to the problems caused by urbanization and, therefore, its planning and management are essential to supply ecosystem services to the cities' populations (Escobedo *et al.*, 2019; Castellar *et al.*, 2021; Kooijman *et al.*, 2021). Ecosystem services are the benefits that people obtain from ecosystems, which include provision, regulation, support and cultural services (MEA, 2005). Moreover, Nature-based Solutions (NbSs) are actions to protect, sustainably manage and restore natural or modified ecosystems that effectively and adaptively address societal challenges, providing benefits to human well-being and biodiversity (IUCN, 2016).

Practically all benefits provided by forests in general also apply to urban forests, considering, of course, their scale and their particularities. However, as urban forests are closer to a greater number of people, they generate benefits that are more directly perceived by the population (Biondi & Lima Neto, 2012). These benefits include food and clean water provision; biodiversity; carbon storage and climate change mitigation; microclimate regulation and energy savings through shade and cooling; water infiltration, surface runoff decrease and flooding reduction; removal of atmospheric pollutants and noise mitigation; soil protection and erosion control; access to open and natural spaces; recreation and environmental education opportunities; people's physical and mental health; and a sense of identity and belonging (MEA, 2005; FAO, 2016; Fares *et al.*, 2020).

Generation of these benefits depends on the spatial distribution of the urban forest, the area it occupies (individually and as a group), the connec-

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tivity between areas, permeability of the areas and the quantity and quality of its vegetation, among other factors (Ribeiro, 2012; Oliveira, 2018). In this context, garden squares stand out as an important part of the urban forest. Although they have a relatively small individual area, squares generally occur in greater numbers and are better distributed throughout the urban mesh, providing spaces for soil permeability and for the occurrence of vegetation (Viezzler, 2015). Due to this, garden squares can approach the concept of pocket forests, which aims at generating benefits for cities through small areas full of biodiversity (Frantzeskaki, 2019).

However, by definition, squares are open and public urban spaces, free of buildings, which, however, are not necessarily permeable or covered by vegetation (Viezzler, 2015; Ecker, 2020). Therefore, there is a need to assess whether squares generate ecosystem benefits on a case-by-case basis. On the other hand, their social benefits are unanimous (Robba & Macedo, 2010; Viezzler, 2015; Ecker, 2020). Squares are the type of urban forest most present in the population's everyday life (Viezzler *et al.*, 2016). Despite this, there is evidence that people in worse socioeconomic conditions are, at the same time, those with less access to these spaces and the benefits they provide, as well as the most impacted by the lack of urban planning and vegetation cover (FAO, 2016; Morato *et al.*, 2018; Rezende *et al.*, 2018; Kivimaki *et al.*, 2020; Arantes *et al.*, 2021).

In this context, Curitiba stands out as an internationally recognized city for its public policies on the environment and management of green areas (C40, 2016; CSC, 2019; ICF, 2019; 2020; 2021). Therefore, this research hypothesizes that squares and their benefits are well distributed among the Curitiba inhabitants, regardless of their socioecon-

omic status, which would differentiate it from other cities and guarantee its benefits to those who need it the most. Therefore, the objectives of this research were as follows: to select environmental indicators referring to the quantity and quality of squares in the city and to correlate them with a socioeconomic indicator: total mean monthly income. Thus, we expect to subsidize urban planning to maintain the equal distribution of benefits to the population or reduce inequalities, if any.

## 2. Study Area

The study area of this research is the city of Curitiba, capital of the state of Paraná, located in the Brazilian South Region at latitude 25°25'48" S and longitude 49°16'15" W. The municipality has an area of 435 km<sup>2</sup> divided into 75 neighborhoods (IPPUC, 2021). All 75 neighborhoods of Curitiba are grouped in two ways: into 10 administrative regions (IPPUC, 2021) and into 40 clustered neighborhoods (Figure 1), based on the reference units used by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*, IBGE) to organize the census sectors (DIEESE, 2016).

Curitiba is within the Atlantic Forest Biome, in the phytophysognomy of the Mixed Ombrophylous Forest, and its urban forest covers approximately 15% of the total area of the municipality (FBDS, 2020). The city has 1,106 green areas, including 351 squares (IPPUC, 2021).

The population is 1,773,733 inhabitants according to the 2022 Demographic Census (IBGE, 2023). The mean monthly salary of formal workers was 4 minimum wages in 2018, with a *per capita*

Gross Domestic Product (GDP) of R\$ 45,458.29 in the same year (IBGE, 2020).

### 3. Methodological procedures

As a first step, we performed a quantitative assessment of the 40 clustered neighborhoods of Curitiba, considering five environmental indicators referring to the squares as dependent variables in function of a socioeconomic indicator as independent variable (Table 1). The dependent variables are the absolute number of squares (S1) and the number of squares relative to the neighborhood area (S2); and the absolute area of squares (S3) and the area of squares relative to both the number of squares (mean; S4) and the of the neighborhood area (S5). The independent variable is the total mean monthly income (Socec).

All variables referring to the squares were calculated from secondary data available in shapefiles from the Curitiba Institute for Research and Urban

Planning at <https://ippuc.org.br/> (IPPUC, 2021). The data files have the limits of the 75 neighborhoods of the municipality and the polygons of all 351 squares of the city. The spatial information was redesigned for the EPSG geographic coordinate system: 31982 – SIRGAS 2000, UTM zone 22 S, and manipulated in QGIS 3.14.16. Calculations of the number of squares and the total areas of the squares and the neighborhoods were performed using the field calculator from the QGIS attribute table. This table was later processed in a Microsoft Excel 365 spreadsheet to determine the dependent variables.

The independent socioeconomic variable was the total mean monthly income, collected from the Labor Observatory of the Inter-Union Department of Statistics and Socioeconomic Studies, available at <https://curitiba.dieese.org.br/> (DIEESE, 2016). The DIEESE data were generated based on the 2010 IBGE Demographic Census and presented only for the 40 clustered neighborhoods. Therefore, the quantitative information corresponding to the

TABLE 1 – Quantitative variables for assessing the squares of Curitiba, PR, Brazil, in relation to the socioeconomic condition of its population.

Code	Variable	Unit	Indicator
ID1	Name of the clustered neighborhood	Name	-
ID2	List of neighborhoods that are part of the clustered neighborhood	Name	-
Area	Total area of the clustered neighborhood	km <sup>2</sup>	-
S1	Absolute number of squares	Number	Environmental
S2	Number of squares relative to the neighborhood area	Number/km <sup>2</sup>	Environmental
S3	Absolute area of the squares	km <sup>2</sup>	Environmental
S4	Area of the squares relative to the number of squares	km <sup>2</sup>	Environmental
S5	Area of the squares relative to the neighborhood area	%	Environmental
Socec	Total mean monthly income	BRL	Socioeconomic

KEY: BRL = Brazilian Real.

SOURCE: Data from DIEESE (2016) and IPPUC (2021), prepared by the authors.

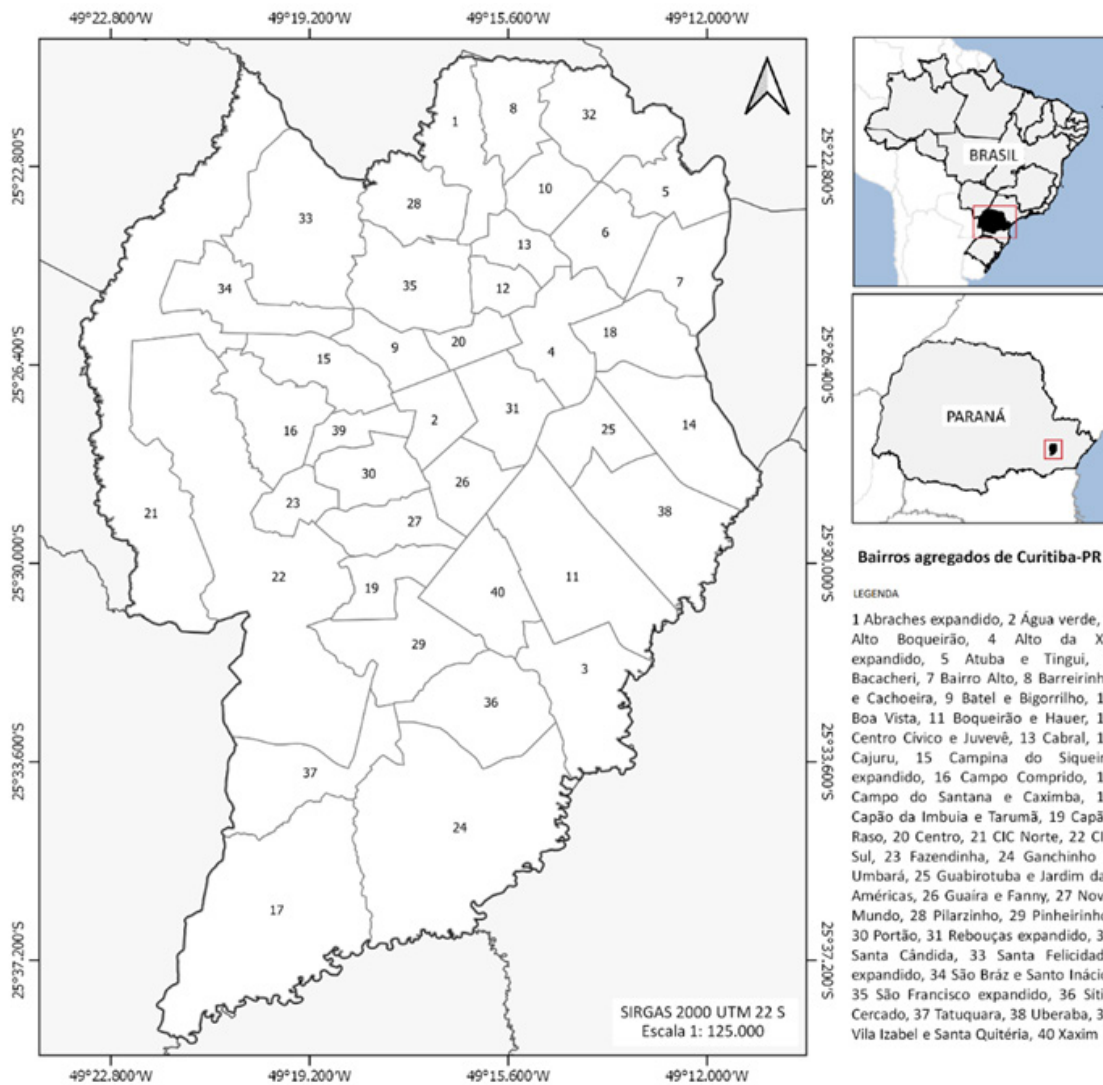


FIGURE 1 – Location of Curitiba, PR, Brazil, study area of this research, and its 40 clustered neighborhoods.

KEY: 1 = Abranches expanded; 2 = Água verde; 3 = Alto Boqueirão; 4 = Alto da XV expanded; 5 = Atuba and Tingui; 6 = Bacacheri; 7 = Bairro Alto; 8 = Barreirinha and Cachoeira; 9 = Batel and Bigorrrilho; 10 = Boa Vista; 11 = Boqueirão and Hauer; 12 = Centro Cívico and Juvevê; 13 = Cabral; 14 = Cajuru; 15 = Campina do Siqueira expanded; 16 = Campo Comprido; 17 = Campo do Santana and Caximba; 18 = Capão da Imbuia and Tarumã; 19 = Capão Raso; 20 = Centro; 21 = Cidade Industrial de Curitiba (CIC) Norte; 22 = CIC Sul; 23 = Fazendinha; 24 = Ganchinho and Umbará; 25 = Guabirota and Jardim das Américas; 26 = Guaíra and Fanny; 27 = Novo Mundo; 28 = Pilarzinho; 29 = Pinheirinho; 30 = Portão; 31 = Reboças expanded; 32 = Santa Cândida; 33 = Santa Felicidade expanded; 34 = São Bráz and Santo Inácio; 35 = São Francisco expanded; 36 = Sítio Cercado; 37 = Tatuquara; 38 = Uberaba; 39 = Vila Izabel and Santa Quitéria; 40 = Xaxim.

SOURCE: Data from DIEESE (2016) and IPPUC (2021), prepared by the authors.

squares was grouped in the same way, so that they could be compared. Squares located in more than one neighborhood were counted in the one with most of its area.

After the quantitative assessment, a qualitative evaluation was conducted based on data available in the following publications about the squares in Curitiba: permeable area (Viezzler *et al.*, 2016); vegetation (Viezzler *et al.*, 2018); and biodiversity (Viezzler *et al.*, 2020). However, these publications did not evaluate all squares in Curitiba, but a sample of 32. For this reason, the qualitative assessment included 19 of the 40 clustered neighborhoods (47.5%) where the 32 sampled squares are located.

The variables considered in the qualitative assessment were the following (Table 2): absolute

permeable area (S1) and permeable area relative to the total area of the squares (S2); absolute number of tree individuals (S3) and number of tree individuals relative to both the number of squares (density; S4) and the total area of the squares (S5); absolute number of tree species (richness; S6) and number of tree species relative to both the number of squares (average; S7) and the total area of the squares (S8); in addition to the Odum Biodiversity Index (S9) as dependent variables; and again the total mean monthly income as independent variable (Socec).

The numbers of tree individuals and species relative to the number and total area of the squares were calculated according to the following equations.

TABLE 2 – Qualitative variables for assessing the squares of Curitiba, PR, Brazil, in relation to the socioeconomic condition of its population.

Code	Variable	Unit	Indicator
ID1	Name of the clustered neighborhood	Name	-
ID2	List of neighborhoods that are part of the clustered neighborhood	Name	-
Area	Total area of the clustered neighborhood	km <sup>2</sup>	-
AreaS	Total area of the squares of a clustered neighborhood	km <sup>2</sup>	-
NS	Number of squares	Number	-
S1	Absolute permeable area	km <sup>2</sup>	Environmental
S2	Permeable area relative to the area of the squares	%	Environmental
S3	Absolute number of tree individuals	Number	Environmental
S4	Number of tree individuals relative to the number of squares	Number	Environmental
S5	Number of tree individuals relative to the area of the squares	Number/km <sup>2</sup>	Environmental
S6	Absolute number of tree species	Number	Environmental
S7	Number of tree species relative to the number of squares	Number	Environmental
S8	Number of tree species relative to the area of the squares	Number/km <sup>2</sup>	Environmental
S9	Odum Biodiversity Index	Number	Environmental
Socec	Total mean monthly income	BRL	Socioeconomic

KEY: BRL = Brazilian Real.

SOURCE: Data from Viezzler *et al.* (2016, 2018 and 2020), prepared by the authors.

$$S4 = \frac{\sum n_p}{NS} \quad S5 = \frac{\sum n_p}{\sum AS}$$

$$S7 = \frac{\sum S_p}{NS} \quad S8 = \frac{\sum S_p}{\sum AS}$$

Where S4 = Number of tree individuals relative to the number of squares (density); np = Number of tree individuals in each square; NS = Number of squares; S5 = Number of tree individuals relative to the area of the squares; AS = Area of each square; S7 = Number of tree species relative to the number of squares (mean); Sp = Number of tree species in each square; and S8 = Number of tree species relative to the area of the squares.

On the other hand, the Odum Biodiversity Index, which measures the intensity of species composition to express diversity, was calculated following the equation below (Rode *et al.*, 2009).

$$S9 = \frac{S}{\ln N}$$

Where S9 = Odum Biodiversity Index; S = Absolute number of tree species; and N = Absolute number of tree individuals.

Both the quantitative and qualitative assessments were elaborated by visualizing the spatialized data on graduated maps and by calculating the bivariate correlations between each pair of environmental indicators with the socioeconomic indicator. The Pearson, Spearman and Kendall correlation coefficients (Croux & Dehon, 2010) were applied in the IBM SPSS Statistics 25 software, according to the equations presented below.

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}}$$

$$r_s = 1 - 6 * \frac{\sum d_i^2}{n(n^2 - 1)}$$

$$\tau = \frac{[(concordant) - (discordant)]}{0.5 * n * (n - 1)}$$

Where  $r_{xy}$  = Pearson's coefficient; n = Sample size;  $x_i$  and  $y_i$  = Individual points of the x and y variables, respectively;  $\bar{x}$  and  $\bar{y}$  = Mean values of the x and y variables;  $r_s$  = Spearman's rho;  $d_i$  = Difference between the ranks of two parameters; n = Number of alternatives;  $\tau$  = Kendall's tau; concordant = Number of concordant pairs; discordant = Number of discordant pairs; n = Number of pairs.

Correlation is used to measure the association between two variables and investigate possible connections between them, with results ranging from -1 to +1 (Kozak, 2009), interpreted as shown in Table 3.

TABLE 3 – Interpretation of the correlation coefficients values.

Correlation meaning	Correlation value
Very strong inverse	-1.00 – <-0.70
Strong inverse	-0.70 – <-0.50
Weak inverse	-0.50 – <-0.20
Non-important	-0.20 – 0.20
Weak positive	>0.20 – 0.50
Strong positive	>0.50 – 0.70
Very strong positive	>0.70 – 1.00

SOURCE: Values based on Kozak (2009), prepared by the authors.

All data were also analyzed using descriptive statistics performed in IBM SPSS Statistics 25, containing minimum and maximum values, means and standard deviations.

## 4. Results

The descriptive statistical analysis of the variables in the quantitative assessment of the 40

clustered neighborhoods in Curitiba, considering the squares and the total mean monthly income, is presented in Table 4.

It is possible to assess that the clustered neighborhoods of Curitiba differ a lot from each other regarding the variables considered. While the Fazendainha, Ganchinho and Umbará neighborhoods have only one square each, CIC Sul has 34, or 9.69% of the city's squares (although it also represents approximately 10% of the total area of the municipality). The second clustered neighborhood with more squares is Alto da XV Expanded, with 19 (5.41%, occupying 2.03% of the city area). Ganchinho and Umbará is also the neighborhood with the smallest number of squares relative to the total neighborhood area (S2), with 0.0296 squares per km<sup>2</sup>; Campo do Santana and Caximba come next with 0.0671 squares per km<sup>2</sup>. On the other hand, Centro Cívico and Juvevê have 4.2554 squares per km<sup>2</sup> and Centro presents 4.2642, the highest value found.

Ganchinho and Umbará, Campo do Santana and Caximba, and Fazendainha also appear as the worst clustered neighborhoods in relation to the absolute area of squares (S3), with 0.0079, 0.0104 and 0.0111 km<sup>2</sup>, respectively. CIC Sul again has the best parameter, with 0.2319 km<sup>2</sup>, almost doubling the second place: Boqueirão and Hauer, with 0.1291 km<sup>2</sup>. Diversely, the area of squares relative to the number of squares variable (S4), or mean area, places Batel and Bigorrião, and Cabral as the worst clustered neighborhoods with 0.0015 and 0.0016 km<sup>2</sup> per square, respectively. The largest squares are located in CIC Norte, with 0.0127 km<sup>2</sup> per square, and in Tatuquara, with 0.0135 km<sup>2</sup>. Finally, the area of squares relative to the area of the neighborhoods again shows Ganchinho and Umbará, and Campo do Santana and Caximba as the clustered neighborhoods with the worst values, 0.0235% and 0.0349%, respectively. In turn, Centro Cívico and Juvevê have 2.9878%, and Centro, 3.6455%, representing the best proportions.

TABLE 4 – Descriptive statistical analysis of the variables in the quantitative assessment (N = 40).

Variable code	Minimum	Maximum	Mean	Standard deviation
S1 (number)	1	34	8.7800	6.2000
S2 (number/km <sup>2</sup> )	0.0296	4.2642	1.1544	0.9466
S3 (km <sup>2</sup> )	0.0079	0.2319	0.0464	0.0429
S4 (km <sup>2</sup> )	0.0015	0.0135	0.0056	0.0029
S5 (%)	0.0002	0.0265	0.0059	0.0069
Socec (BRL)	579.7224	4,252.2254	1,736.9972	988.7402

KEY: S1 = Absolute number of squares; S2 = Number of squares relative to the neighborhood area; S3 = Absolute area of the squares; S4 = Area of the squares relative to the number of squares; S5 = Area of the squares relative to the neighborhood area; Socec = Total mean monthly income; BRL = Brazilian Real.

SOURCE: The authors.

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As for the total mean monthly income, the neighborhoods with the worst socioeconomic conditions are Campo do Santana and Caximba, with BRL 579.72, and Tatuquara, with BRL 597.39; whereas the best conditions are found at Água Verde, with BRL 4,115.61, and at Bacacheri, with BRL 4,252.23.

The spatial distribution of these variables among the clustered neighborhoods is shown in Figure 2.

Through the maps it is possible to visually assess that the socioeconomic condition, represented by the total mean monthly income variable, is worse in the entire southern region of Curitiba, reaching the clustered neighborhood of CIC Sul, also with emphasis on Cajuru. The western and northern portions of the city come after these areas, with the CIC Norte, Pilarzinho, Barreirinha and Cachoeira, and Santa Cândida clustered neighborhoods. The region with the best conditions is the central one, where the Água Verde, Alto da XV Expanded, Bacacheri, Cabral, Campina do Siqueira Expanded, Centro, Centro Cívico and Juvevê, and São Francisco Expanded neighborhoods are located.

The total mean monthly income is spatially distributed similarly to the variables of the squares, except for the mean area (S4). The absolute number of squares (S1) has the lowest values in the South, West and North of Curitiba, with the highest values in the central and East areas. The number of squares relative to the area of the neighborhood (S2) was the variable most visually similar to the socioeconomic condition, also showing the lowest values for the South, West and North of the city and the highest values for the center. The absolute area of the squares (S3) appears in lower values in the South and North portions; however, it is not the

central part that presents the highest values, but the East and West ends. The area of squares relative to the neighborhood area (S5) also has smaller values towards the South, although the Sítio Cercado clustered neighborhood is among the highest values. In turn, the area of squares relative to the number of squares (S4) is the only variable that does not have its lowest values in the southern region of Curitiba, which are concentrated in the North and even in central districts such as Batel and Bigorriho, and São Francisco Expanded.

Thus, with the visual evaluation of the maps it is possible to perceive similarities in the spatial distribution, mainly between the total mean monthly income and the S1, S2, S3 and S5 variables, which indicate that in places with worse socioeconomic conditions, the quantitative environmental indicators of the communities are also worse – and vice versa.

The correlation coefficients calculated between the quantitative environmental indicators of the squares and the socioeconomic indicator of the 40 clustered neighborhoods of Curitiba are presented in Table 5.

Of the 15 calculated correlations, four were not statistically significant, with an error greater than 5%, including all correlations between total mean monthly income and total area of the squares (S3). Therefore, these correlations were excluded from the analysis.

The values show an important, albeit weak, positive correlation between the socioeconomic indicator and the number of squares (S1) and the area of squares relative to the neighborhood area (S5). With the number of squares relative to the neighborhood area (S2), the values point to a strong positive correlation with the total mean monthly

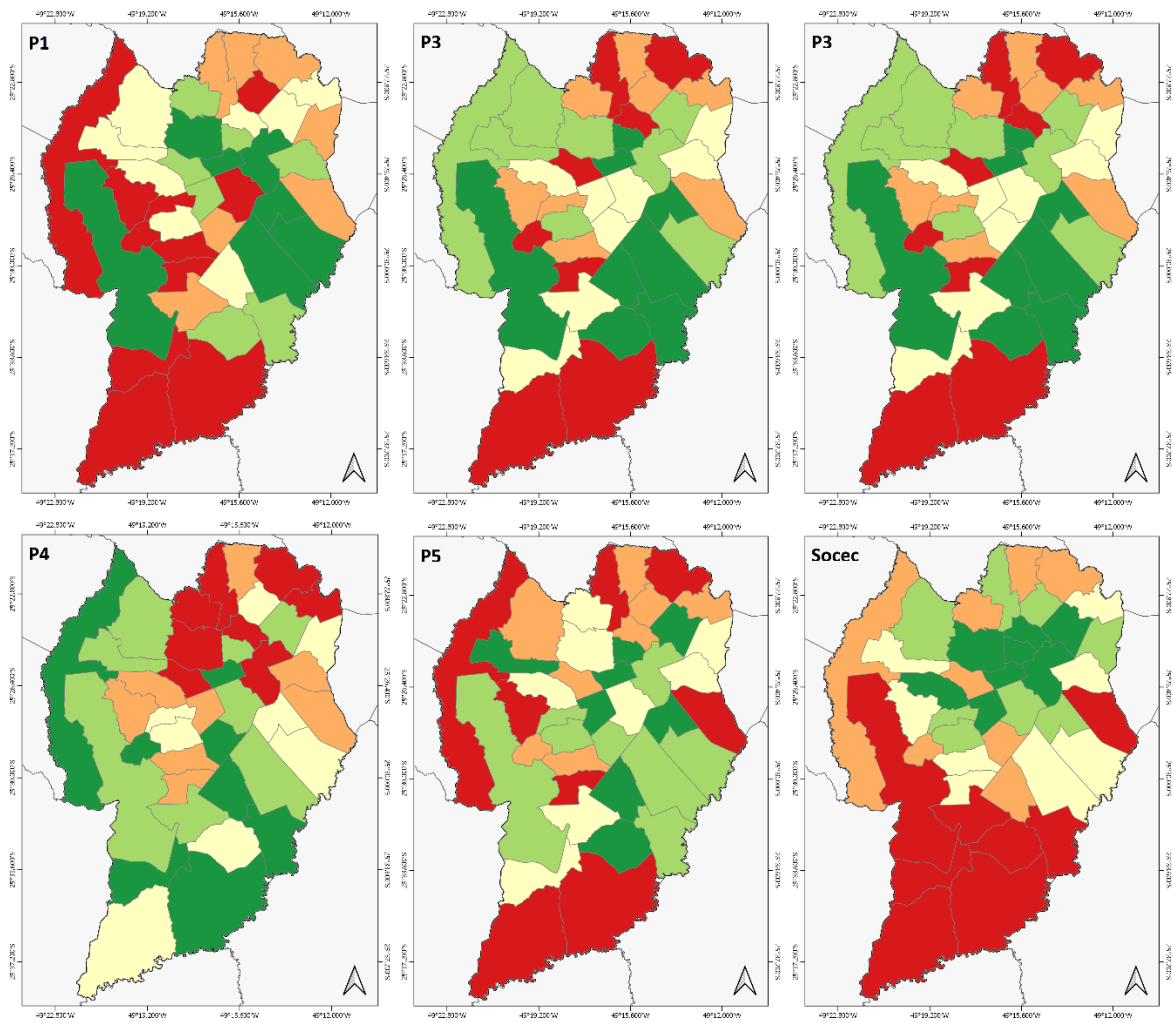


FIGURE 2 – Spatial distribution of quantitative variables in the 40 clustered neighborhoods of Curitiba, PR.

KEY: S1 = Absolute number of squares; S2 = Number of squares relative to the neighborhood area; S3 = Absolute area of the squares; S4 = Area of the squares relative to the number of squares; S5 = Area of the squares relative to the neighborhood area; Socec = Total mean monthly income. Data grouped into five classes of equal count (quartile), where red represents the lowest values for all variables (worst), and green represents the highest values for all variables (best).

SOURCE: Data from DIEESE (2016) and IPPUC (2021), prepared by the authors.

TABLE 5 – Correlation analysis of the variables in the quantitative assessment (N = 40).

Correlation with the socioeconomic indicator	Pearson's coefficient	Spearman's coefficient	Kendall's coefficient
Code of environmental indicator variables			
S1	0.187 (0.124)	0.342 (0.015)*	0.241 (0.016)*
S2	0.598 (0.000)*	0.613 (0.000)*	0.438 (0.000)*
S3	0.008 (0.481)	0.151 (0.176)	0.113 (0.153)
S4	-0.277 (0.042)*	-0.302 (0.029)*	-0.190 (0.042)*
S5	0.397 (0,006)*	0.417 (0.004)*	0.292 (0.004)*

KEY: S1 = Absolute number of squares; S2 = Number of squares relative to the neighborhood area; S3 = Absolute area of the squares; S4 = Area of the squares relative to the number of squares; S5 = Area of the squares relative to the neighborhood Area; The correlation coefficients are shown with standard error between round brackets. Significance \* = p-value <  $\alpha$ -value 0.05 (5%). Non-significant values are shown without an asterisk, in gray.

SOURCE: The authors.

income. This was the same interpretation given from the visualization of the spatialized data in Figure 2, which means that the worse the socioeconomic indicator, the worse these quantitative environmental variables of the squares. The correlation between the mean area of the squares (S4) and income was the only negative one, although weak, showing that larger squares are more frequently located in neighborhoods with worse socioeconomic conditions.

The descriptive statistical analysis of the variables considered in the qualitative assessment for 19 clustered neighborhoods in Curitiba, considering 32 squares and the total mean monthly income, is presented in Table 6.

The Cabral neighborhood had a single square with 0.000338 km<sup>2</sup> (or 337.66 m<sup>2</sup>) of permeable area (S1), the worst absolute value, which represents 56.46% of the total area of the squares (S2), while São Francisco Expanded was the second worst, with two squares adding up to 0.000931 km<sup>2</sup> (930.93

m<sup>2</sup>), or 20.84% – the worst relative value. In turn, Boqueirão and Hauer, with two evaluated squares, and Guabirota and Jardim das Américas, with a single square, were the clustered neighborhoods with the largest permeable area (S1), with 0.020839 km<sup>2</sup> (20,839.42 m<sup>2</sup>) and 0.021611 km<sup>2</sup> (21,611.31 m<sup>2</sup>), respectively. However, these neighborhoods are not among those with the highest relative permeable area (S2), namely: Alto Boqueirão, with three squares and 90.79% of permeable area; Pilarzinho, with two squares and 92.63% of permeable area; Campina do Siqueira Expanded, with two squares and 94.65% permeable area; and São Bráz and Santo Inácio, with one square and 98.69% permeable area.

On the other hand, regarding the number of tree individuals (S3), São Bráz and Santo Inácio were the worst clustered neighborhoods, as they did not present any individual in the evaluated square. Therefore, these neighborhoods presented a value equal to zero in all other variables that indicate

TABLE 6 – Descriptive statistical analysis of the variables in the qualitative assessment (N = 19).

Variable code	Minimum	Maximum	Mean	Standard deviation
S1 (km <sup>2</sup> )	0.000338	0.021611	0.006405	0.006047
S2 (%)	20.8430	98.6900	70.0379	21.8638
S3 (unit)	0	396	76.6300	102.4740
S4 (unit)	0	261	44.6053	59.8414
S5 (unit/km <sup>2</sup> )	0	0.0485	0.0094	0.0112
S6 (unit)	0	69	15.2600	15.4190
S7 (unit)	0	25	8.4517	5.6714
S8 (unit/km <sup>2</sup> )	0	0.1505	0.0024	0.0032
S9 (unit)	0	11.5357	3.6110	2.4402
Socec (BRL)	729.7558	4,115.6110	2,033.2811	1,053.2114

KEY: S1 = Absolute permeable area; S2 = Permeable area relative to the area of the squares; S3 = Absolute number of tree individuals; S4 = Number of tree individuals relative to the number of squares (density); S5 = Number of tree individuals relative to the area of the squares; S6 = Absolute number of tree species (richness); S7 = Number of tree species relative to the number of squares (mean); S8 = Number of tree species relative to the area of the squares; S9 = Odum Biodiversity Index; Socec = Total mean monthly income; BRL = Brazilian Real.

SOURCE: The authors.

the environmental quality of the squares (S4 to S9). The second worst neighborhood in terms of number of individuals was Guaíra and Fanny, with 7 individuals, and the best ones were Guabirotuba and Jardim das Américas, with 261, and Centro, with 396. As several neighborhoods (47.37%) had only one square evaluated, the density of trees per square (S4) was similar to the absolute number (S3), with São Bráz and Santo Inácio, and Guaíra and Fanny in the worst positions, with 0 and 7 trees per square, respectively, and Guabirotuba and Jardim das Américas in the best, with 261. Centro, which had four squares sampled, was in the second best position in terms of density, with 99 tree individuals per square. The results were different when considering the number of individuals per square area (S5). Here, Pilarzinho was the second worst, after São

Bráz and Santo Inácio, with 0.0017 trees per km<sup>2</sup>, and Sítio Cercado and Cabral were the best ones, with 0.0247 and 0.0485 trees per km<sup>2</sup>, respectively.

As for species richness (S6), Capão Raso was the second worst neighborhood after São Bráz and Santo Inácio, with only three species, the best being Alto Boqueirão, with 28, and Centro, with 69 (S7), São Francisco Expanded was the second worst, with 2.50 species per square, and Centro and Guabirotuba and Jardim das Américas were the best ones, with 17.25 and 25.00 species per square, respectively. Among the worst neighborhoods concerning the number of species per square area (S8) are Vila Izabel and Santa Quitéria, and Boqueirão and Hauer, with 0.0008 species per km<sup>2</sup> each, as well as Xaxim, with 0.0009 species per km<sup>2</sup>. The Cabral neighborhood was the one that presented

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the best value, with 0.0150 species per km<sup>2</sup>, almost four times more than the second-best neighborhood, Portão, with 0.0042 species per km<sup>2</sup>. Finally, the Odum Biodiversity Index (S9) was lower, after São Bráz and Santo Inácio, in the Capão Raso clustered neighborhood, with 1.0014, and higher in Centro, with 11.5357.

Considering the total mean monthly income only for the group of 19 clustered neighborhoods, the worst socioeconomic conditions are found in Sítio Cercado, with BRL 729.76, and in Alto Boqueirão, with BRL 831.59. At the other end are Campina do Siqueira Expanded, with BRL 3,764.80, and Água Verde, with BRL 4,115.61.

The spatial distribution of these variables among the clustered neighborhoods is shown in Figure 3.

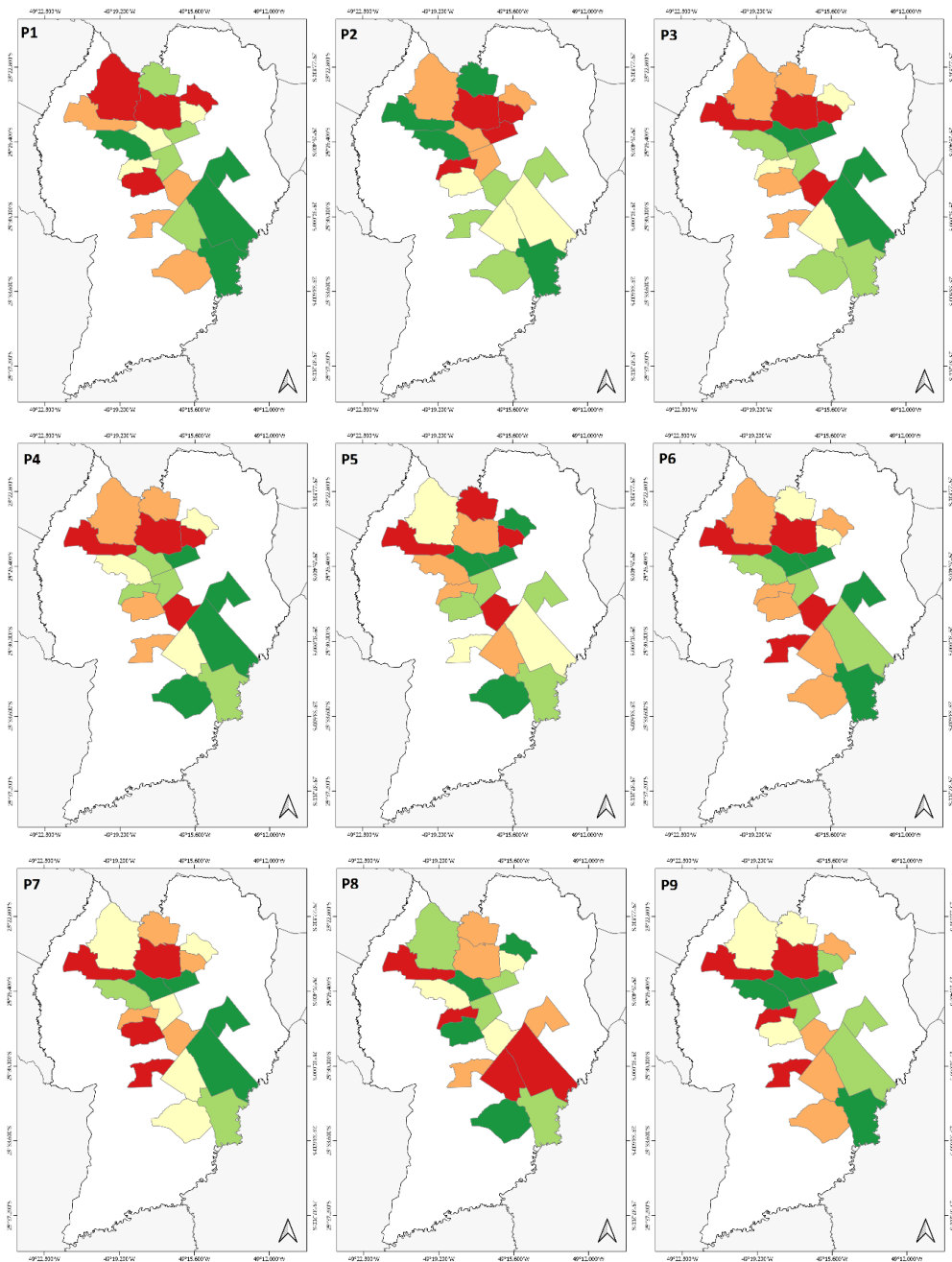
Through the maps it is possible to visually assess that the socioeconomic condition of the 19 clustered neighborhoods, represented by the total mean monthly income variable, is worse in the Southeast region of Curitiba, in Alto Boqueirão, Sítio Cercado and Xaxim, in addition to Batel and Bigorriho, followed by Boqueirão and Hauer, Capão Raso, and Guaíra and Fanny.

The spatial distribution pattern of the total mean monthly income differs from those presented by the market permeability variables. The absolute permeable area (S1) was smaller in the North and central portion of the city, in the Cabral, Portão, Santa Felicidade Expanded and São Francisco Expanded neighborhoods, two of which have the best socioeconomic conditions. On the other hand, permeability was higher in the Southeast area, in the Alto Boqueirão, Boqueirão and Hauer, Campina do Siqueira Expanded, and Guabirota and Jardim das

Américas neighborhoods; with the first two among the worst yields, and the last two among the best.

The same occurs for the relative permeable area (S2), where the neighborhoods with the lowest values – Centro, Centro Cívico and Juvevê, São Francisco Expanded, and Vila Izabel and Santa Quitéria – are among those with the highest incomes. Among the neighborhoods with the largest relative permeable area, there is also one among the highest incomes (Campina do Siqueira Expanded), whereas two are among the lowest values (Alto Boqueirão and Pilarzinho). Thus, it is possible to infer that permeability is somewhat inversely related to socioeconomic condition, that is, the most impermeable squares are located in neighborhoods with higher incomes.

As for the environmental indicators that consider the number of tree individuals in the squares of Curitiba, Centro Cívico and Juvevê, Guaíra and Fanny, and São Bráz and Santo Inácio appear among the clustered neighborhoods with the lowest number of individuals both in absolute values (S3) and relative to the number of squares (S4) and their area (S5), accompanied by São Francisco Expanded, in the case of absolute values and density, and by Pilarzinho, when the distribution of individuals by area is considered. Of these neighborhoods, two are among those with the worst incomes (Guaíra and Fanny, and Pilarzinho), whereas another two are among the best values (Centro Cívico and Juvevê, and São Francisco Expanded). Batel and Bigorriho (S3 and S5), Boqueirão and Hauer (S3 and S4), Cabral (S5), Centro (S3, S4 and S5), Guabirota and Jardim das Américas (S3 and S4) and Sítio Cercado (S4 and S5) were the clustered neighborhoods with the highest values considering the variables of tree individuals, of which three are among the



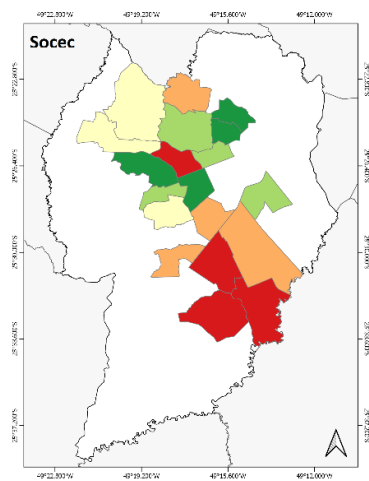


FIGURE 3 – Spatial distribution of qualitative variables in the 40 clustered neighborhoods of Curitiba, PR.

KEY: S1 = Absolute permeable area; S2 = Permeable area relative to the area of the squares; S3 = Absolute number of tree individuals; S4 = Number of tree individuals relative to the number of squares (density); S5 = Number of tree individuals relative to the area of the squares; S6 = Absolute number of tree species (richness); S7 = Number of tree species relative to the number of squares (mean); S8 = Number of tree species relative to the area of the squares; S9 = Odum Biodiversity Index; Socec = Total mean monthly income. Data grouped into five classes of equal count (quartile), where red represents the lowest values for all variables (worst), and green represents the highest values for all variables (best).  
SOURCE: Data from DIEESE (2016) and IPPUC (2021), prepared by the authors.

neighborhoods with the lowest total monthly mean income, and two are among the neighborhoods with the highest incomes.

Regarding the species richness of the squares (S6), the northern and central portions were the ones with the lowest values, in the Capão Raso, Guaíra and Fanny, São Bráz and Santo Inácio, and São Francisco Expanded neighborhoods. The first two neighborhoods also have the lowest values of the socioeconomic indicator, whereas the last one is among the best incomes. Alto Boqueirão, Batel and Bigorriho, Centro, and Guabirotuba and Jardim das Américas were the neighborhoods with the highest species richness, with the former having low total monthly mean yields and the others, high. Capão Raso, São Bráz and Santo Inácio, and São Francisco Expanded also have the lowest mean number of

species per square (P7), next to Portão, whereas Batel and Bigorriho, Boqueirão and Hauer, Centro, and Guabirotuba and Jardim das Américas have the highest numbers of species per square, which may indicate a positive correlation between these variables and the socioeconomic indicator. In the case of the species by area of the squares variable (P8), Boqueirão and Hauer, São Bráz and Santo Inácio, Vila Isabel and Santa Quitéria, and Xaxim presented the highest values, whereas Batel and Bigorriho, Cabral, Portão, and Sítio Cercado presented the lowest values.

Finally, the Odum Biodiversity Index (P9) was lower in the Capão Raso, São Bráz and Santo Inácio, São Francisco Expanded, and Vila Isabel and Santa Quitéria clustered neighborhoods, the first among the worst incomes, and the last two among the best;

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and higher in Alto Boqueirão, Batel and Bigorriho, Campina do Siqueira Expanded and Portão, the first two among the worst yields, and the third among the best ones.

Correlation coefficients between the qualitative environmental indicators of the squares and the socioeconomic indicator of 19 clustered neighborhoods in Curitiba were calculated. However, all had an error greater than 5%, probably due to the reduced sample size and, therefore, they were excluded from the analysis. Thus, it was possible to make inferences about the qualitative data only through descriptive statistical analysis and spatial visualization on the maps.

## 5. Discussion

Studies on the benefits of nature for people are more frequent in the Global North than in the Global South (Sudmeier-Rieux *et al.*, 2021). However, even among the most developed countries, there is evidence that these benefits are not well distributed across the entire population (Gerrish & Watkins, 2018). When analyzing 10 cities in the United States, for example, Nesbitt *et al.* (2019) found a high correlation between vegetation cover and schooling and income indicators.

Although the Global South has fewer publications on this topic, mainly due to lower investments in research (Shuvo *et al.*, 2020; Sudmeier-Rieux *et al.*, 2021), here some studies show inequality in the distribution of ecosystem benefits. Venter *et al.* (2020) found that public or private green infrastructure is more abundant, affordable and of higher quality in high-income areas of South Africa.

In Brazil, Morato *et al.* (2018) analyzed, among other environmental quality indicators, vegetation cover in relation to mean *per capita* income specifically in a watershed from the South area of São Paulo, finding deep inequalities between rich and poor neighborhoods. Rezende *et al.* (2018) found a correlation between lack of vegetation cover in Permanent Preservation Areas and vulnerability and poverty in the state of Rio de Janeiro and, thus, stated that these areas should be a priority target for environmental and social policies. In turn, Arantes *et al.* (2021) identified the occurrence of forest remnants in peripheral regions with lower mean *per capita* incomes in the city of São Paulo, whereas green areas with better access and infrastructure are found in regions with higher incomes, in an unequal distribution favoring rich neighborhoods.

This study adds to previous research diverse evidence of inequalities in the distribution and access to ecosystem benefits by the populations with the worst socioeconomic conditions.

Squares were selected as the object of this study because they are the type of green area most present in the everyday life of the population. However, it is important to carry out research studies that also consider other types of urban forest, as they can assess whether the gaps left by squares are filled by other green areas. In addition, it is suggested that a qualitative assessment of all squares be carried out, which will allow confirming correlations herein deduced based on the data spatial distribution maps.

In addition, it is recommended that studies be carried out on the population's experiences and perceptions about the squares, in order to assess access and use of these green areas by people from different socioeconomic groups.

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Among the gaps faced in carrying out this study is the updating of secondary data for the study area. The total mean monthly income figures are from the 2010 Demographic Census, more than a decade ago, and it was not possible to find more recent data. Therefore, it is possible that the relationships between the socioeconomic indicator and the squares are not the same today. Consequently, it is suggested to update this survey after the new census is conducted.

This study can be added to others that support the creation of new green areas and management and improvement of existing green areas in Curitiba, seeking to ensure that the benefits generated by nature are achieved by all people, especially those who need it most. In addition, this research can be reproduced in other municipalities for the same purpose.

## **6. Conclusions**

With this research it was possible to select environmental variables that indicate the quantity and quality of squares in Curitiba, PR, based on secondary data available for the study area, although the qualitative variables were only available on a sample basis.

It was found that the visual analysis carried out based on the data spatial distribution maps allowed deducing positive relationships between the quantitative environmental indicators and the total mean monthly income, especially regarding the number of squares relative to the neighborhood area. The mean area of the squares was an exception, with larger ones in neighborhoods with lower incomes.

Calculation of the correlation coefficients between the quantitative environmental indicators and the total mean monthly income confirmed the strong positive relationship with the number of squares relative to the neighborhood area and showed a weak negative correlation with the mean area of the squares.

It was not possible to consider the correlation coefficients between the qualitative environmental indicators and the total mean monthly income in the analysis due to the high statistical error. However, the visual analysis of the data spatial distribution maps indicates a possible inverse correlation between the permeability variables of the squares and the socioeconomic indicator, mainly regarding the relative permeable area.

It is also possible that there is a positive correlation between species richness and the mean number of species per square and the total mean monthly yield, although this needs to be confirmed in a broader study by calculating the correlation coefficients.

Finally, the results obtained in this research indicate that the squares and their benefits are not equally distributed across the entire population of Curitiba, as neighborhoods with better socioeconomic conditions have a greater number and area of squares per neighborhood and, possibly, with greater total and per square numbers of tree species. In this way, access to the benefits generated by the squares and their ecosystem services by the population with worse socioeconomic conditions is impaired.

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