Analyzing Urban Segregation with Variograms: The Case Study of the Federal District in Brazil

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CAPES

Background

- Segregation is a multidimensional phenomenon.
- Although, two dimensions are the most important: Evenness or Clustering and Isolation/Exposure.
- The (length) spatial scale of segregation matters.
- Using spatial segregation indexes for the two of the most important dimensions overlap the scale problem.
- However, until now little was done to explore the contribution of the geoestatistics methods, like the variogram, in urban segregation analysis.
- In this work we applied the variogram to analyze urban segregation, considering segregation by income level and place of residence in Distrito Federal (Brasilia), Brazil's capital.

Methods

- The variogram, $\gamma(h)$, shows the variance as a function of distance h and it is used to analyze any spatial data.
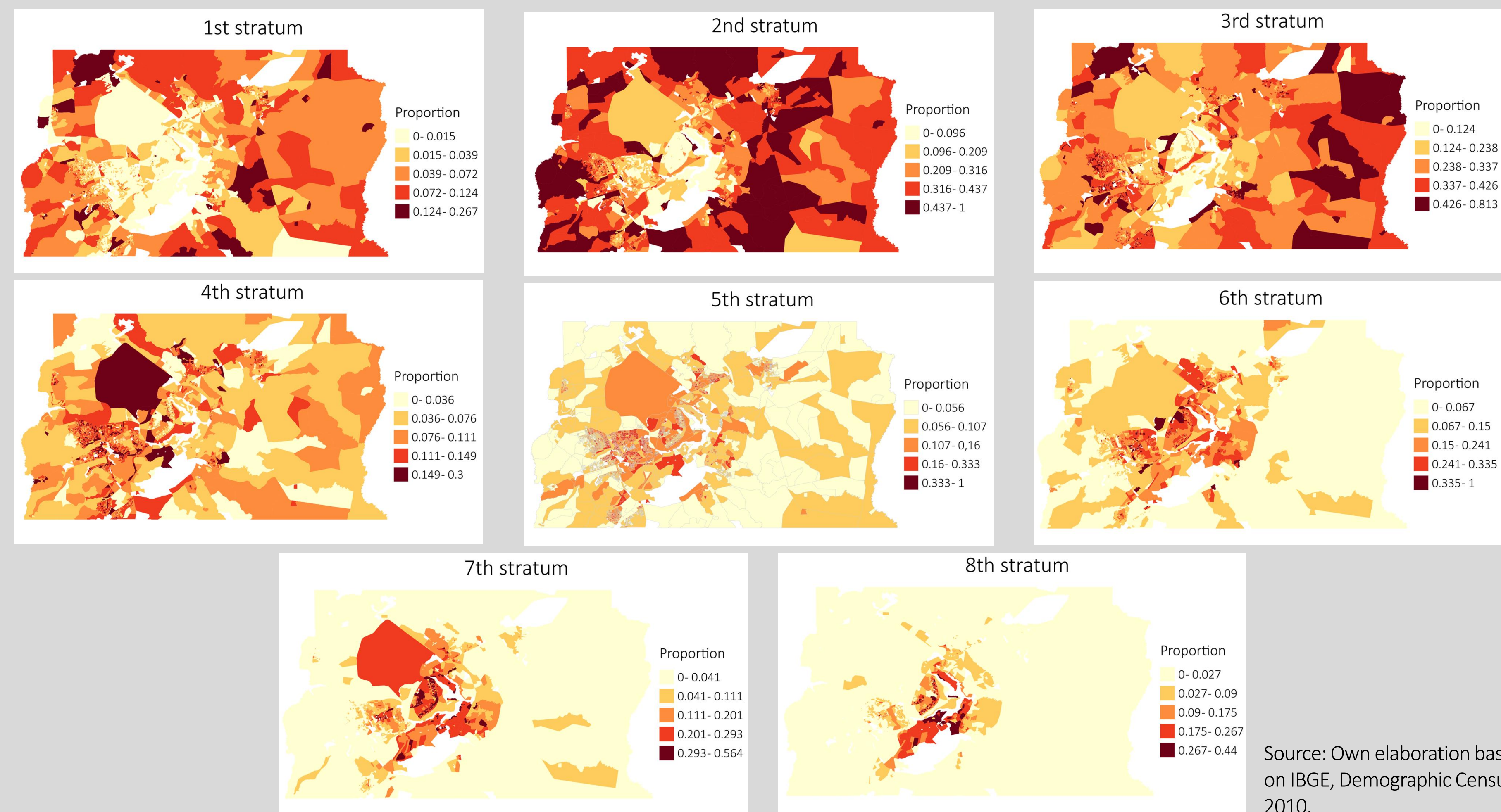- It can be defined as the average squared difference of values separated by a distance lag (or vector) h.

$$\gamma(h) = \left(\tfrac{1}{2}\right)\mathrm{Var}\left(S(x+h) - S(x)\right)$$

$\gamma(h)$ is the variogram function;
h is a modulus distance vector $\left(h \in \Re^d\right)$;
$\mathrm{Var}\left(S(x+h) - S(x)\right)$ shows how the variability between two different locations in space separated by a modulus distance vector h changes when h increases.

- The shape, the parameters and the other measures extracted from the variogram function could be interpreted in terms of urban segregation.
  1. Nugget effect (τ^2): shows the variance in the origin and derives from measurement errors and other micro-scale effects.
  2. Sill ($\tau^2+\sigma^2$) represents the level where the variogram reaches the maximum variability.
  3. Partial Sill (σ^2): shows the contribution of distance to the variance.
  4. Range (h): shows the range of the spatial correlation.
  5. Relative Nugget Effect (RNE): the ratio between the nugget effect (σ^2) and the sill ($\tau^2+\sigma^2$), we could check spatial continuity.
  6. Spatial Dependency Index (SDI): the complement of the RNE.

- Data: Census Data from the Brazilian Institute of Geography and Statistics (IBGE) for 2010.
- Population: all people aged 10+ years with income (1.424.647 people or 55.4% of total pop.), which was stratified into eight social strata.
- Spatial information: centroids of each census tract that had any information (4.077 or 93.7% of the total).
- Software: the variogram analysis was performed in R Software (v. 4.1.0). Two packages were used: geoR, or Package for Geostatistical Data Analysis and locpol, or Local Polynomial Estimation, to smooth the variogram function.
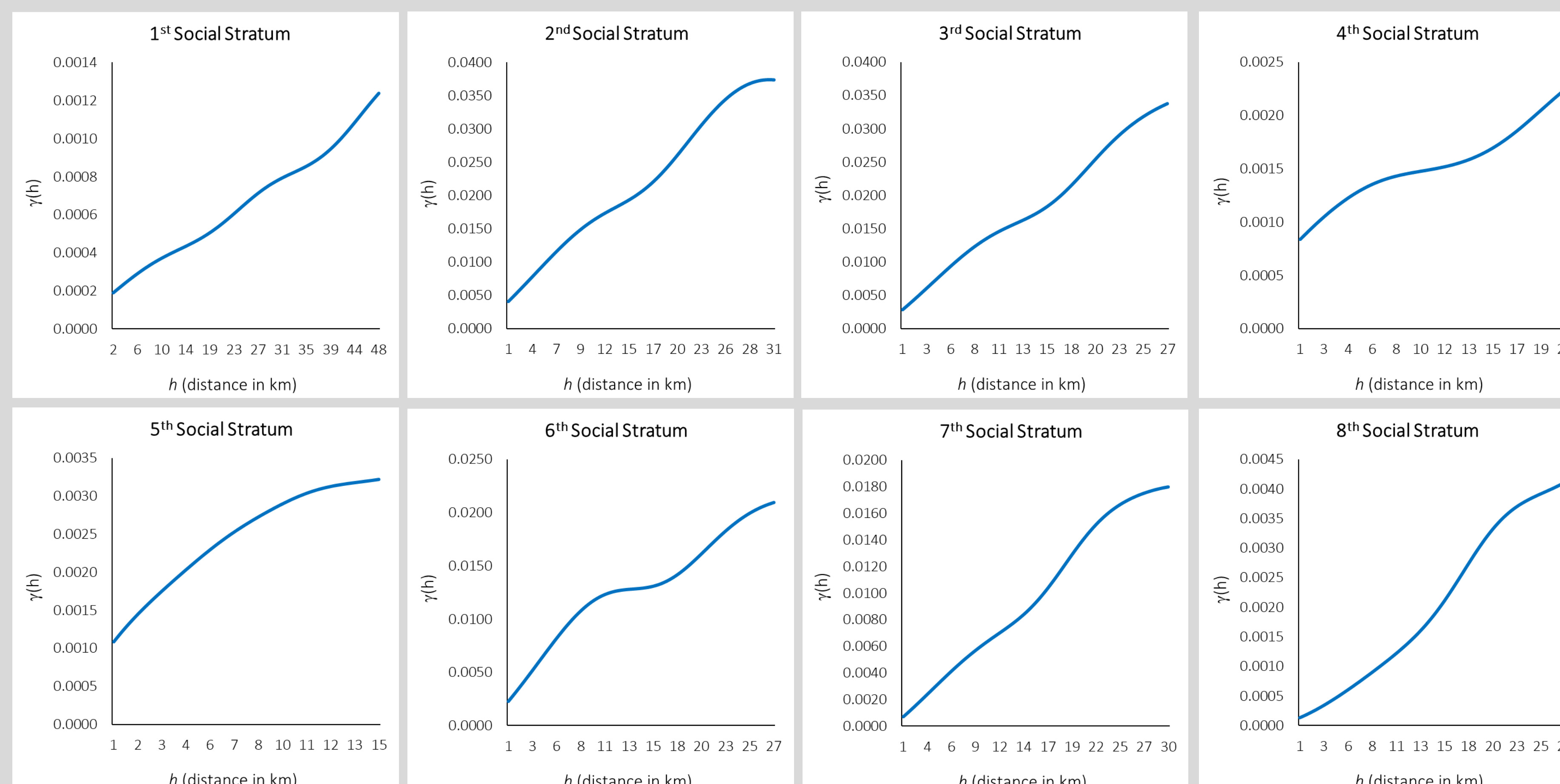
Results

### Figure 1 – Spatial concentration/proportion of each social strata in each census tracts

1st stratum — Proportion: 0- 0.015; 0.015- 0.039; 0.039- 0.072; 0.072- 0.124; 0.124- 0.267

2nd stratum — Proportion: 0- 0.096; 0.096- 0.209; 0.209- 0.316; 0.316- 0.437; 0.437- 1

3rd stratum — Proportion: 0- 0.124; 0.124- 0.238; 0.238- 0.337; 0.337- 0.426; 0.426- 0.813

4th stratum — Proportion: 0- 0.036; 0.036- 0.076; 0.076- 0.111; 0.111- 0.149; 0.149- 0.3

5th stratum — Proportion: 0- 0.056; 0.056- 0.107; 0.107- 0.16; 0.16- 0.333; 0.333- 1

6th stratum — Proportion: 0- 0.067; 0.067- 0.15; 0.15- 0.241; 0.241- 0.335; 0.335- 1

7th stratum — Proportion: 0- 0.041; 0.041- 0.111; 0.111- 0.201; 0.201- 0.293; 0.293- 0.564

8th stratum — Proportion: 0- 0.027; 0.027- 0.09; 0.09- 0.175; 0.175- 0.267; 0.267- 0.44

Source: Own elaboration based on IBGE, Demographic Census, 2010.

Figure 2 – Estimated variograms for each of the eight social strata

1st Social Stratum; 2nd Social Stratum; 3rd Social Stratum; 4th Social Stratum; 5th Social Stratum; 6th Social Stratum; 7th Social Stratum; 8th Social Stratum — $\gamma(h)$ vs h (distance in km)

Source: Own elaboration based on IBGE, Demographic Census, 2010.

Figure 3 – Estimated variograms for each social strata plotted together for comparison

Social Strata — $\gamma(h)$ vs $h\,(meters)$ — 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th
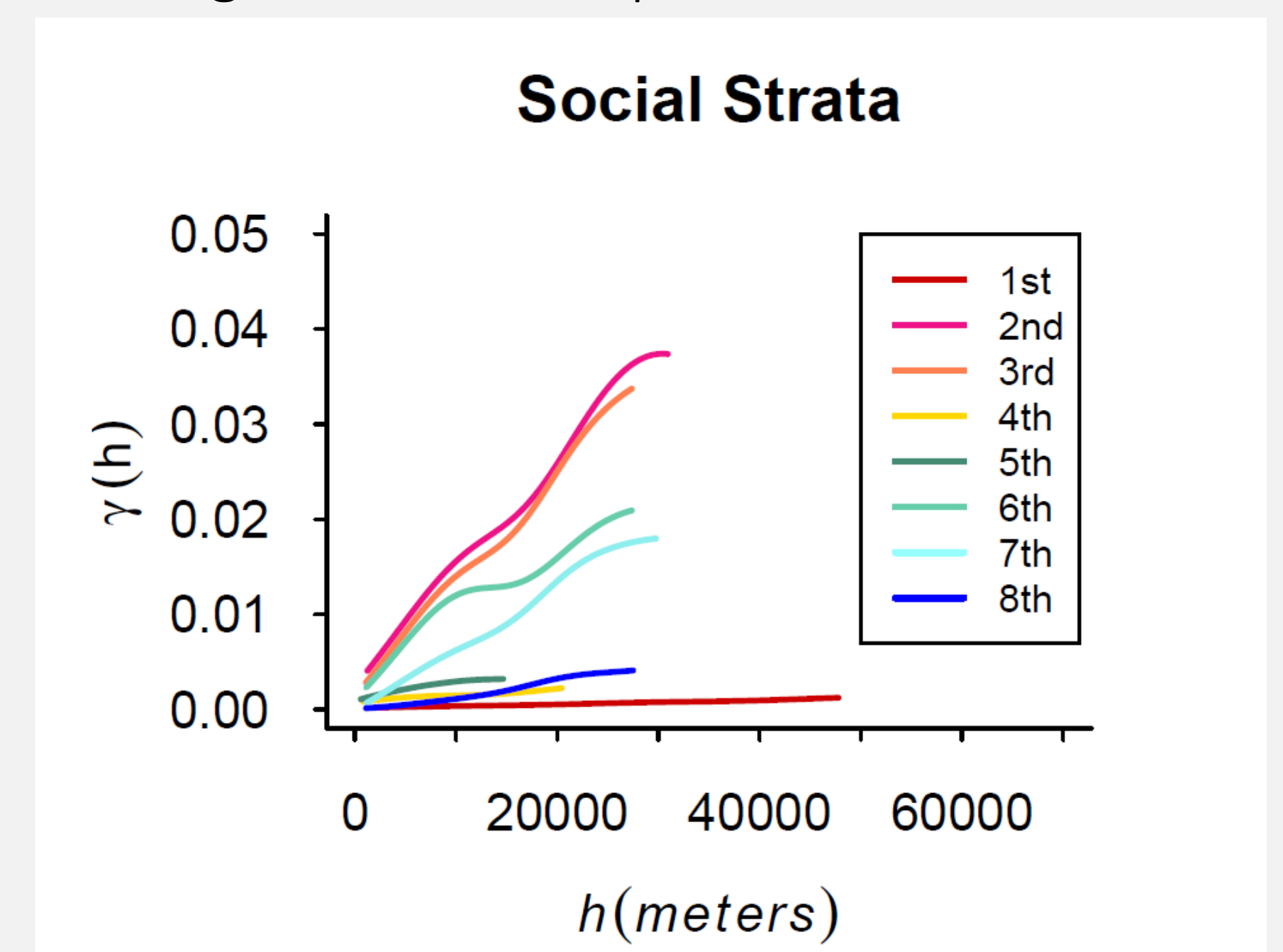
Source: Own elaboration based on IBGE, Demographic Census, 2010.

Table 1 – Estimated values for the parameters and other measures derived from the variogram

Social Strata	Nugget Effect (τ^2)	Partial Sill (σ^2)	Sill ($\tau^2+\sigma^2$)	Range (h) Crude distance (km)	Range (h) Standardized distance	Relative Nugget Effect (RNE)	Spatial Dependency Index (SDI)
1st	0.00019	0.00105	0.00124	47.8	0.6287	0.152	0.848
2nd	0.00408	0.03329	0.03737	30.9	0.4068	0.109	0.891
3rd	0.00285	0.03087	0.03373	27.3	0.3599	0.085	0.915
4th	0.00084	0.00141	0.00224	20.4	0.2688	0.373	0.627
5th	0.00108	0.00213	0.00322	14.6	0.1925	0.337	0.663
6th	0.00229	0.01864	0.02093	27.3	0.3599	0.109	0.891
7th	0.00071	0.01727	0.01798	29.7	0.3912	0.039	0.961
8th	0.00014	0.00397	0.00411	27.5	0.3616	0.033	0.967

Source: Own elaboration based on IBGE, Demographic Census, 2010.

Discussion | Final Remarks

- Highest segregation: 8th and 1st strata (i.e., richest and poorest groups).
- Lowest segregation: 4th and 5th strata (i.e., the middle of social hierarchy).
- In between: 7th and 2nd strata (higher/middle), 3rd and 6th (lower/middle).
- Segregation tends to increase from the top and the bottom to the middle of social stratification.
- Results suggested that the variogram could be applied to urban segregation studies.
- Further analysis is necessary for better understanding the results derived from the variogram and how they interact with the ones derived from the traditional (spatial) measures.
- Additionally. it is also desirable to promote comparative studies between and within cities.