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AN ACCESSIBILITY INDEX FOR THE METROPOLITAN REGION OF SÃO PAULO

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Abstract. The objective of this paper was to elaborate an index to measure accessibility to jobs in the Metropolitan Region of São Paulo. The index followed a gravitational formulation as proposed by HANSEN (1959), weighting the opportunities according to the impedance to achieve them. We defined 'opportunities' as the number of jobs in each zone, and 'impedance' as an inverse exponential function of travel time between each pair of zones, which was calculated by an Engineering Company. Two indices were calculated, one for trips made by private vehicles and a second one for public transportation. We observed that: a) accessibility is usually higher as nearer the zone is to city center; b) the spatial distribution of accessibility is different between the two modes, being shaped as concentric rings for the case of private vehicle and being somehow attached to the railway network for the case of public transportation; c) there is a significant spatial correlation between income and accessibility.

1. Introduction

According to SPIEKERMANN e NEUBAUER (2002), accessibility is the main product of transportation, being the measurement of locational advantage of a region over others. This way, accessibility can be understood as a degree of the benefits of transportation over a certain area. Meanwhile, as stated by CARRUTHERS e LAWSON (1995), urban accessibility is a relevant aspect of population welfare, and its importance is increasing with the urbanization of population, and because of that, the authors argue that cities should be planned in a way that all the citizens should have good access to all of its places.

However, according to VASCONCELOS (1993) the cities of the developing had an unplanned and uncontrolled growth, leading to a spatial segregation of the population, with the poorer settling themselves on the peripheries, where they face a lack of opportunities and higher transportation costs.

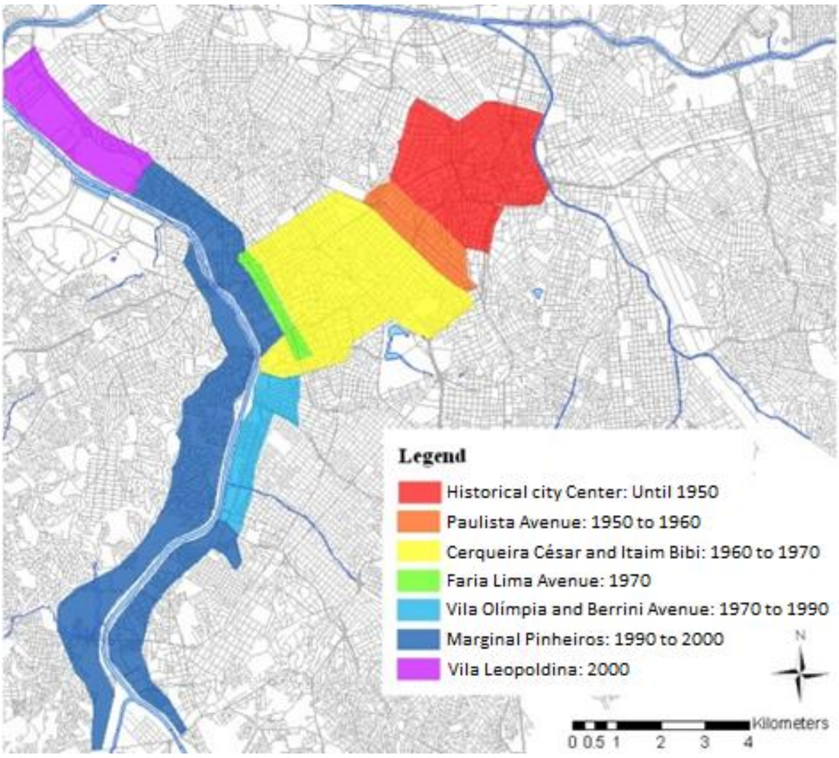
As the biggest metropolitan area in Brazil, São Paulo is a clear example of this problem. As observed by VILLAÇA (2011), the central southwestern quadrant of the city is inhabited by rich people, and it is also the area with the highest concentration of employment and urban services. On the other hand, the poorer (the majority of population) reside on the periphery, which are areas with low density of employment, forcing the majority of the population to commute from the city edges (where they live) to downtown São Paulo (where they work). Also, as stated by ROLNIK (2011), the transport infrastructure of São Paulo privileges the private vehicle mode, with large avenues and urban highways which are exclusive for cars; meanwhile, the public system was never a priority for city planners. As a result, São Paulo has an insufficient public transportation system. Summing up the accessibility problem, the wealthy ones live on central areas, very close to their job, and use their private vehicles on high-speed avenues. On the other hand, the poorer reside on the periphery, far from their employment and they depend on public transportation, which was historically ignored by urban planners.

As a measurement of locational advantage, accessibility is a common component of hedonic models for housing valuation. However, because of the lack of data, some simple approximations of accessibility are used, for example, HERMAN and HADDAD (2005) calculate the Euclidian distance to Sé Square, which is the historical landmark of São Paulo and is located in the region with the highest density of jobs in the Metropolitan Area, GOMES et. al. (2012) estimate accessibility as the distance to the closest subway station. However, both these approximations do not consider the total distribution of jobs and neither the heterogeneity of transport infrastructure, and that is why this study aims to elaborate a measurement that contemplates both this aspects.

2. The Accessibility Issue in the Metropolitan Region of São Paulo

In 2010, the Metropolitan Region of *São Paulo* had 19,683,975 inhabitants, corresponding to 10% of Brazilian population, and 14.4% of its GDP (IBGE, 2010). However, the city reached this size in a relatively short period; in 1890 it was inhabited only by 65,000 inhabitants, and as a consequence of European immigration and national industrialization the city received millions of immigrants during the first half of the Twentieth Century. Up to 1950, the transport system was centered on the tram, however, according to ROLNIK (2011), during the decade of 1950, the core of transport structure changed from rail to road.[1] The city kept growing rapidly until the end of the 1980's, when the total population reached 8.6 million inhabitants[2], and by this time, the city's economy was already consolidated on the services' sector.

Figure 1. CBD's Spatial Shift



Source: NADALIN (2010)

According to NADALIN (2010), during the second half of the Twentieth Century there was a "displacement" of the Central Business District (CBD), which went from the historical downtown to the southwestern quadrant of the city, as shown on Figure 1. It is hard to identify nowadays where is the CBD, since there is not a central and unique region that has both the highest concentration of employment and companies' headquarters. For instance, while historical downtown has the highest employment density of the urban area, it not the most expensive area and neither have the jobs with higher wages, which instead are concentrated around *Faria Lima* and *Berrini* avenues on the southwestern quadrant.

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[1] For a detailed revision of the historical development of São Paulo's transportation network, see ROLNIK (2011).

[2] Not counting the other cities of the metropolitan region

The population of São Paulo is fairly distributed over the urban area, being hard to identify any spatial pattern regarding the population density over the metropolitan area. Other variables such as employment, income and education have a clear spatial pattern, with higher values on central areas, however, while Employment distribution is centered Downtown, Income and Superior Education have the highest values on the Southwestern Quadrant of the city (See these figures on Appendix 1).

According to VILLAÇA (2011), the spatial distribution of employment and transport infrastructure are the cornerstones of the socioeconomic segregation in *São Paulo* and other Brazilian cities; the richer live near the jobs and take advantage of the road infrastructure, while the poorer live on the periphery, and are dependent on public transportation. So while developing a measurement of accessibility, it is relevant to capture these two vectors (distribution of jobs and transport infrastructure).

3. Methodology

The accessibility index to be developed in this study is based on Hansen's formulation (HANSEN, 1959), which defines accessibility as the potential of opportunities for interaction. According to Du & Mulley (2006), Hansen–gravity accessibility measures can be considered the most robust approach to measure accessibility to a certain service such as employment since the main advantage of this indicator is the ability to combine the effects of transport and land use. The limitations are: the calibration of the impedance function and the segregation of the effects of separation and attractiveness. Nevertheless, indicators derived from Hansen's model have been widely used for this type of measurement in the literature. (RAIA Jr., 2000), and its basic formulation is shown below:

$$A_i = \sum_{j=1}^{n} \frac{w_j}{\boldsymbol{d_{ij}}}$$

According to this formula, the accessibility A for each region i is given by the summation of opportunities w available at each region j divided by the impedance d to go from i to j.

We defined the opportunities w_j as the total employment E in each region j.

$$w_j = E_j$$

The values of E_j were extracted from the OD Survey of 2007, which interviewed 30,000 households collecting socioeconomic and commuting data of all residents. The Metropolitan Region of São Paulo was divided into 460 zones, and applying multipliers, the carriers of the survey projected the values of each variable for the whole population in each zone. Thus, regions i and j are defined according to the 460 zones of the OD survey.

We defined the impedance function d_{ij} as an exponential function of travel time between each pair of zones.

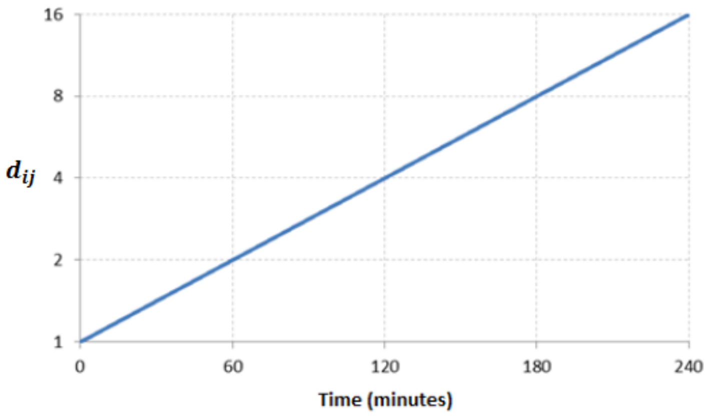
$$d_{ij} = e^{\alpha t}$$

Where α is a calibration parameter which was defined in a way that:

$$e^{\alpha \times 60} = 2 \quad \rightarrow \quad \alpha = 0.01154$$

From this definition, the impedance function has the following characteristic shown in Figure 2:

Figure 2. Impedance Function with $\alpha = 0.01154$



The consequence of such a calibration is that an opportunity within 0 minutes is weighted as 1, an opportunity that takes 1 hour to be reached is weighted as 0.5, an opportunity within 2 hours is weighted as 0.25 and so on.

The travel time was calculated by an engineering firm, which used EMME software. They estimated the travel times both by the private vehicle and by public transportation. For the case of private vehicle the estimations included only the travel time, and for the public transportation it considered walking, waiting and in vehicle times. So it was possible two indices:

$$(a) \quad A_{i,pv} = \sum_{j=1}^{460} \frac{E_j}{e^{0.01154 \times t_{ij}}} \qquad (b) \quad A_{i,pt} = \sum_{j=1}^{460} \frac{E_j}{e^{0.01154 \times t_{ij}}}$$

Where (a) calculates the accessibility A by Private Vehicle for each region i, and (b) the accessibility A by Public Transportation also for each region i.

4. Results

4.1 General Results

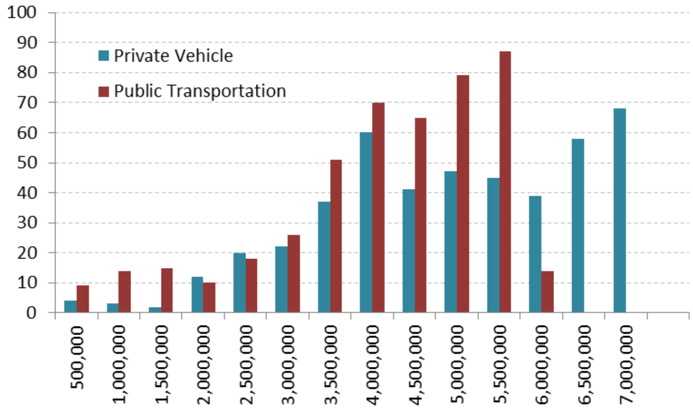
The Accessibility values for Private Vehicle mode are higher than the values for Public Transportation for all the quartile break values. The average value for Private Vehicle is

22% higher than the average value for Public Transportation, and the standard deviation is 18% higher.

Table 1. Basic Statistics for the Accessibility Indices

	Private Vehicle	Public Transportation
Minimum	444,496	107,324
1st quartile	3,619,281	3,243,575
Median	4,789,450	4,113,647
3rd quartile	6,081,871	4,881,718
Maximum	6,984,029	5,835,243
Average	4,721,267	3,871,235
Std Deviation	1,533,880	1,293,130

Figure 3. Histograms for the Accessibility Indices



The histograms (Figure 3) show that the main difference between the two distributions is that the accessibility by private vehicle surpasses 6 million in 25% of regions, but for no one in the case of public transportation.

4.2 Spatial Distribution of Results

Figures 4 and 5 show the spatial distribution of the two indices, and both maps were coloured according to a division of the 460 zones into 10 groups with the same number of zones within each group (46), the darker the colours the higher the accessibility of the group.

From Figure 4, it becomes clear that the accessibility by Private Vehicle has a spatial distribution with the shape of concentric rings, with higher accessibility the closer the zone is to the center. It is interesting to observe that the group of zones with the highest accessibility values is completely located in-between *Pinheiros* and *Tietê* rivers.

However, the center of the distribution does not seem to be *Sé*, but some point western to it. By plotting this map over a satellite picture of the city, it can be observed that the central point of the distribution seems to be somewhere around *Paulista* Avenue (shown on Appendix 2).

Regarding the accessibility by Public transportation, Figure 5 displays its spatial distribution. Although it also has a pattern of higher accessibility the closer the zone is to the centre, it is not possible to observe the concentric rings of Figure 4. Besides that, the group of zones with the highest level of accessibility were also located in-between the main rivers.

While the centre of the distribution seems to be *Sé* Square, from plotting it over a satellite picture of the city, it can be observed that there is a relationship between the spatial distribution of the index and the urban railway network of the city (Appendix 2).

We also analysed the difference between the two indices, which is shown on Figure 6. Surprisingly there are a few regions where accessibility is higher for Public Transportation, which is the case of some peripheral zones to the east, south and southeast of the city, which are regions served by the public railway network. The probable explanation to this result might be that the eastern and southern parts of the city does not have as many high speed roads as the western, however it concentrates a huge proportion of the population, and since their jobs are located downtown, the commuting of this population leads to traffic jams on the streets connecting these peripheries to the city center. Such congestions do not affect the users of the rail system, increasing their relative accessibility.

Figure 4. Spatial Distribution of Accessibility by Private Vehicle Mode

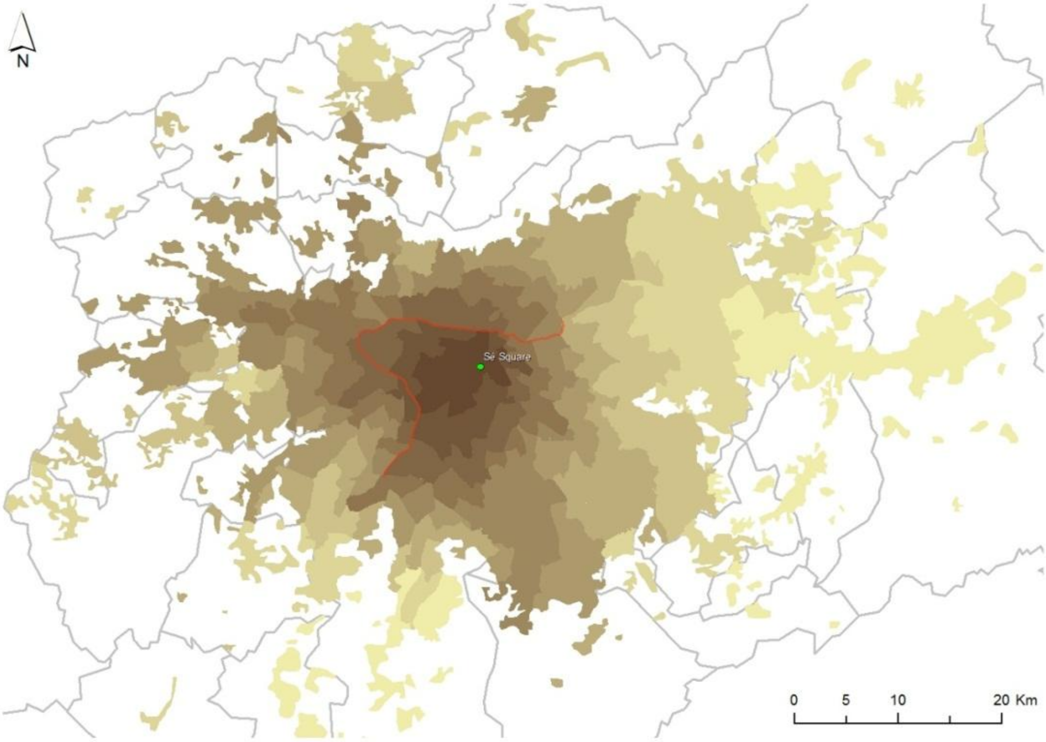


Figure 5. Spatial Distribution of Accessibility by Public Transportation Mode

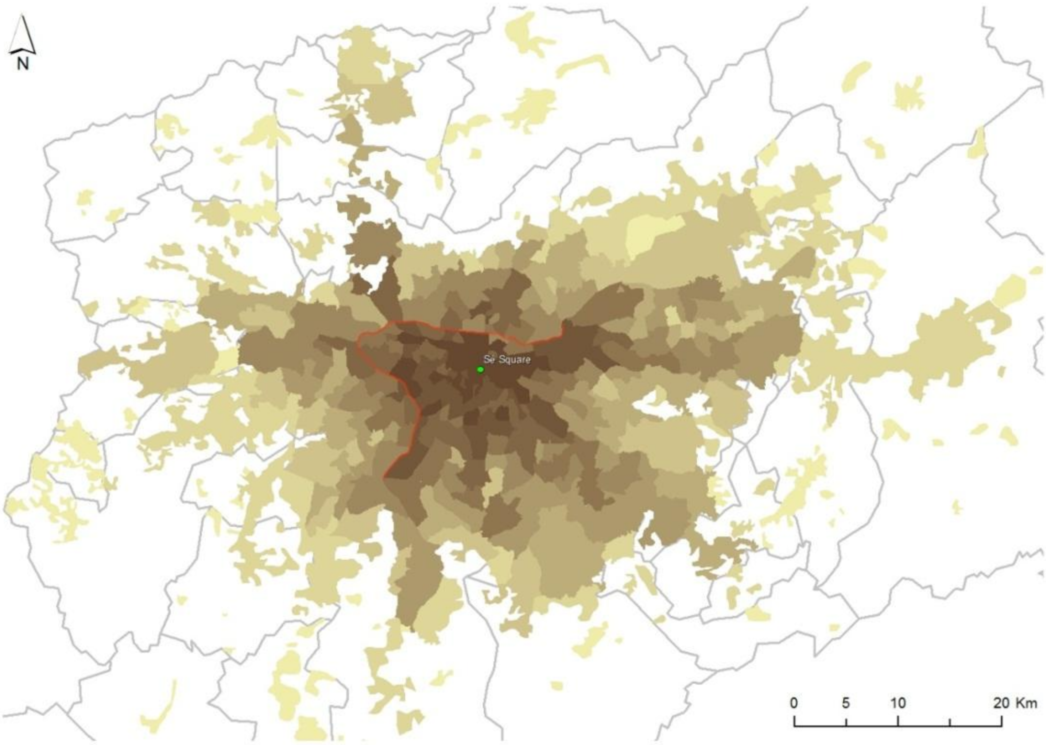
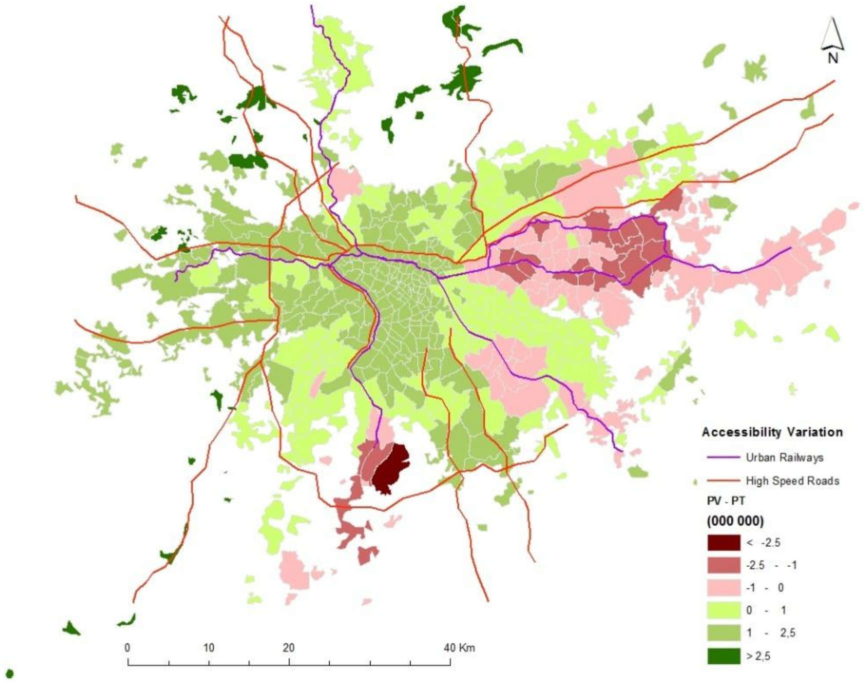


Figure 6. Difference between Private and Public Accessibility



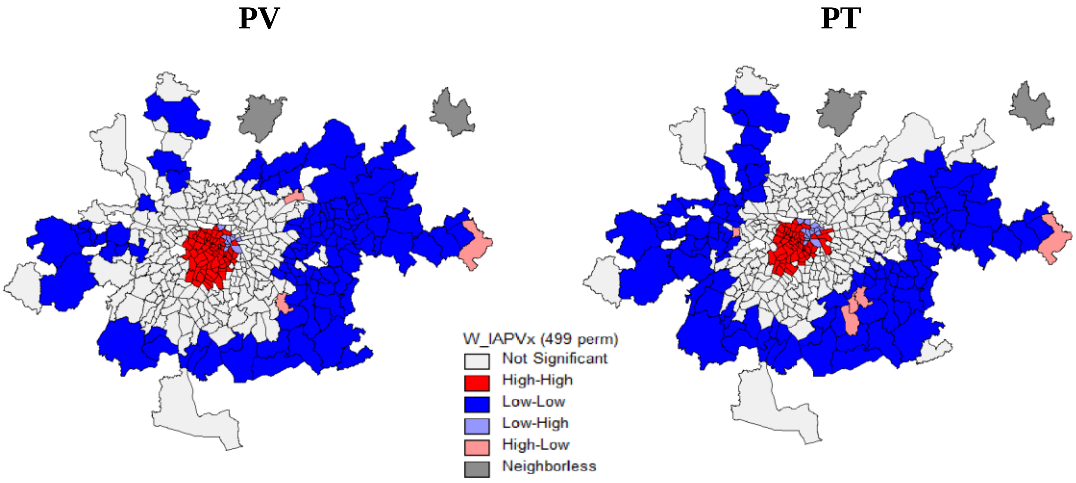
The western part however, has a higher accessibility by private vehicle, independently if the zones are closer or farther to the city centre, and the explanation might be the same as the one given above, since this part of the city has less inhabitants and larger infra-structure of high-speed roads.

4.3 Spatial Correlation between Income and Accessibility

VILLAÇA's (2011) argued that the richer live on central areas with higher accessibility while the poorer live on the peripheral regions with lower accessibility, so we calculated a spatial multivariate LISA for income per capita and the accessibility indices; the significant clusters are presented on Figure 7.

Both maps were calculated with a spatial weighting matrix of the queen type, and they show significant clusters of high income and high accessibility in the central-western part of *São Paulo* and a low income low accessibility cluster through the peripheries, confirming VILLAÇA's proposition. However, we also observed an interesting outlier; for both maps in the central part of the city, there are some zones with low income and high accessibility, opposing the pattern observed for almost all other zones. The city center has the best public transportation infra-structure of the city, with several subway stations and also the highest density of jobs; however it is a poor neighborhood.

Figure 7. Multivariate LISA Clusters for Accessibility Indices and Income per Capita

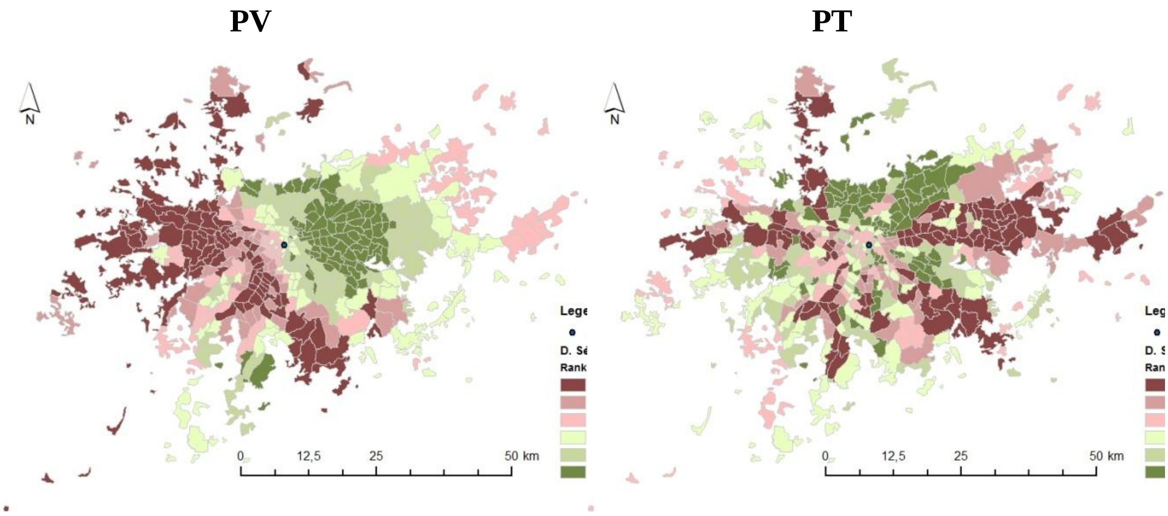


4.4. Comparing this Index to other Measurements

Figure 8 compares the difference between the indices calculated in this study and the measurement used by HERMAN & HADDAD (2005), i.e., Euclidian distance to Downtown São Paulo (Sé Square). The green regions indicate zones where the Euclidian distance overestimates accessibility, while the red ones indicate underestimation. For the case of private vehicle, distance to Sé does not capture the differences between the eastern and western parts of the city, overestimating accessibility on the first one and underestimating on the second. Meanwhile, when we compare it to the Public Transportation Index, the main difference is related to the proximity of a region to train and subway stations, which is not considered when calculating the distance to Sé.

From Figure 8 it is clear that the gravity based accessibility indices captures a broader picture of accessibility distribution, including the transport infra-structure and heterogeneities on spatial distribution of employment.

Figure 8. Difference Between the Indices and Distance to Sé



5. Conclusions

This study developed for the Metropolitan Region of São Paulo an accessibility index to employment, which was constructed according to Hansen’s gravity-based formulation. From the database it was possible to create two indices; one for the private vehicle mode and a second to public transportation.

The first observation was an average higher accessibility by Private Vehicle mode in the majority of the city’s zones, which was expected. However for a few regions located on the extremes of eastern, southern and southwestern parts of the city, the values for the accessibility by public transportation were higher, probably as a consequence of road congestions and the availability of train and subways, making public transportation a faster option to reach the most job dense areas.

It was also noted a similarity between both indices, in the sense that zones have higher accessibility the closer they are to the city center. However, Private Vehicle Index’s distribution is shaped as concentric rings which are centered somewhere near *Paulista Avenue.* Meanwhile, the map for Public Transportation is attached to the railway network.

Finally it was observed a significant spatial correlation between income and accessibility, confirming the observation that the richer live on regions with better accessibility closer to the central parts of the city and the poorer on the distant periphery with lower accessibility. The main exception to this pattern was the area around downtown, which besides having high accessibility are inhabited by poor people.

This study is just an initial step into exploratory analyze of the accessibility issue. With more data and more sophisticated tools, we aim to better understand this issue. For now, we make the following recommendation for further topics of research:

- ✓ Reproducing the index for other metropolitan areas, in order to allow for a comparison of the results;
- ✓ The comparison of this formulation with other accessibility indicators;
- ✓ The effects of accessibility on the structure of the urban economy (e.g. land value).

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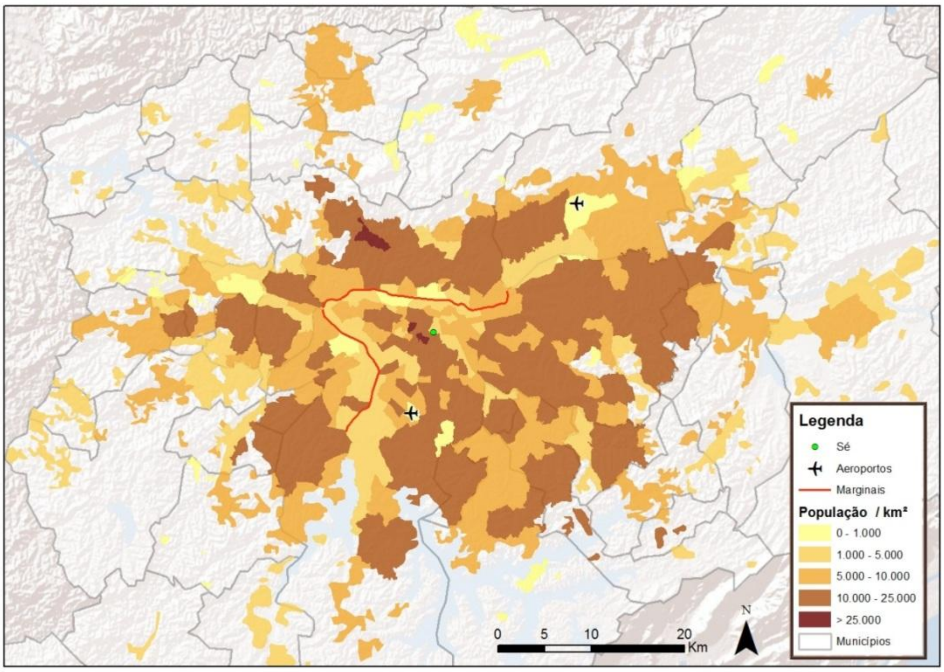
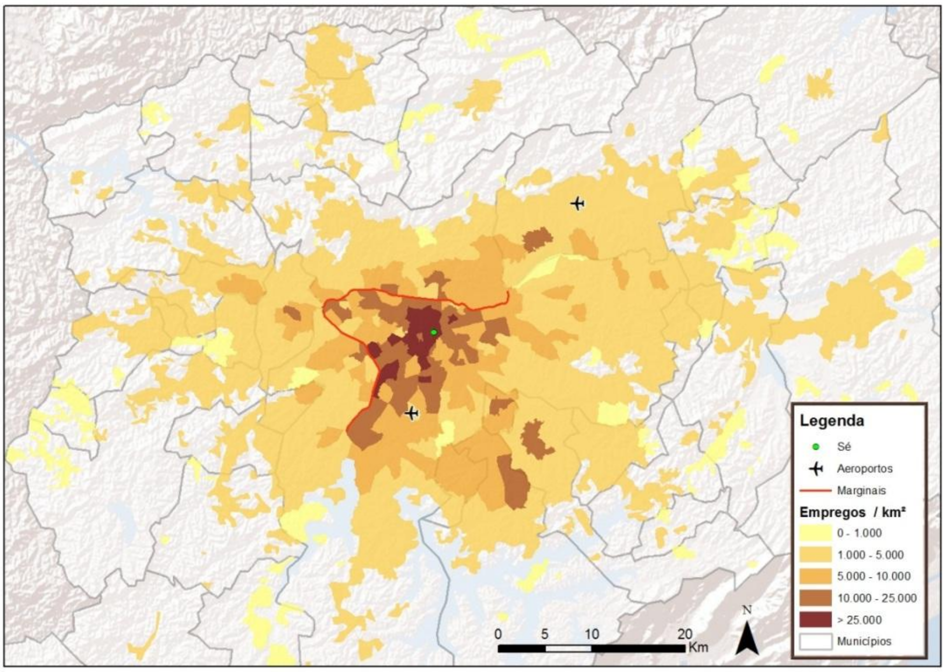
Appendix 1. Demographic Figures for the Metropolitan Region of São Paulo

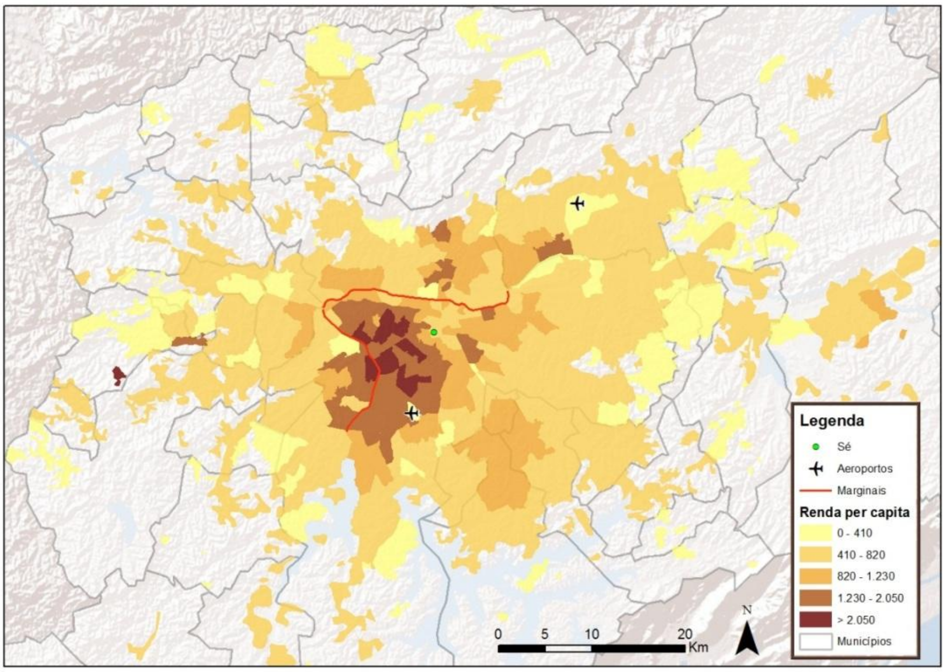
Population Density



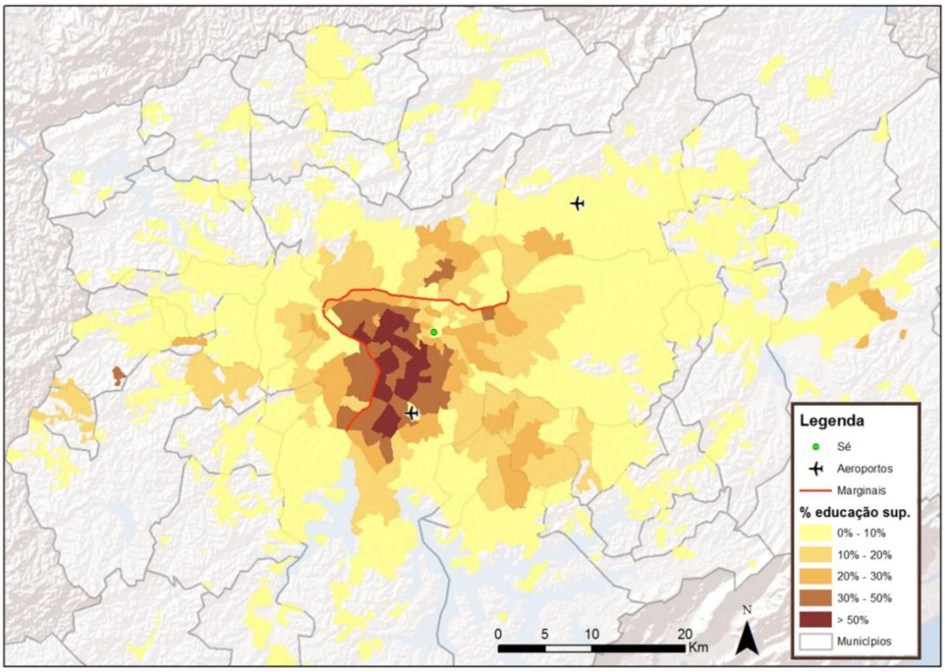
Employment Density



Income per Capita

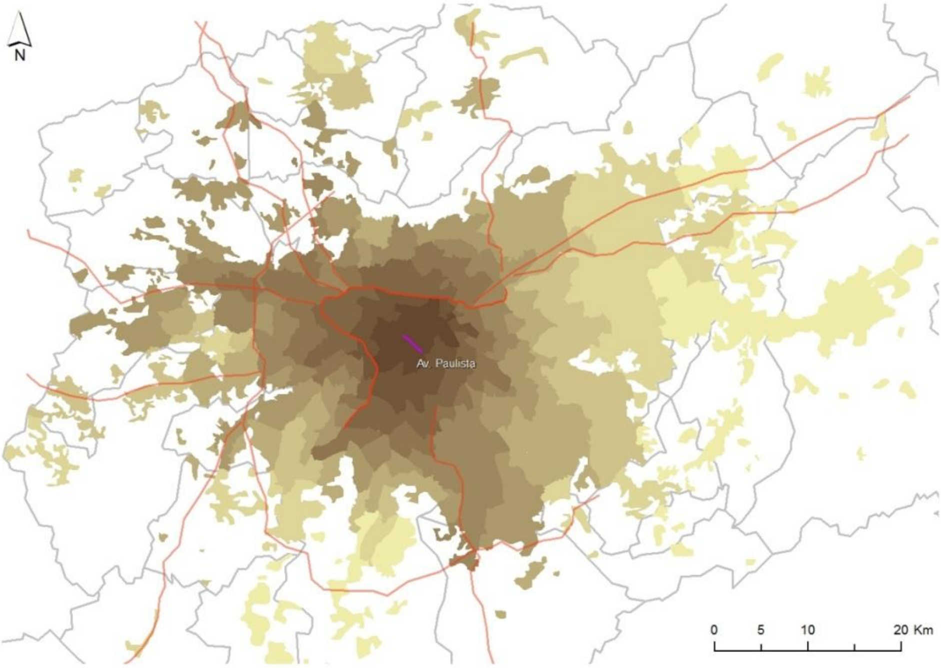


Proportion of Population with Superior Education



Appendix 2. Spatial Distribution of Accessibility and the Transport Infrastructure

Accessibility by Private Vehicle, Paulista Avenue and Main Roads



Accessibility by Public Transportation, Subway and Train Network