Article

Accessibility to Food Retailers: The Case of Belo Horizonte, Brazil

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Abstract: Access to food systems is essential to sustain urban life. In this paper, we discuss the differences concerning accessibility levels to food systems among potential consumers in Belo Horizonte, Brazil. The goal was to characterize spatial mismatches regarding food opportunities and identify suitable areas for sustainable food mile solutions, such as non-motorized home delivery and purchase trips. For this, we have spatially related: (i) the population concentration; (ii) the income of households; and (iii) accessibility measures considering both the spatial structure of food retailers and the distance between households and stores, considering the food mile. We have then used spatial statistics and spatial analysis methods to determine the spatial pattern of variables and the cumulative opportunity measure for households. There is great spatial differentiation regarding the accessibility levels of food retailers and the results can be considered to support the development of policy and land use regulation that can stimulate non-motorized and collaborative delivery as an effective last-mile solution.

Keywords: accessibility; food service facilities; grocery retailers; city logistics; last-mile delivery

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1. Introduction and Background

The concentration of people in cities is a growing worldwide phenomenon and by 2050 there will be at least nine billion people in the world to be fed, with two-thirds of them living in cities [1,2]. Despite that, food goods are mostly produced in rural areas and need to be distributed to consumers throughout a supply chain that encompasses different stakeholders, facilities, territories and decision making processes. As a result of the urbanization process, citizens increasingly demand food supplies in cities and this upward trend must be accommodated in urban freight distribution systems [3]. Even though urban freight transport is an essential activity for the development of cities and the maintenance of the urban lifestyle, the movement of goods is responsible for negative externalities such as greenhouse gas emission, noise, congestion, among others [4].

Recently, freight transportation has acquired some relevance in urban planning policy, especially in large cities and even in the Latin American context [5,6]. Nevertheless, city logistics solutions are still not broadly explored by local public authorities in decision-making and most of the indicators considered to include freight movement in urban plans are not based on the spatial structure of the city [6–9]. Recent epistemological discussions regarding the needs to structure a more comprehensive analysis of urban systems have emerged, and a holistic approach has resulted in a paradigm shift, where integrated urban planning studies are performed, considering subsystems such as the location of activities, the land-use, and the transport structure [6,10–13]. Cumulative indicators and measures of centrality, concentration, accessibility, and attractiveness are already

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discussed in research work on urban freight planning but are not often considered in policymaking [6,14–17]. In strategic planning, these measures can be applied for urban freight transport management, relating to logistics demand generation (i.e. the number of establishments) [18] and might result in an important contribution to urban planning [6,13,15,19].

Accessibility can be defined as the opportunity to reach urban functions by different means as a result of the interaction between spatial structure (land-use) and transport systems [20,21]. Even though the notion of accessibility is consolidated in urban and transport planning, few researchers have address freight accessibility [6,22], despite its potential contributions to urban freight transport planning. A typology for accessibility measures [6] concerns 5 categories of indicators: (i) infrastructure or service level; (ii) freight generation; (iii) distance and cost based on the urban network; (iv) gravity-based; and (v) compatibility measures. Distance-based indicators [23] are interesting measures for urban freight transport, meaning the "cost" to reach zone i from or to a logistics facility in zone j [6]. The spatial gaps between the number and location of establishments and the demand site can be estimated taking into account different impedance measures, from Euclidean distance to generalized travel time or cost. Accessibility indicators can be considered for retailing land use planning, in order to enhance the attractiveness of establishments and, when sustainability dimensions (economic, environmental and social) are considered in urban planning, retailing accessibility can drive the design of land-use planning that might help decrease motorized shopping trips and, at the same time, provide basic food to households in a walkable distance, assuring food security [6,13,24].

Specifically for cities located in developing countries, some challenges might affect urban logistics operations, such as high population density, rapid and disorganized population growth, underdeveloped infrastructure, fragmented industry, diversity among logistics operators' resources, wide-ranging informal sector and increased motorization [25,26]. Along with these structural attributes, at the beginning of this century, there have been significant changes in the retail structures and shopping habits in emerging economies, especially regarding consumers' behaviors [26]. In wealthier urban areas of these countries, e-commerce has been replacing part of the conventional retail shopping, including food purchase, which results in the growth of the demand for parcel delivery to the end consumer [27]. More e-shopping implies more home deliveries and, therefore, more dispersed trips and possible failed deliveries. Other important drivers that might affect the urban freight transport in cities of emerging countries are (i) socioeconomic factors, such as rising income and aging population; (ii) urban dynamics; (iii) economic development [28]; (iv) increasing consumption of industrialized food [26]; and (v) a trend to substitute local and walking distance retailers for large chain stores, recurrently located in accessible corridors, stimulating the usage of motorized modes for this purpose. Even though this last trend might help to diminish some urban freight logistics problems in the short-term period, from an overall urban planning viewpoint, the capillarity of the retail spatial structure should be preserved, especially to enable non-motorized pickup and delivery of food products [27].

The urban food supply depends on a mix of urban policies, commercial activities, regulatory conditions, infrastructure provision, and transportation supply [29]. In this process, different stakeholders interact in order to deliver food to the final consumer, and these actors have different goals. Transportation operators need efficiency and low-cost processes; urban planners should provide access to freight vehicles but need to regulate the transport activity to minimize negative impacts such as noise, congestion, and pollution; retailers need to receive and deliver goods to consumers efficiently, and consumers want to have effective access to food [29]. Also, food systems, defined as a supply chain involving different actors, from agriculture to the final demand [30], include the design and assessment of the supply of fresh products, which are more complex and should entail higher operational costs [31]. Analogous to the last mile concept, 'food mile' [29] can be defined as the last part of the food supply chain. The food mile is usually characterized by small pickups and deliveries handled by transport operators, suppliers, wholesalers, distributors, as well as by receivers themselves [31]. Concerning the changes in food consumption habits, deliveries as an outcome of e-food and e-grocery purchases are still underrepresented in the literature involving

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applied research to enhance urban logistics solutions for this economic sector [31–33], even though this market is currently growing in Brazil and research findings show that the wealthier the social strata, the greater the purchasing trends through e-food and e-grocery channels in this country [26].

Considering food supply in urban areas, accessibility in the food mile can be described as the ability of households or individuals to purchase food, which depends on income, food price, the location of food retailers and the possible connectivity among urban functions [34]. Hence, food can be affordable from an economic perspective but spatially inaccessible. This spatial accessibility can be measured with contour-based or cumulative indicators since they consider the spatial structure of the retailers and the distance between households and retailers [3,6,35]. These indicators allow the characterization of food accessibility and can subsidize better design and land-use planning regarding the spatial structure of retailers and, therefore, enhancing food security and the sustainability of food pickup and delivery in cities [32,36].

In this context, the main objective of this work is to analyze the differences in accessibility levels to food systems among potential consumers with disparate income considering last-mile events. For this, we present an exploratory analysis for Belo Horizonte, Brazil, based on accessibility measures that allow us to analyze the proximity of households to and from retailers (home deliveries and purchase trips).

This paper is composed of four main sections. This section is composed of a background review and an introduction to the thematic and research objectives. In section 2 we present the methodological approach, which results are presented and discussed in section 3. Finally, we make some final considerations in the last part of this work.

2. Data and Methods

This methodological approach results in combined transport and land-use perspective, gathering morphological aspects of the city (road network and establishments' location) as well as spatial socioeconomic and demographic attributes. We spatially matched the concentration of households from different income groups and the spatial structure of grocery retailers and foodservice facilities, in order to differentiate the food systems' accessibility across the city and among income groups.

To understand the accessibility levels concerning food systems in Belo Horizonte, we measured the distance between food retailers and households and spatially combined it with socio-economic and demographic variables. In Figure 1 we present the methodological approach adopted for this work, composed of four main steps: (i) data collection; (ii) indicators' definition; (iii) spatial pattern characterization; and (iv) food systems' spatial analysis.

2.1. Data Collection

Belo Horizonte is the sixth-largest urban area in Brazil, concerning population (2,5 million people), and has the fifth-largest Gross Domestic Product among Brazilian cities. Belo Horizonte has a territorial area of 331 square kilometers and 495 districts [37].

The retailers located in Belo Horizonte were categorized into two main groups: (i) grocery retailers or stores with predominant availability of groceries that were subcategorized as local markets, supermarkets, hypermarkets, and fresh food; (ii) food services or vendors that provide food ready to be consumed (the foodservice industry) that were also subcategorized as restaurants, snacks bars, cafeterias, and bakeries also entitled as "Ho.Re.Ca" sector [33].

Data regarding the location and facility area (in square meters) of food retailers were obtained from the municipal register of contributors (MRC) [38], with information on legal companies that carry out commercial activities in the municipality. The retailers' activities were assorted accordingly to the National Classification of Economic Activities (CNAE). The CNAE is a Brazilian classification system used to standardize the identification codes of the productive activity of businesses. The CNAE is similar to the NACE (European Nomenclature Générale des Activités Économiques dans les Communautés Européennes) and NAICS (North American Industrial Classification System). Socio-economic and demographic data were obtained from the last Brazilian census, performed by

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the Brazilian Institute of Geography and Statistics [39]. Network links data were retrieved from OpenStreetMap datasets [40].

Figure 1. Methodological approach.

2.2. *Indicators' definition*

Since we had various vector-based data presented in different spatial units, we decided to gather the data homogeneously. For that, we created hexagon bins of 350 meters of horizontal and vertical

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spacing and manipulated the variables in order to have all information spatially distributed in the hexagons. When the overlapping layers resulted in areas that were not spatially compatible, the composition of the hexagons was performed considering the proportion of overlaying area as weight. For that, we have used QGIS 3.6.1 from the QGIS project, R 3.6.2 and RStudio 1.2.1335.

The accessibility indicator considered in this work was the cumulative opportunity measure based on the network distance, taking into account the centroid of each bin. This indicator estimates the accessibility considering the number of facilities that can be reached within a threshold distance from households. Since we intended to analyze the accessibility by active transportation modes, within walkable and cyclable distances, we have considered a previous result for Belo Horizonte regarding the perception of citizens concerning maximum distances for trips to parcel lockers as a reference [41]. We have considered an average speed of 5 km/h for pedestrians [42] and 12.8 km/h for bicycles when cycling uphill at gradient 5.4% [43], since Belo Horizonte is a city built in mountainous terrain. Hence, we adopted two threshold distances to calculate the cumulative opportunity indicator: (i) 500 meters for pedestrians; and (ii) 1,000 meters for cyclers. We understand the limitations of this approach, since it does not consider competition effects, but the cumulative indicator is easy to communicate and assembles land-use and transportation attributes [44]. In equation 1 we present the calculation for the accessibility to food retailers, considering the number of facilities within a threshold. A_i is the accessibility for households located in bin *i*; O_j is the number of facilities in bin *j*; $f(C_{ij})$ is the weighting function where (C_{ij}) is the distance from *i* to *j*; and t_{ij} is the threshold in each computation.

$$A_i = \sum_{j=1}^{n} O_j f(C_{ij})$$

$$f(C_{ij}) = \begin{cases} 1 \; if \; C_{ij} \leq t_{ij} \\ 0 \; if \; C_{ij} > t_{ij} \end{cases} \tag{1}$$

To calculate the distances, we have built a network without direction restrictions since we intended to assess the accessibility to food systems in a non-motorized suitable distance. The distances were calculated considering the Dijkstra shortest path algorithm implemented through the Network Analysist of ArcGIS 10.3 [45].

The distance to the closest facility, based on the network distance counting as a reference to the centroid of each bin, was calculated to analyze the location of facilities for the distribution of food goods. For the spatial gap measure X_{ij}, between zones *i* and *j*, we used the same network considered for the cumulative opportunity measure.

To characterize the socio-economic and demographic attributes of Belo Horizonte, we have considered the population and the average monthly household income. Both variables were gathered in the hexagons. Also, considering home deliveries and pickups especially from the food purchases through e-commerce channels, we have calculated an index that represents the potential market for each bin. This index, named InPop, is the product between population and average monthly household income and can be considered as a proxy of the e-food market.

2.3. Spatial pattern characterization

To have a better understanding of the spatial distribution of the food retailers in Belo Horizonte, we have assessed the spatial pattern of the stores according to the method average nearest neighbor, considering the Manhattan distance as impedance [46]. This approach was applied for each retailer category as a first analysis of the spatial structure of food systems in the study area. We have also presented the location of food retailers through choropleth and cluster analysis maps (Anselin Global and Local Moran's I) [47–50]. Since we have a few bins that concentrate a significant number of stores compared to the average frequency, for both categories, for the choropleth maps we have generated classes considering the geometrical interval metrics.

The accessibility levels were also mapped considering grocery retailers and foodservice facilities and the thresholds determined. Both box maps and cluster analysis are presented.

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In addition, to represent the population characteristics from different economic strata, we have considered the population and the average monthly household income for each hexagon bin. We have represented each variable, including the InPop index, through choropleth box maps and Anselin Global and Local Moran's I cluster analysis to determine the respective spatial structure. To characterize the food systems' spatial structure, we have also presented box maps and cluster analysis for grocery retailers and foodservice facilities. A fixed-distance band radius of 2,300 meters and the inverse Manhattan distance were considered.

2.4. Food systems' spatial analysis

To differentiate areas and social groups considering the access to food goods, we performed a spatial analysis regarding two approaches: (i) spatial mismatch analysis; and (ii) sustainable food mile opportunities. The spatial analyses were performed in ArcGIS 10.3 from ESRI developer, the GeoDa software from The Center for Spatial Data Science of the University of Chicago, R 3.6.2 and QGIS 3.4, from the QGIS Project.

For the differentiation of groups considering the access to food (spatial mismatch analysis), we related the accessibility index with the population and the average household income. This analysis was developed through the computation of the population and income (quartiles) matching spatially: (i) frequency of stores in each bin for both food retailers' categories; and (ii) cumulative opportunity measure for both retailers' categories. To compute the relative proportion, the population within the quartiles was associated with the total population of the city and the income, to the average household monthly revenue.

To analyze sustainable opportunities for the food mile, we have spatially matched the InPop clustered bins (the potential market for e-food) with the accessibility levels. We calculated the percentage of the population served in the high-high InPop area, the average income, the average distance to the closest facility, the maximum distance to the closest facility and the average number of establishments within the thresholds. Besides the computation of distances and potential market, the area composed of the hexagons with superimposed layers represented the most suitable area where sustainable policy, designed to stimulate non-motorized purchase trips and collaborative delivery initiatives, such as crowd deliveries, would better succeed.

3. Results and Discussion

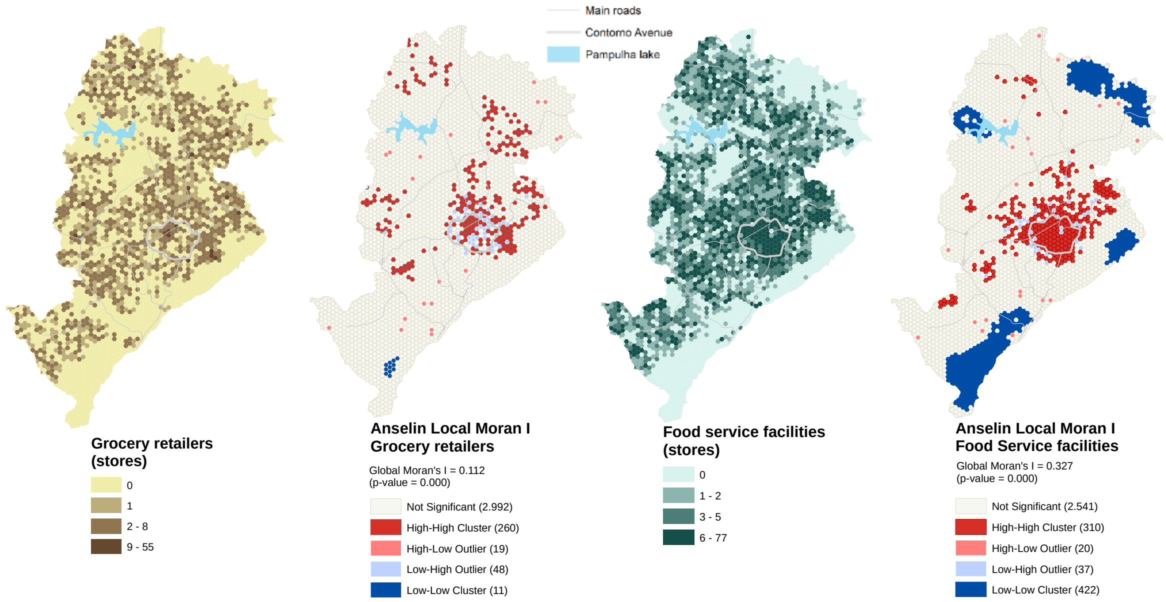
Considering that we have presented the data collection process and the description of attributes and variables in the methodology section, we here present the spatial pattern characterization of the population, respective income, potential market for food e-purchase and retailers' locations; and the spatial analysis of food system's accessibility for Belo Horizonte, Brazil.

The first analysis for the spatial pattern characterization was performed through the average nearest neighbor method, presented in Table 1. The only category that is not clustered within Belo Horizonte territory is Hypermarkets, which present a dispersed spatial structure. These stores are designed for consolidated purchases and are mostly accessed by individual motorized modes. Therefore, we have excluded this category from the analysis of the Groceries group since we are evaluating the sustainable distribution of food through active trips for the home delivery and pickup of food goods. From Table 1, we can also notice that the availability of stores concerning the foodservice group is higher than the one of grocery retailers.

In Figure 2 we present the choropleth and cluster maps for the location of grocery retailers (a,b) and foodservice facilities (c,d), respectively. We can understand from the stores' concentration, that Belo Horizonte still has concentrated urban functions in a Central Business District (CBD), but restaurants, snack bars, cafeterias, and hotels are even more concentrated in the originally planned area of the city. The CBD (within Contorno Avenue); Pampulha lake; and the main roads of the city are presented in the maps.

Table 1. Categories and Spatial Structure for Food Retailers in Belo Horizonte.

Group	Category	Number of retailers	Stores density (stores/km²)	Number of stores per capita (stores/1,000 inhabitants)	Spatial pattern	p-value
Food service	Restaurants	4,231	12.8	1.7	Clustered	0.00
	Cafes and bars	5,822	17.6	2.3	Clustered	0.00
Groceries	Bakeries	1,232	3.7	0.5	Clustered	0.00
	Local markets	2,111	6.4	0.8	Clustered	0.00
	Supermarkets	372	1.1	0.1	Clustered	0.00
	Hypermarkets	23	0.1	0.009	Dispersed	0.000057
	Fresh food	1,131	3.4	0.5	Clustered	0.00



(a) (b) (c) (d)

Figure 2. Choropleth map and spatial cluster analysis for grocery retailers (a,b); and foodservice facilities (c,d).

In Figures 3 and 4 we present the choropleth and the cluster maps for the accessibility index determined for grocery retailers and food system facilities, respectively, considering both distance thresholds 500m (a,b) and 1,000m (c,d). The choropleth maps were categorized in quartiles. For both food categories, the Global Moran's I index increases with the threshold, which was expected, since more establishments are computed for each distance limit. Belo Horizonte presents some natural barriers: (i) Curral mountain range, in the southeast of the city; (ii) Pampulha lake, in the northwest; and (iii) the confluence of the river basins Onça, Arruda and Velhas in the northeast. These areas are coincident with those of low-low clusters, meaning that low accessibility bins are gathered among low accessibility neighborhood. The CBD is strongly represented in the cluster analysis for both food retailers' groups, but for grocery stores, there are other high-high cluster areas besides the central one. This indicates that more areas of the city area have better access to grocery goods compared to the access to Ho.Re.Ca food services.

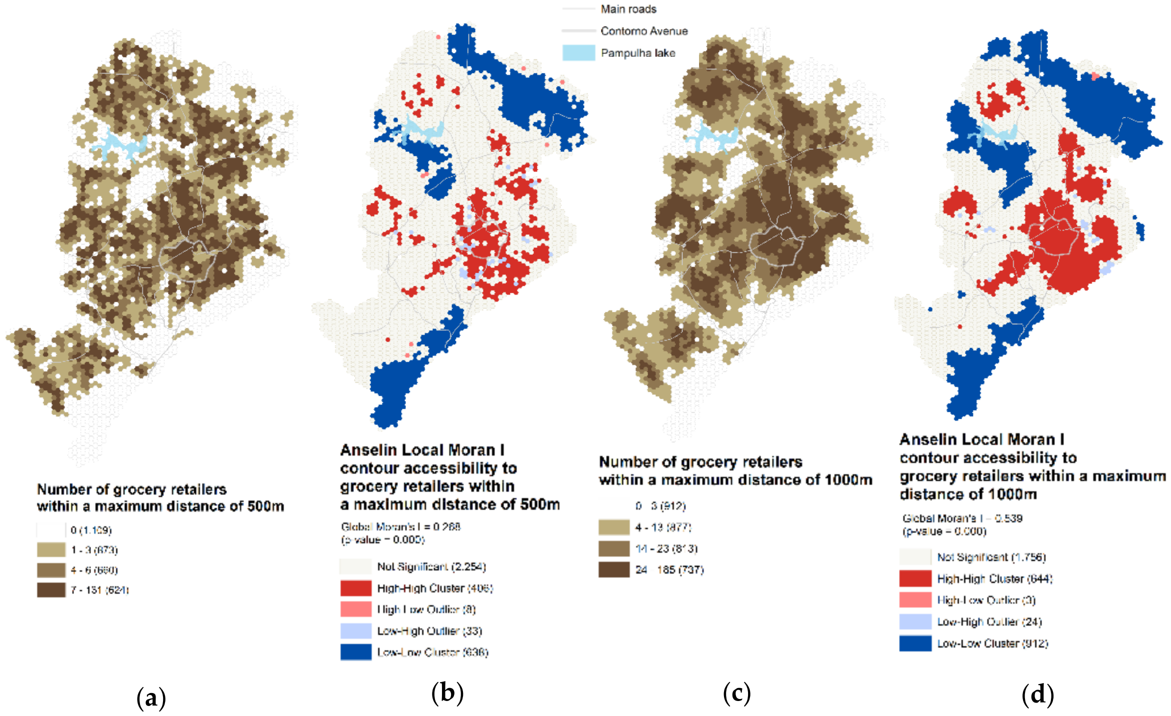


Figure 3. Cumulative opportunity measure (choropleth and cluster maps) for grocery retailers: (a,b) 500 meter-threshold; and (c,d) 1,000 meter-threshold

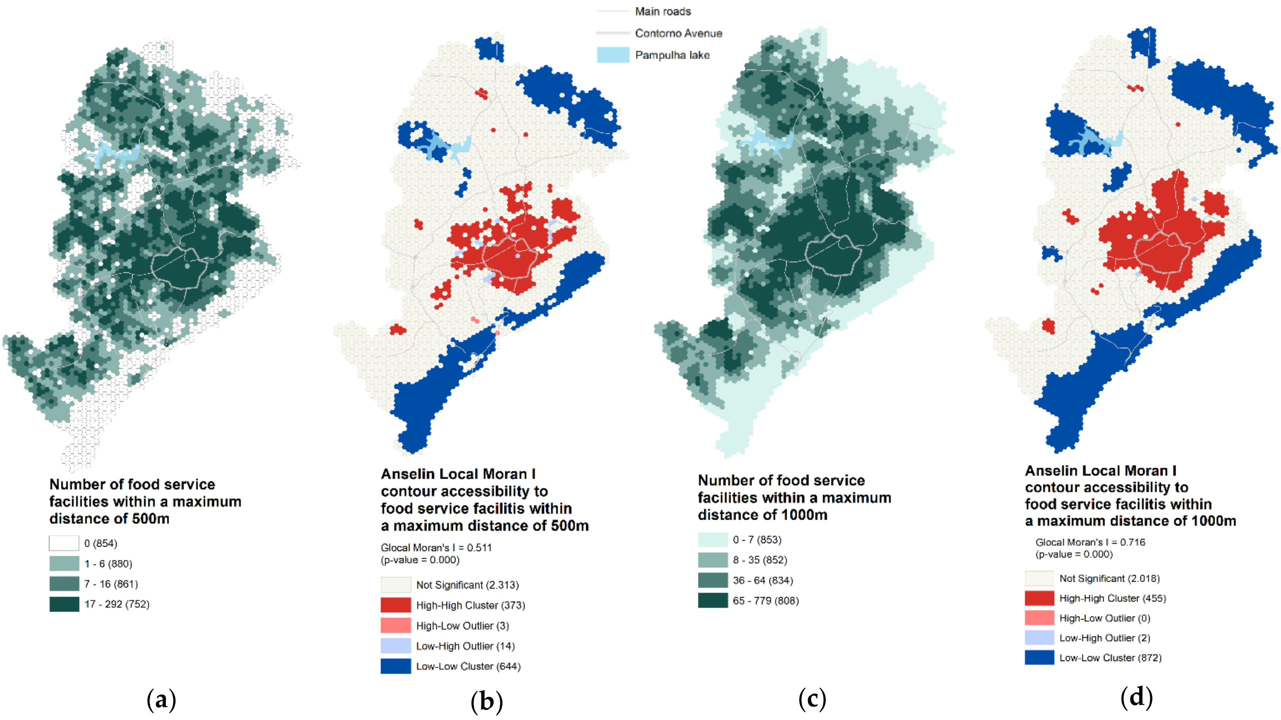


Figure 4. Cumulative opportunity measure (choropleth and cluster maps) for foodservice facilities: (a,b) 500 meter-threshold; and (c,d) 1,000 meter-threshold

In Figure 5 we present the choropleth and cluster maps for the population (a,b) and for average monthly household income (c,d). The same representation is presented for the InPop index (Figure 6). There is only one region of the city that spatially concentrates high-income population, which includes the central area and expands to the south-eastern boundary of the municipality. Belo Horizonte is a city that was originally planned within the area delimited by Contorno Avenue. The idealizers of the city imagined that it would remain contained within the limits of this Avenue, but the urbanized area expanded to the borders of the county in the early stages of its development.

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Today, Belo Horizonte is a fully urbanized municipality. The cluster analysis (Anselin Local Moran I), as well as the Global Moran's I index for population, income and InPop measure, indicate a spatially concentrated pattern.

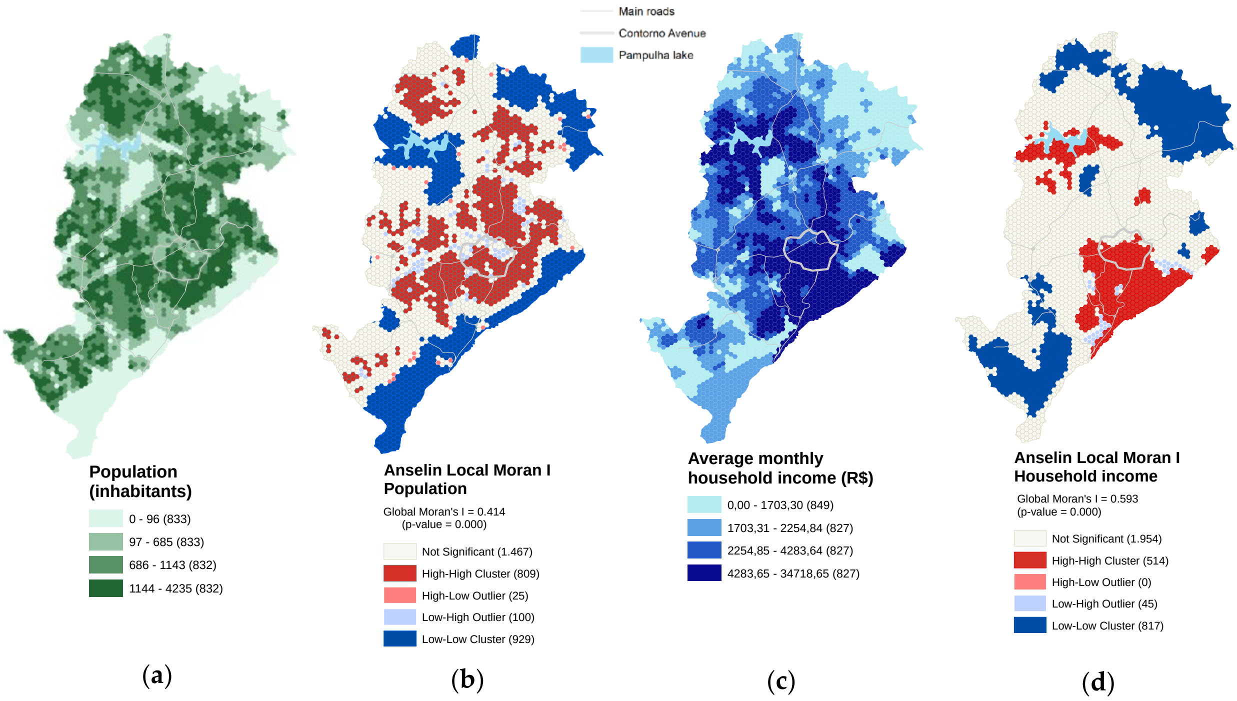

Figure 5. Choropleth map and spatial cluster analysis for: population (a,b); and income (c,d)

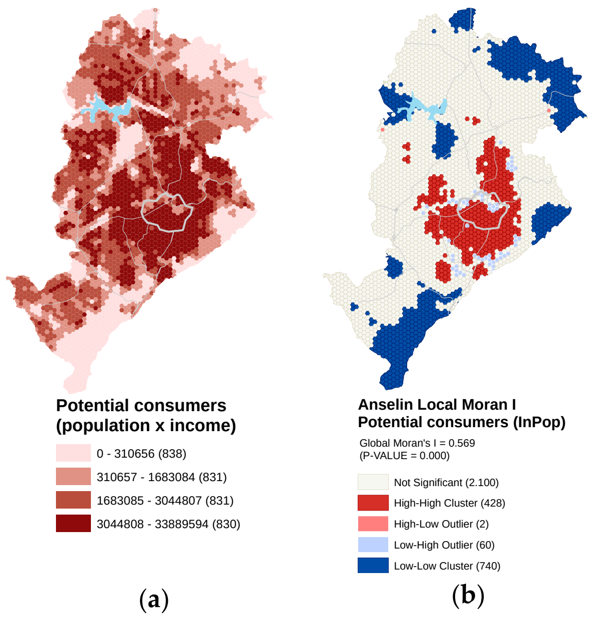

Figure 6. Choropleth map (a) and spatial cluster analysis (b) for the InPop index.

To analyze the spatial mismatch, we have computed the proportion of population and income with the spatial structure of the food systems, presented in (i) Figure 7 for the frequency of grocery retailers (a) and foodservice facilities (b); (ii) Figure 8 for the accessibility to food purchase opportunities for grocery with a 500-meter threshold (a) and a 1,000-meter threshold; and (iii) Figure 9 for the accessibility to food services within 500 and 1,000 meters from the households.

From Figure 7a, although the proportion of the population in the first three classes does not differ greatly, income decreases with the increase in the number of grocery stores in each hexagon. For the upper quartile, there is only a little more than 1% of the population served and a small increase

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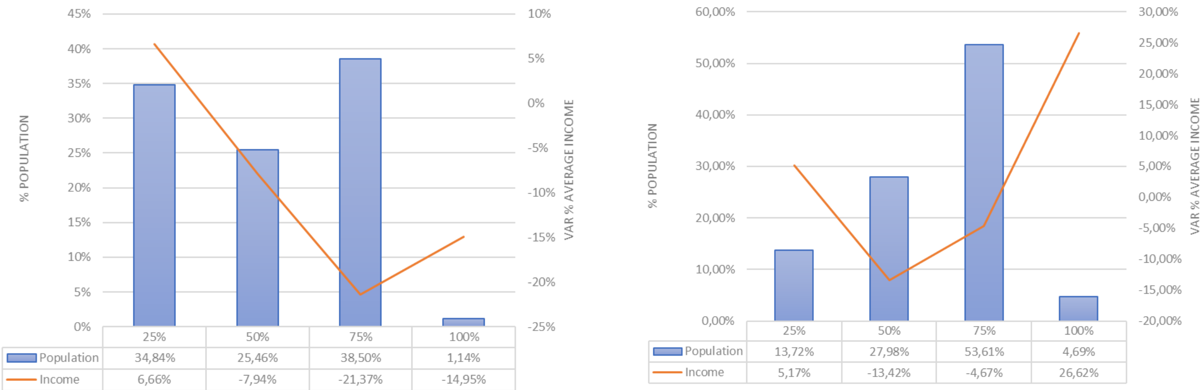
in the average income, but this population still has a lower average income than the average of the city of Belo Horizonte. The population with a higher average income than the municipal one is concentrated only in the lower quartile. This fact indicates that the wealthier population count on motorized trips to receive or to collect grocery goods, unlike the lower-income population.

When we consider the distribution of the population and the respective income in the quartiles regarding the concentration of foodservice facilities (7b), there is also a concentration of the population in the first three classes, but with an increase in the number of citizens located in bins with a higher concentration of facilities. The class with the highest concentration of this category of establishments represents slightly less than 5% of the population. However, in this case, the population with higher average income compared to the average of the city is either concentrated in the first class or the last one. This phenomenon highlights the concentration of Ho.Re.Ca establishments in areas with higher income and, once again, that the high-income population relies on motorized displacement to purchase and deliver prepared food.

If we consider the accessibility to grocery stores (Figure 8), the higher the income, the greater the accessibility. Still, the higher the spatial threshold considered, the greater the inequalities.



(a) (b)

Figure 7. Spatial mismatch considering the frequency of (a) grocery retailers and (b) food service facilities

(a) (b)

Figure 8. Spatial mismatch considering the accessibility to grocery retailers within 500 meters (a) and 1,000 meters (b)

Considering the accessibility to foodservice facilities (Figure 9), the upper quartile presents the highest concentration of low-income populations and once again the pattern of the high-income population is concentrated in the less accessible area and in the area with greater accessibility to food prepared for consumption.

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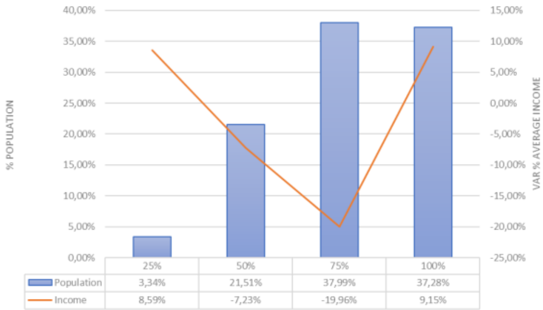
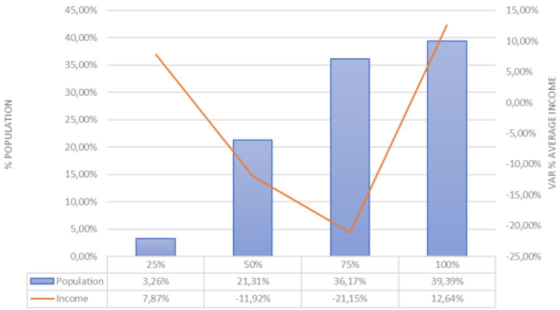


(**a**)



(**b**)

Figure 9. Spatial mismatch considering the accessibility to foodservice facilities within 500 meters (a) and 1,000 meters (b)

Finally, concerning the last methodological step (sustainable food mile opportunity), we spatially matched the clustered potential market for e-purchasing (high-high InPop) and the intersecting bins considering the accessibility. The overlaying area, composed of 430 hexagon bins, represents 25% of the city's population with an average household monthly income almost twice the average value for Belo Horizonte. The average distance to the closest retailer is less than 500 meters, setting a walking distance for both categories of establishments. The distance to the nearest retailer is considered a walking distance for foodservice facilities. Also, the average number of stores within the 500 and 1000 meter thresholds is equivalent to the 25% bins with the best accessibility in the city. The results, which are adequate for non-motorized delivery and pickup trips, are presented in Table 2. These results corroborate the spatial structure analysis, showing that Ho.Re.Ca stores are more concentrated in the CBD, where most of the overlaid bins are located. The spatial concentration of the high-income population is important because it represents the most suitable potential market for e-food delivery services [26].

Table 2. Attributes to analyze suitable areas for non-motorized deliveries and purchase trips for food retailers in Belo Horizonte.

Attribute	Grocery retailers	Foodservice facilities
Population (% out of municipality)	599,217 (25%)	
Income (4.50 Brazilian real ~ 1 US$)	7,274.08	
Average distance to the closest facility (m)	263	147
Maximum distance to the closest facility (m)	1,483	1,071
The average number of facilities within a 500-meter threshold	6.57	87.75
The average number of facilities within a 1000-meter threshold	28.44	114.07

4. Conclusions

In this paper, we present an exploratory analysis of the accessibility of food systems in an important Brazilian city. The methodological approach proposed was designed to allow the analysis of the last-mile delivery of food to consumers regarding the transportation system and land use. The results indicate that there is a significant spatial concentration of food retailers in Belo Horizonte. This concentration is identified both in the spatial structure analysis and through the accessibility levels to food retailers. The areas with higher accessibility levels, in a comparative analysis, are mostly coincident with areas of clusters of high-income populations. Also, the food accessibility levels vary within the territory and might indicate that the locational decision for food retailers might have considered profitability issues. Nevertheless, with the growth in e-commerce as a food and grocery channel, the distance to consumers must be considered as impedance for retailers to perform their activity through this channel. Equally delivery and pickup of purchased food in stores need to be efficient both for the consumer and the retailer and should not increment the externalities of the urban freight distribution, such as congestion levels, emission of pollutants, among others. Considering that,

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public policy can be directed to land use regulation in order to stimulate more equity regarding access to food retailers and, therefore, more efficiency in the last mile and the active participation of the consumer in the last mile delivery.

Even though sustainable mobility and efficiency have been the main issues while planning urban distribution systems, accessibility is one approach that can help the development of sustainable and efficient food supply systems. We hereby present a methodological approach that, combines the concept of accessibility considering land-use and transportation matters, and enhances the literature regarding food systems' analysis, city logistics solutions and equity issues. Cumulative accessibility to consumers from retailers can be a guideline towards a public policy to promote non-motorized deliveries and crowd shipping. The introduction of the accessibility approach as a measure of equity and efficiency for the last mile to food supply might result in suitable planning strategies for the food distribution, concerning the stakeholders' different requirements. Also, this approach can subsidize the decision-making on urban structural elements, such as the land use regulation for food retailers with greater assertiveness and more spatial equality. To our knowledge, this kind of analysis has not yet been explored in the literature or in practical approaches and, therefore, it brings a phenomenological contribution through the characterization of the food systems' accessibility in Belo Horizonte.

Concerning further investigation, we suggest: (i) the enhancement of the accessibility analysis with other retail models and more detailed impedance function; (ii) the inclusion of local consumption habits in the analysis; and (iii) the analysis should also consider the assessment of the environmental, economic and social impacts of different accessibility levels to food, including the assessment of food deserts. Consumers' preferences should then be related to the population characteristics and the access levels to the food retailing system.

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