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The effects of informality on socio-spatial inequalities in accessibility to job opportunities: evidence from Fortaleza, Brazil

Davi Garcia Lopes Pinto^{a,*}
Carlos Felipe Grangeiro Loureiro^a
Francelino Franco Leite de Matos Sousa^b
Benjamin Motte-Baumvol^c

^aDepartment of Transport Engineering, Federal University of Ceara, Campus do Pici - Bloco 703 - CEP 60.440-900, Fortaleza, CE – Brazil

^bNUTEC, Centro Universitario Christus, Fortaleza, Brazil

^cUMR THEMA, CNRS, Université Bourgogne Franche-Comté, France

*Corresponding Author

E-mail addresses: davi.garcia@det.ufc.br (D. G. L. Pinto), felipe@det.ufc.br (C. F. G. Loureiro), francolms@gmail.com (F. F. L. M. Sousa), benjamin.motte-baumvol@u-bourgogne.fr (B. Motte-Baumvol)

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ABSTRACT

Unequal access to job opportunities among different socioeconomic groups can be a result from the land-use spatial mismatch problem, especially for peripheralized individuals in low-income groups. This type of spatial pattern is commonly observed in large cities of the Global South, that tend to present a highly concentric distribution of formal jobs. In the last decades, these cities have also experienced growth in informal jobs, which are normally more dispersed across the territory. Therefore, failing to include informal jobs in analyses of access to employment may bias conclusions about the degree of socio-spatial inequalities in accessibility to job opportunities. The main purpose of this paper is, thus, to analyze the effects of informality on these inequalities, using the city of Fortaleza, Brazil, as a representative case study of large cities in the Global South. In addition, the paper makes a methodological contribution by comparing two approaches for estimating the spatial distribution of formal and informal jobs, aiming to validate an alternative method based on official socioeconomic data from annually available surveys, to be applied whenever a recent Household Travel Survey (HTS) is not available. On this secondary goal, it was observed that, although the alternative method provided a more concentrated distribution of informal jobs than the HTS method, it can be a valuable tool for analysis in the absence of more specific

employment data. Regarding the main findings, the case study's empirical evidence showed that incorporating informal jobs into the analyses lessens the problem of socio-spatial inequalities in job accessibility, reinforcing the need to consider informality especially in large developing cities with similar socio-spatial patterns to Fortaleza.

KEYWORDS

Socio-spatial ;

inequalities

Accessibility

Spatial mismatch

Informal employment

Household travel

survey

1. Introduction

Throughout most of the 20th century, Brazilian cities exhibited a pattern of large-scale residential segregation: high-income groups were concentrated in their central regions, where most economic activities and job opportunities were located, while low-income population settled mainly in distant and poorly serviced peripheral areas (Moreno-Monroy and Ramos, 2021; Andrade et al., 2020). The urbanization pattern described has led to a sharp divide between peripheral areas and the city center, yielding a form of land-use spatial mismatch (Kain, 1968) that could permanently threaten access to employment for low-income individuals, as well as their accessibility to everyday activities and resources (Curtis and Scheurer, 2010; Smith et al., 2020). Also, in the Brazilian context, these poor populations have limited access to motorized modes (Motte-Baumvol et al., 2017) which, alongside the shortage of public transport infrastructure, often leads to longer commuting times for the residents of peripheral areas. This gives rise to socio-spatial inequalities in accessibility to jobs, a critical urban and metropolitan problem in Brazil (Slovic et al., 2019; Pereira et al., 2019a; Boisjoly et al., 2020; Lima et al., 2021).

Although this phenomenon has been examined in a range of studies in the context of large metropolises of the Global South, few studies have taken into account informal jobs (Boisjoly et al., 2017), which represent 40 to 60% of metropolitan employment in Brazil (Hallak

Neto et al. 2012; Ramos and Ferreira, 2006). Informal jobs are more often held by low-income individuals (Henley et al., 2009), they are more widely scattered across the metropolitan area, and they tend to generate shorter commuting times and distances (Motte et al., 2016). Accordingly, it has been suggested that informal jobs are relatively more accessible and could potentially mitigate spatial mismatch (Motte-Baumvol et al., 2017), consequently reducing the socio-spatial inequalities in accessibility to jobs.

However, there is a lack of availability of official data about the spatial distribution of informal jobs in Brazilian cities. The *Relações Anuais de Informações Sociais* (RAIS) database, compiled by the Brazilian Ministry of Labor and Employment, annually accounts for information on formal jobs and enterprises in Brazil. On the other hand, the *Pesquisa Nacional por Amostra de Domicílios Contínua* (PNAD-C), a survey organized by the *Instituto Brasileiro de Geografia e Estatística* (IBGE), provides a sample with information on status of employment, formal and informal, at the municipality level of large Brazilian cities, but no information about where these activities take place. An alternative to estimate the location of jobs in Brazilian metropolises is to use a Household Travel Survey (HTS), which usually accounts for disaggregated information on formal and informal jobs at the traffic zone level. The main limitation of this type of survey, however, is that HTSs are normally conducted over 10 to 20-year time intervals in most Brazilian large cities, and sample numbers, usually 1-2% of households, may not be representative of the spatial distribution of jobs.

In this context, this study aims to evaluate the effects of informality on land-use spatial mismatch and, consequently, on socio-spatial inequalities in accessibility to jobs, assuming Fortaleza, Brazil, as a representative case study of large cities in the Global South. To achieve its main goal, first existing studies of segregation patterns and spatial mismatch in Brazilian cities were reviewed (Section 2). Section 3 makes the case for focusing on both formal and informal jobs, with previous contributions in this area being summarized. Section 4 presents the methodological approach for spatially distributing formal and informal jobs, including an alternative method for spatializing jobs in the context of large Brazilian cities in the absence of a recent HTS. Section 5 analyzes the configuration of the jobs-population spatial mismatch problem in Fortaleza; based on the case study's results it is also discussed the validity of the proposed alternative method to distribute jobs using official socioeconomic data from annually available surveys. Section 6 then discusses the evidence concerning the effects of informality on socio-spatial inequalities in accessibility to job opportunities, while Section 7 draws the main conclusions and some lessons that can be learnt for future studies.

2. Spatial mismatch and socio-spatial inequalities in accessibility to jobs

Latin American cities have experienced a rapid and chaotic process of urban sprawl, associated with strong demographic growth in peripheral areas. In the 1970s, migration of low-income rural families in search of better opportunities increased poverty and inequality within cities (Ribeiro and Lago, 1995; Rodríguez Vignoli, 2008). Accordingly, as access to housing in the city center has become more costly, low-income groups have settled mainly in peripheral areas, developing a large-scale segregation pattern of urbanization (Sabatini, 2006).

In most Brazilian cities this large-scale segregation model has led to a deep divide between these areas and the city center, where most jobs, and most cultural and economic opportunities, are concentrated (Fernández-Maldonado et al., 2014). This imbalance between residential locations and the geographic concentration of job opportunities, combined with low levels of automobile access and the poor quality of public transport, entails unequal conditions, especially for low-income individuals, that are often described in the literature as “spatial mismatch” (Kain, 1968).

Theories of spatial mismatch postulate that the poor have low levels of access to employment, reduced activity and higher unemployment rates, when they live in neighborhoods that are deprived of jobs and with poor access to metropolitan employment centers (Holzer, 1991; Preston and McLafferty, 1999). Such a phenomenon was first studied in the early 1960s, as suburbanization occurred in large North American cities and was characterized by the sprawling of high-income households and jobs into the suburbs, creating a mismatch between the residential location of low-income groups and job opportunities (Gobillon et al., 2007). In recent decades, many empirical results have pointed out that the geographical dimension, associated with transport issues, can explain the unequal access to employment for certain populations such as single mothers, immigrants, minorities, and low-income workers (Wang, 2003). Also, more recent studies have shown that the issue of low accessibility to employment is a significant factor in determining inequalities (Parks, 2004; Johnson, 2006; Korsu and Wenglenski, 2010).

In Brazilian cities land-use spatial mismatch manifests itself differently from the trends observed in North America: jobs are mainly concentrated in the city center, with socioeconomic minorities being located predominantly in the periphery. Barufi and Haddad (2017) have investigated the impacts of jobs-population spatial mismatch in different Brazilian metropolitan areas, demonstrating a clear correlation between income and accessibility levels to jobs, which

is stronger in larger cities and has a more detrimental effect for low-skilled workers. Pereira et al. (2019b) demonstrate that, despite substantial investments in Rio de Janeiro's transport system due to the 2014 Football World Cup and the 2016 Olympic Games, average access by public transport to jobs and public high schools has decreased over the past few years. Nonetheless, wealthier areas had on average small but statistically significant higher gains in access to schools and job opportunities than poorer areas, fostering socio-spatial inequalities in access to opportunities.

Despite the contributions of the investigations mentioned above, those studies have not addressed the relationship between accessibility and informal jobs. The latter account for a large share of the labor market in developing countries and should be considered when estimating accessibility levels.

3. Informal jobs, land-use spatial mismatch and accessibility inequalities

Most investigations of land-use spatial mismatch ignore informal jobs, although these play a particularly important role in developing countries. According to PNAD-C 2019, informal jobs, which are mainly held by individuals with the lowest incomes and qualifications, accounted for approximately 41% of jobs in Brazil in 2019 (IBGE, 2019a). Informal workers are less skilled, younger and less experienced (Gong and van Soest, 2002; Marcouiller et al., 1997). In addition, some economic sectors are characterized by higher rates of informality, such as agriculture, mining, construction, or non-specialized services (Hallak Neto et al., 2012; Motte et al., 2016; Ramos and Ferreira, 2006). Besides, informal jobs are less well paid (Bargain and Kwenda, 2011; Jonasson, 2011) and do not offer social security coverage or subsidies for transport. As a result, informal workers are less able to afford transportation costs and they tend to have on average much shorter commuting distances (Motte et al., 2016; Motte-Baumvol et al., 2017). According to Boisjoly et al. (2017) and Hernandez and Titheridge (2016), low accessibility levels might contribute to higher rates of informality in the labor market.

Although informality plays an important role in the job markets of developing countries, the difference in accessibility to formal and informal jobs has received little attention in the literature (Abane, 1993; Mitra, 2005). Previous investigations have demonstrated that informal jobs tend to be more dispersed in metropolitan areas than formal sector jobs (Motte et al., 2016). Informal employment rates are higher in peripheral areas and/or poor neighborhoods, not only because workers have to pay for the entire cost of transport (which does not apply in the formal sector), but also because of the precarious nature and low remuneration of informal jobs

(Bargain and Kwenda, 2011; Motte et al., 2016; Boisjoly et al., 2017).

Motte et al. (2016) report significant differences between travel times for individuals employed formally and informally in Rio de Janeiro. Their study points out that travel times of informal workers are shorter, with the exception of domestic workers (such as housekeepers), who work predominantly in the city core, where most wealthier households are located. On a similar note, Abane (1993) and Mitra (2005) demonstrate that many informal workers, particularly female traders, prefer to live close to their business in order to reduce commuting costs and distances. Therefore, we argue that the inclusion of informal jobs in accessibility measures is necessary to grasp the full array and complexity of socio-spatial inequalities in developing countries. Moreover, we hypothesize that including informal jobs in surveys could potentially reduce the perception of the home-work spatial mismatch, and consequently of socio-spatial inequalities in accessibility to jobs, as they tend to be spatially more scattered.

4. Methodology

4.1. Study area: Fortaleza, Brazil

Fortaleza is located in the Northeast region of Brazil and is the country's fifth largest city, with a population of 2.7 million people (IBGE, 2021) (Fig. 1). Like most Brazilian metropolises, it is characterized by a high concentration of economic activities in the city center and a peripheralization of the poor population, resulting in the occurrence of a land-use spatial mismatch problem, a phenomenon that has been aggravated in the last two decades (Andrade et al., 2020; Lima et al., 2021). In terms of transport infrastructure, the city is mainly dependent on a bus network system, which serves the majority of the travel demand, and three radial metro lines. In the last few years, major investments have been made in the construction of BRT corridors, dedicated bus lanes, and a new metro line.

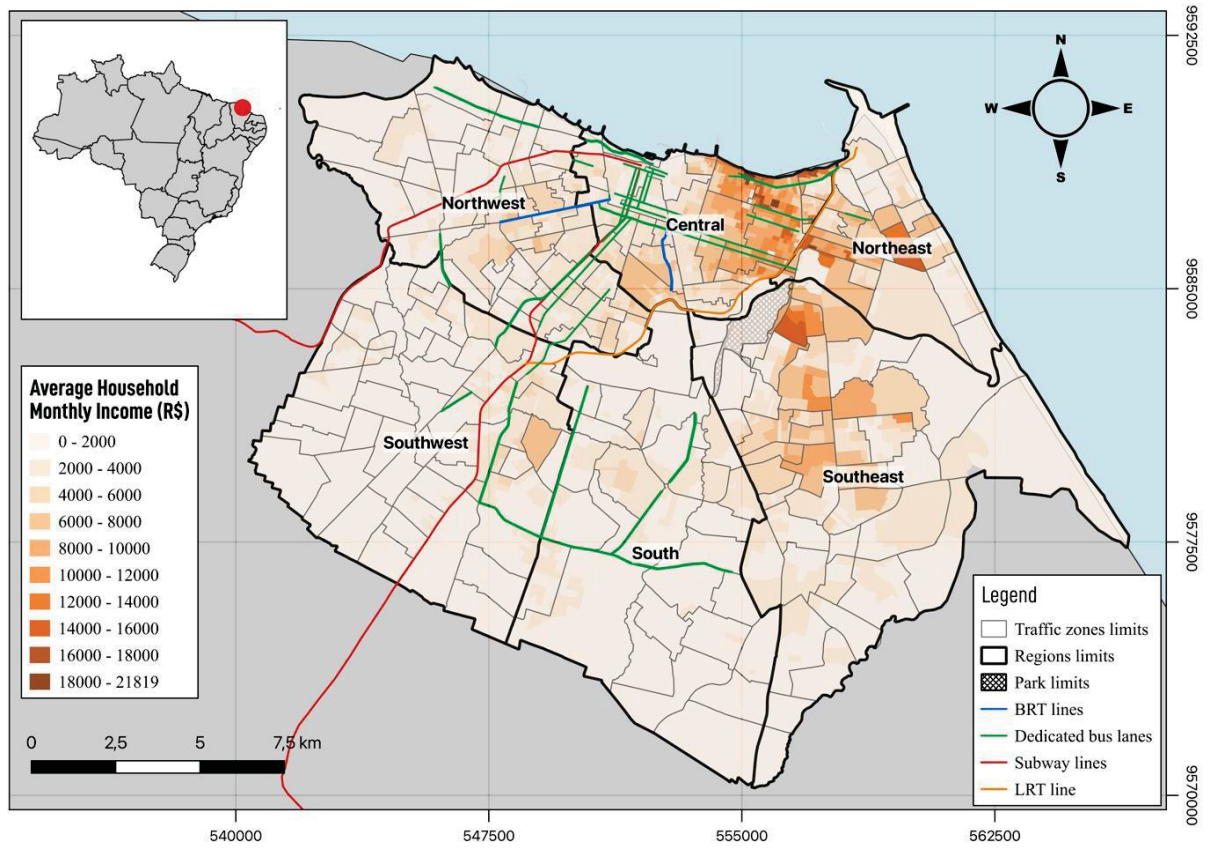


Fig. 1. Main public transit network, TAZ zoning system, and income distribution in Fortaleza

4.2. Methodological approaches for spatializing jobs

The spatial distributions of formal and informal jobs were estimated at the level of the Traffic Analysis Zones - TAZs (Fig. 1), which are the spatial unit of analysis in this case study. Two different approaches were conducted. The first and most reliable, named here the “HTS method”, considered the job distribution obtained from the Fortaleza 2019 HTS. A similar approach was used by Motte et al. (2016) to estimate the location of formal and informal jobs in Rio de Janeiro. However, household OD (origin-destination) surveys have their limitations, especially related to periodicity, usually from 10 to 20 years in Brazilian metropolises, and the representativeness of their samples, which is based on places of residence and not on places of work. Such limitations, among other issues, may restrict the analysis to the period in which the survey was conducted. For this reason, an alternative approach was conceived and tested, here named the “Alternative method”, combining three Brazilian Government databases: RAIS (Ministério do Trabalho e Emprego, 2019), which contains the exact address (ZIP code) of all formal companies and the number of employees registered in each company; PNAD-C (IBGE, 2019a), which provides a sample of the total number of formal and informal workers at the city level; and POF (Family Budget Survey) (IBGE, 2019b), which provides information on the consumption patterns of goods and services of a sample of households at the city level. The methodological hypothesis to be tested is that their yearly basis availability could potentially make it possible to carry out this type of analysis when recent HTS data are not available.

As mentioned, the HTS method was based on the Fortaleza 2019 HTS, which surveyed 66,300 individuals between June 2018 and October 2019, from a sample of 23,700 households. The questionnaire inquired about the socioeconomic characteristics of the individuals, the household and its dwelling, and about all the trips made the day before the survey. Approximately 40% of the surveyed individuals were engaged in some kind of job activity whose category and location, given by an ad hoc division of the area covered into 253 TAZs, could be determined.

The Alternative method, in turn, combined three official Brazilian socioeconomic annual databases: PNAD-C, RAIS, and POF. PNAD-C 2019 provided the total of employees in the city in each sector of activity (formal or informal) and employment status (employee, houseworker, self-employed, or other). A total of 4,905 households in Fortaleza, representing 0.2% of the total, were interviewed. By expanding the sample, it can be estimated that Fortaleza has approximately 1.2 million employees, including formal (60%) and informal (40%) workers. With the information of the total number of jobs in each category, we defined some rules, based

on RAIS 2019 and POF 2019, to spatialize them across TAZs. From RAIS 2019, it was accounted 781,416 formal workers with 87,772 companies, which were geolocated (based on ZIP code information) within each TAZ. From POF 2019, it was obtained socioeconomic characteristics of the households that hired domestic services. The rules are shown in [Table 1](#).

Sector of activity	Employment status	Distribution of out-of-home jobs	Distribution of in-home jobs
Formal	Employee	According to the location of all active formal jobs in private companies (RAIS 2019)	According to residential location of individuals with the same types of jobs (Census Sample 2010)
	Houseworker	According to the location of all households that hired domestic services (POF 2019)	
	Self-employed	According to the location of all private companies with at least one active employee (RAIS 2019)	
	Other	According to the location of all active formal jobs in public institutions (RAIS 2019)	
Informal	Employee	According to the location of all active formal jobs in private companies with up to 5 active employees (RAIS 2019)	
	Houseworker	According to the location of all households that hired domestic services (POF 2019)	
	Self-employed	According to the location of all private companies with up to 5 active employees (RAIS 2019)	
	Other	According to the location of all private companies with no active employee (RAIS 2019)	

Table 1. Alternative method: Jobs distribution and representation according to employment status

As summarized in [Table 1](#), all formal and informal jobs were categorized into four groups: employee, houseworker, self-employed, and other. The purpose of this classification is to identify possible differences in accessibility levels among these categories, as already demonstrated by Motte et al. (2016) for houseworkers in Rio de Janeiro. For all categories, jobs carried out at home (8%) were distributed proportionally to the distribution of households of individuals with the same types of employment in the 2010 Census household sample, which subdivided Fortaleza into 55 Weighting Areas (WA). Once the employment totals in each WA were defined, they were disaggregated over the 253 TAZs ([Fig. 1](#)), which are spatial units subdivisions of the WAs, proportionally to the built-up area of residential use in each TAZ (SEFIN, 2019).

For out-of-home jobs, different rules were considered for each category, mostly based on common criteria found in the literature to differentiate between formal and informal jobs (Henley et al., 2009; Maloney, 2004; Galli and Kucera, 2004). Formal jobs classified as

“employee”, “self-employed”, and “other” were spatialized using the RAIS database,

proportionally to the distribution of all jobs in private institutions, all companies with at least one active employee, and all active jobs in public institutions, respectively. In the same way, informal jobs in the “employee”, “self-employed” and “other” categories were also distributed based on data from RAIS 2019. However, for the spatialization of the first two categories consideration was given respectively to the distribution of jobs in private institutions with up to 5 active employees, as well as to the distribution of companies with no more than 5 active employees. These thresholds were determined based on the works of Maloney (2004) and Henley et al. (2009) who recognize that informal workers tend to be employed in small formal companies.

Finally, both formal and informal workers in the “houseworker” category were spatially distributed according to the location of households that hired some type of domestic service over the year 2019. From POF, it was obtained that 53% of households that hired domestic services were in the 10th income decile (high-income group), 10% were below the 6th income decile (low-income group), and the other 37% were in between the 7th and 9th income deciles. Therefore, jobs in the “houseworker” category were distributed proportionally to the location of households in each income group, obtained from the 2010 Census and aggregated to the TAZ level.

4.3. Measuring spatial mismatch conditions and accessibility levels

According to the RAIS database, in 2019 slightly more than 50% of all formal jobs in Fortaleza were concentrated in the Central region of the city (Fig. 1), while another 20% were located in its eastern side (Northeast and Southeast regions). Nonetheless, the poor population, here defined as individuals in the first six deciles of household income, were mostly located in the western side of the city (Northwest and Southwest regions). This situation shows how critical the land-use spatial mismatch problem in Fortaleza can be, especially for the poor. To quantitatively measure the spatial mismatch, the Dissimilarity Index (Cortese et al., 1976) was used, in this case measuring the percentage of individuals who would have to change traffic zone, or region, to reach their jobs. It ranges from 0 (perfect balance) to 100 (perfect imbalance) and is formulated as Eq. 1; the higher the index value, the greater the spatial mismatch problem.

$$D^g = 100 * \left[\sum_i \left(\frac{Ind^g}{Ind^g} - \frac{J^c}{J^c} \right) \right] \quad (1)$$

Where:

D^g is the dissimilarity index for individuals of group g

Ind_i^g is the total of individuals of group g in zone/region i

J_i^c is the total of jobs of category c in zone/region i

The dissimilarity index was calculated for the 253 traffic zones and six regions of Fortaleza (Fig. 1), first considering only formal jobs, and then including informal jobs in the calculation, to measure their impact on the spatial mismatch problem. The individuals were grouped by their household income decile.

Finally, the accessibility levels were quantified using a cumulative-opportunity measure, representing the number of jobs of a given category c that can be reached within the time threshold t by the mode of transportation m , as shown by the formulation in Eq. 2:

$$A_i^g = \frac{\sum_{j=1}^n J_j^c \cdot f(c_{ij})}{\sum_{j=1}^n J_j^c} \quad (2)$$

Where:

A_i^g is the accessibility of zone i for individuals of group g

J_j^c is the total of jobs of category c in zone j

c_{ij} is the travel time between zones i and j

$f(c_{ij}) = 1$ if $c_{ij} \leq t_{lim}$ and $f(c_{ij}) = 0$ if $c_{ij} > t_{lim}$

t_{lim} is the travel time threshold from i to j

Travel-time matrices between all pairs of zone centroids were estimated using the Google's Distance Matrix API, applying General Transit Feed Specification (GTFS) information for public transport trips, and real-time traffic on road network for car trips. These matrices were calculated for the morning weekday peak-hour, identified as 7-8am in Fortaleza. Therefore, departure time was set to 7am. Given that the Fortaleza 2019 HTS registered an average travel time to work of 27 minutes by car and 52 minutes by public transport, accessibility levels by both modes of transportation were calculated considering time thresholds of 30 and 60 minutes and the results compared. We recognize the limitations with the use of

these time thresholds and the choice of a peak-hour time window, related respectively to the

boundary and aggregation effects of MTUP (Modifiable Temporal Unit Problem), since conclusions of accessibility analyses involving equity issues may be very sensitive to both issues (Pereira, 2019). Other limitations are that it assumes all destinations being equally desirable, and that it ignores competition effects or monetary costs of travel (Geurs and van Wee, 2004).

4.4. Representation of socio-spatial inequalities in accessibility to job opportunities

The comparison of job accessibility levels for high- and low-income individuals has been guided by equity principles (Martens, 2016; Van Wee and Geurs, 2011), considering an egalitarian perspective, where everyone should be treated equally so as to reduce or even eliminate differences (Meyer and Roser, 2017). In this sense, following the typology proposed by Garcia et al. (2018), problems of unequal, inequitable, and unsuitable distributions of urban accessibility were analyzed by considering the spatial, social, and transport mode dimensions, respectively. Since our purpose is solely to represent socio-spatial inequalities in access to formal and informal jobs, we based our analyses on the premise that, in the Brazilian and most developing countries' context, the wealthiest population (individuals in the highest decile of household income) consider mostly individual motorized modes in their journey to work. This premise is supported by the fact that over 75% of the wealthiest adult individuals in Fortaleza make their work trips using cars or motorcycles, according to the Fortaleza 2019 HTS. Thus, their perceived accessibility levels (Pot et al., 2021) should be better represented on the road network. Conversely, as a mean to actually reflect the utmost condition of social inequalities in accessibility to employment, the poor population, predominantly dependent on public transportation, should have their accessibility levels assessed on the PT network.

Our main hypothesis is that the inclusion of informal jobs can potentially reduce the degree of socio-spatial inequalities in accessibility to job opportunities in Fortaleza. To investigate such a hypothesis, we analyze two intrinsic dimensions of this phenomenon. First, the spatial distribution of accessibility levels over the territory for low-income workers. Second, we compared the accessibility conditions of the most vulnerable (low-income) and most privileged (high-income) workers, by subtracting the average accessibility levels in each group ($A_{\text{richest10}} - A_{\text{poorest60}}$). To represent socio-spatial inequalities in a more comprehensive way, the proposed approach also assesses differences of accessibility levels in space, among traffic zones and regions, thus expanding the knowledge brought up by other non-spatial

aggregate measures of inequality such as Gini and Theil indexes, as well as Palma and Pseudo-Palma ratio (Giannotti et al., 2022; Herszenhut et al., 2022; de Oliveira Souza et al., 2021).

5. The jobs-population spatial mismatch problem in Fortaleza, Brazil

In order to achieve the main goal of our case study analysis, we start by discussing in this section the intensity of the land-use spatial mismatch problem in Fortaleza; then, in Section 6, we analyze its impacts on the levels of socio-spatial inequalities in job accessibility. First, it is presented an analysis of how the location of low- and high-income workers is related to the spatial distribution of formal and informal jobs. Second, the results of the Dissimilarity Index calculation are analyzed, seeking for quantitative evidence of an unequal land-use configuration in Fortaleza. In addition, it is discussed the validity of the proposed alternative method for estimating the distribution of jobs, to be applied whenever recent HTS data are not available.

5.1. Location of high- and low-income workers

[Fig. 2](#) shows the spatial distribution of the density of high- and low-income workers in Fortaleza, as well as the LISA cluster maps associated with each socioeconomic group. Moran's I statistics, designed to test the null hypothesis of spatial randomness in favor of clustering (Anselin, 1995), were also calculated. Given that Moran's I are global indicators, we also analyze the observed spatial significance (95% confidence level) based on the LISA (Local Indicators of Spatial Association) cluster classification.

The high-high clusters observed especially in the Central region, combined with a concentration of low-low clusters in the peripheries (Moran's I of 0.558), indicate a concentration of the wealthiest in the Central region where most jobs opportunities are located. Contrarily, it is observed a predominance of the poorest on the outskirts of the Northwest and Southwest regions of the city (Moran's I of 0.328), evidenced by the high-high clusters in these areas. This reflects the tendency of socioeconomic spatial segregation, especially marked by the peripheralization of the poor population, a common characteristic of large cities in the Global South. Such a pattern is a first indication of how the land-use spatial mismatch problem strongly affects low-income workers' access to jobs.

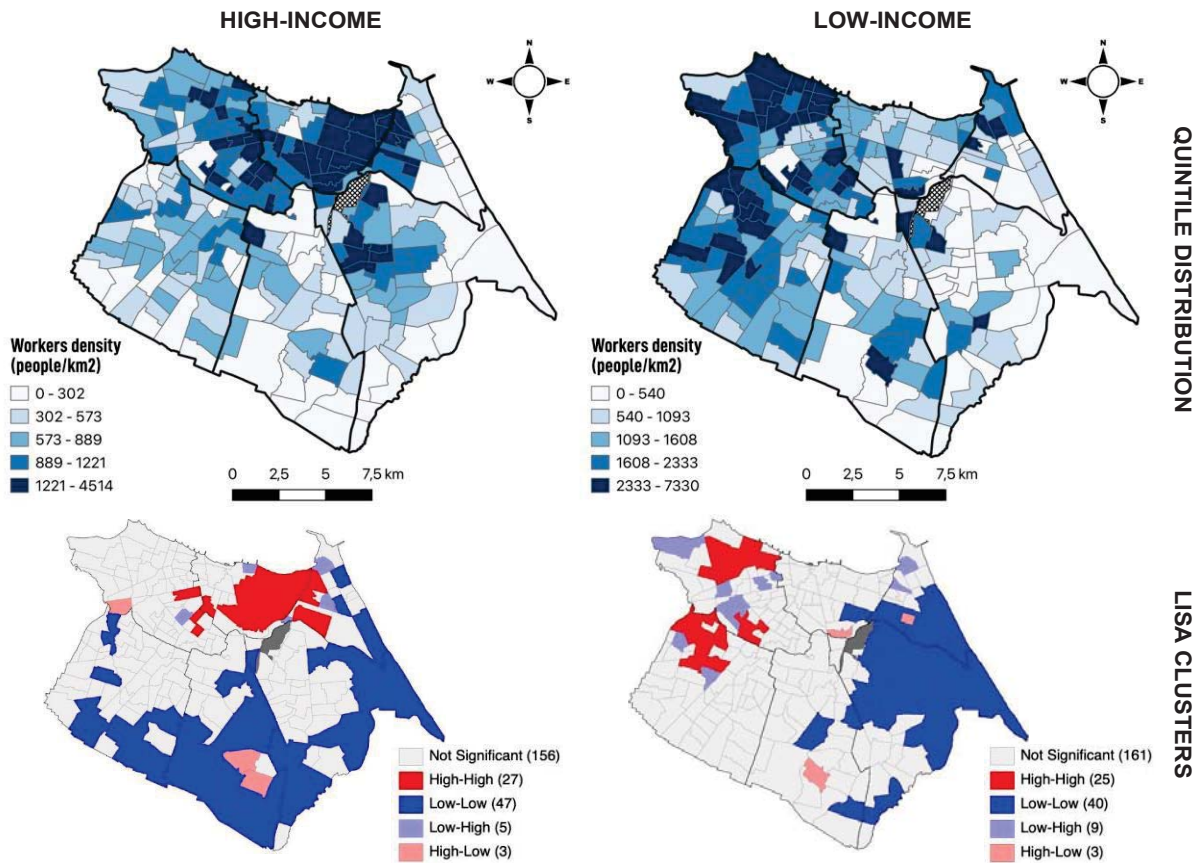


Fig. 2. Spatial distribution of workers density by household income

5.2. Location of formal and informal jobs

The quintile distributions of the density of formal and informal jobs (jobs/km²) in Fortaleza, generated by the two spatializing methods described in Section 4.2, are presented in Fig. 3. Results from both approaches indicate a similar pattern for the quintile distribution of formal jobs, showing a high concentration of zones in the highest quintile in the Central region and the zones of the lowest quintile spread around the city outskirts. To allow a more quantitative analysis of the distribution of workers and formal jobs by region, Table 2 shows that more than half of the low-income workers are located in the western regions (Northwest and Southwest), while both methods indicate that the majority of the formal jobs (38% and 52%, respectively) are concentrated in the Central region, where the largest share of high-income workers (25%) are located. This situation highlights that the current configuration of Fortaleza's land-use system establishes the basis for the occurrence of high levels of inequalities in access to formal job opportunities.

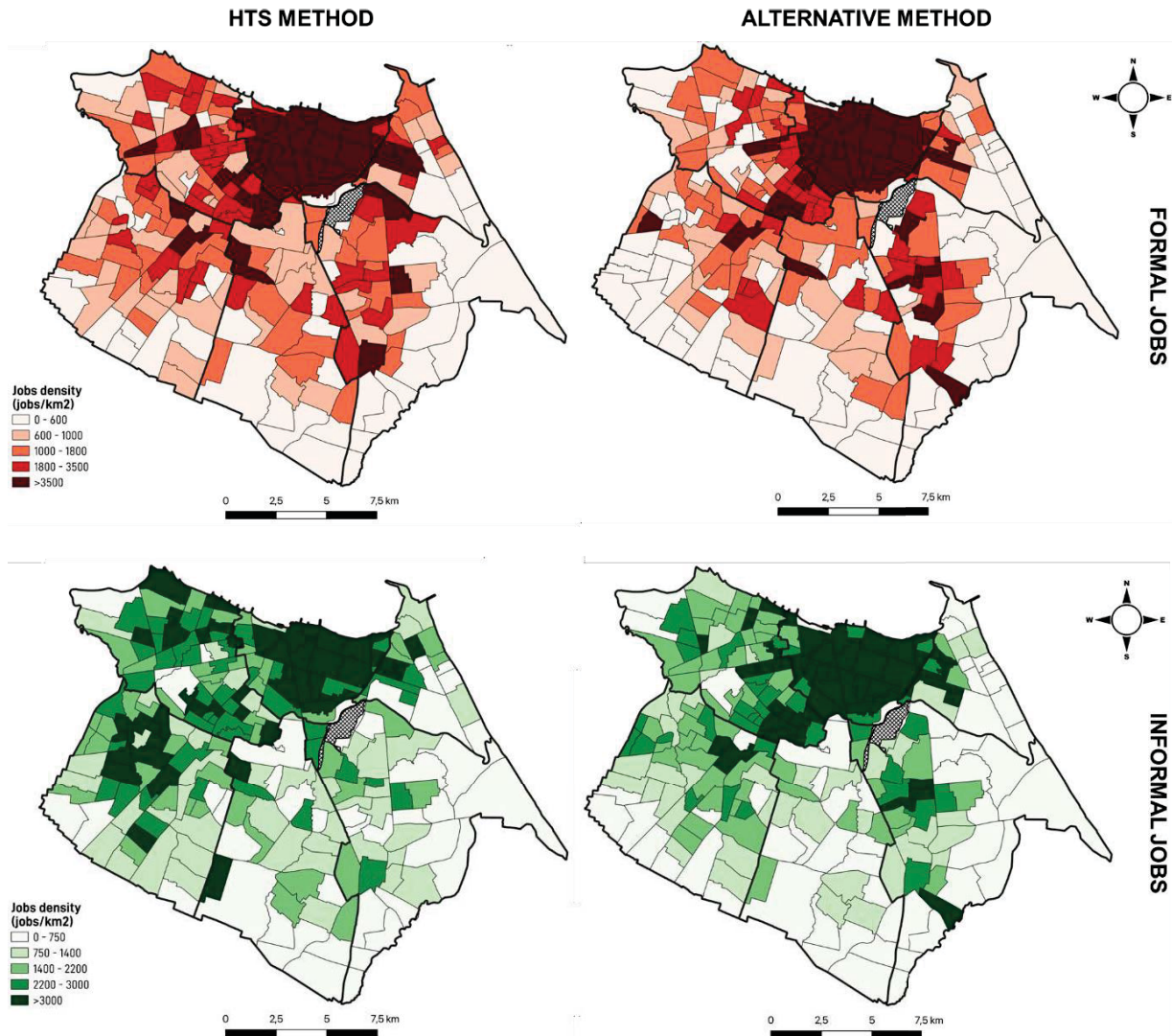


Fig. 3. Spatial distribution of formal and informal jobs by the two methods

Region	High-income workers	Low-income workers	Formal jobs (HTS method)	Formal jobs (Alt. method)	Informal jobs (HTS method)	Informal jobs (Alt. method)	Total jobs (HTS method)	Total jobs (Alt. method)
1. Central	51,284 (25%)	33,978 (9%)	214,099 (38%)	363,152 (52%)	104,283 (22%)	235,615 (41%)	318,382 (31%)	598,767 (47%)
2. Northwest	45,067 (22%)	110,674 (28%)	93,445 (17%)	78,781 (11%)	106,486 (22%)	98,312 (17%)	199,931 (19%)	177,093 (14%)
3. Southwest	33,535 (16%)	114,415 (30%)	76,260 (14%)	73,258 (10%)	116,414 (24%)	89,514 (16%)	192,674 (19%)	162,772 (13%)
4. South	21,950 (11%)	59,550 (15%)	59,371 (11%)	49,505 (7%)	58,637 (12%)	42,967 (8%)	118,008 (11%)	92,472 (7%)
5. Southeast	34,757 (17%)	44,029 (11%)	79,440 (14%)	111,598 (16%)	64,023 (14%)	73,141 (13%)	143,463 (14%)	184,739 (14%)
6. Northeast	17,225 (9%)	25,803 (7%)	36,423 (6%)	29,190 (4%)	29,684 (6%)	30,824 (5%)	66,107 (6%)	60,014 (5%)

Table 2. Total of formal and informal jobs by region considering the two methods

For the distribution of informal jobs, a more dispersed spatial pattern can be observed, especially by the HTS method. Taking this as a more reliable approach, only 22% of informal opportunities are concentrated in the Central region. The Alternative method, in turn, also indicates a lower concentration of informal jobs when compared to the formal employment opportunities, with less than half of the informal jobs located in the Central region.

Contrastingly, a greater concentration of informal jobs is observed in the Northwest and Southwest regions, where the majority of the low-income population live; which together sum up to 46% and 33% of the total informal employment, by the HTS and the Alternative methods respectively. These results indicate overall that, from a spatial configuration perspective, informal job opportunities tend to be closer to lower income workers, which could potentially reflect for them a less severe condition of socio-spatial inequalities in accessibility.

5.3. Measurement of the jobs-population spatial mismatch

Fig. 4 presents a quantitative description of the land-use spatial mismatch problem which workers of different income levels are subjected to in Fortaleza. The bar chart depicts, for formal and informal jobs, the values of the Dissimilarity Index (y-axis) for each income decile (x-axis), considering both methods used to locate jobs. For formal jobs, results show that the indicator tends to remain relatively constant for the first six income deciles (assumed as the low-income group) and starts to decrease after the 7th decile, indicating that the higher the income level, the lower the proportion of individuals who need to leave their residence zone, or region, to access a formal job opportunity. Taking the most extreme condition of inequality, the average proportion of workers in the 1st income decile who need to leave their origin zone to access formal jobs is around 20% to 25% higher than the proportion of workers in the highest (10th) income decile, considering both jobs spatializing approaches. This difference is relatively higher (26-35%) when the same indicator is analyzed at the region level.

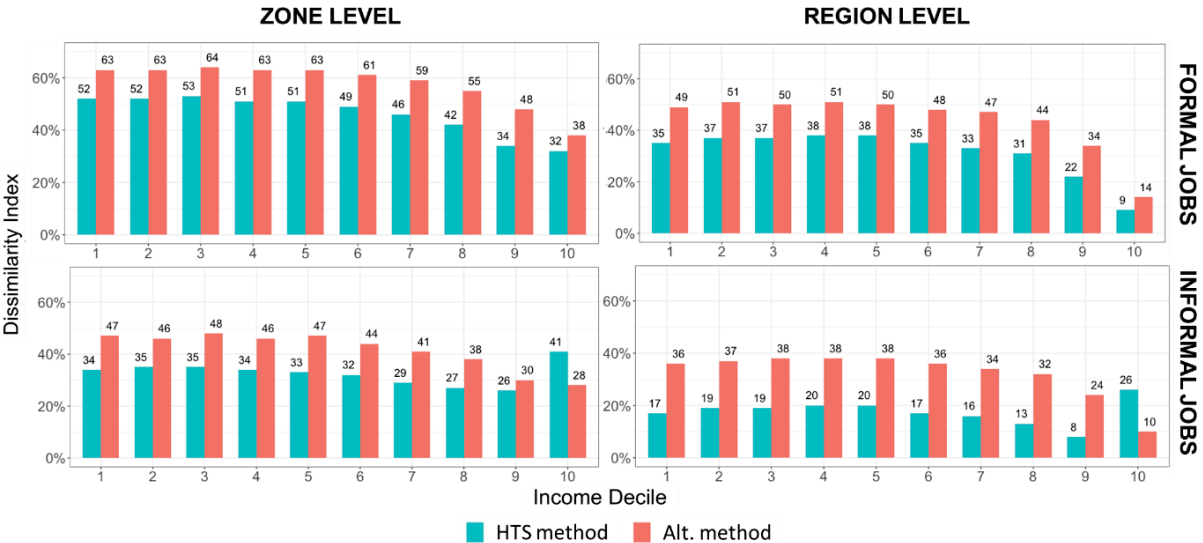


Fig. 4. Dissimilarity Index at the zone and region level, considering formal and informal jobs

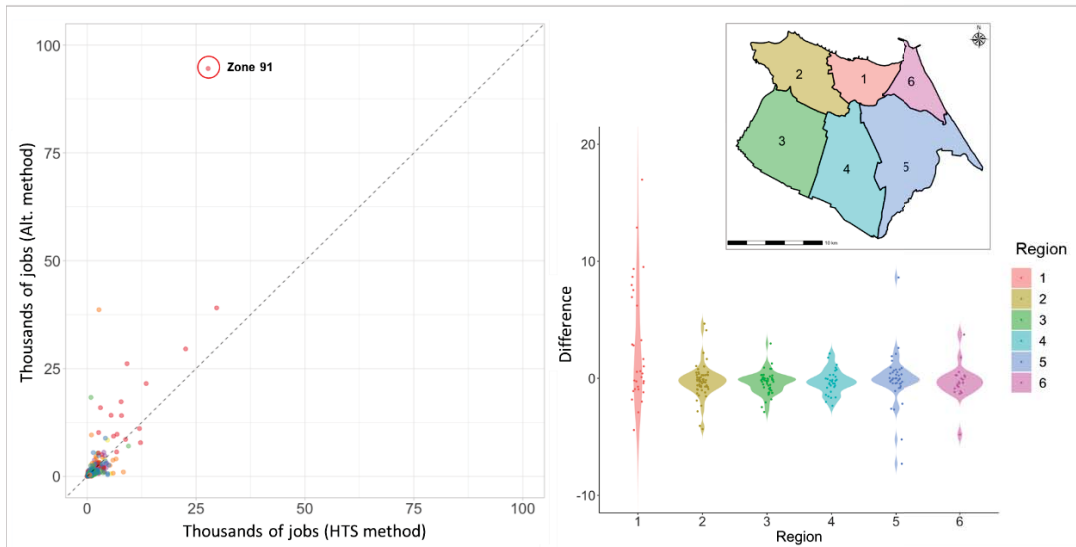
For informal jobs, on the other hand, we can observe a significant reduction in the absolute values of the Dissimilarity Index in almost all income deciles analyzed, considering both zone and region levels. However, the same constant pattern is kept for the six deciles representing the low-income population. It is worth noting, though, the worst condition of spatial mismatch for the high-income workers in the 10th decile, depicted just by the HTS method. Such a result must be cautiously analyzed in light of issues related to the concept of informal jobs for high-income individuals, as well as possible sampling bias in the travel survey within this group.

5.4. Considerations about the validity of the Alternative method for locating jobs

As previously pointed out, the availability of accurate and updated information about the location of formal and informal jobs is one of the main challenges for diagnosing urban problems related to land-use spatial mismatch and inequalities in accessibility to employment opportunities. The availability of a HTS partially overcomes this limitation, thus allowing to estimate the location of jobs from a sample data, if such an information is properly collected. However, besides the sampling representativeness issue for jobs location within a home-based survey, the low periodicity of travel surveys, especially in the Global South, limits such analyses to the time interval in which the survey was carried out. In this context, as a secondary contribution of this paper, we discuss the validity of the proposed alternative method, based upon official socioeconomic data from annually available surveys in Brazilian municipalities, to be applied as a proxy analytical effort in the absence of a more precise approach. To do so, we checked the convergence of its estimates to the ones resulting from the HTS method, assuming the latter as the most reliable existing approach.

Based on the results previously discussed in sections 5.2 and 5.3, the main source of divergence between the two methods was related to the distribution of informal jobs, especially considering the greater dispersion of these jobs towards the Northwest and Southwest regions estimated by the HTS method, which consequently led to differences in the values of the Dissimilarity Index for workers in the 10th income decile. To investigate the nature of these differences, we analyzed the scatter pattern of total jobs by traffic zones estimated by the two approaches (Fig. 5); we also evaluated the distribution of the differences between the total of jobs in a traffic zone for each region, as shown in the violin plot of Fig. 5.

(A) FORMAL JOBS



(B) INFORMAL JOBS

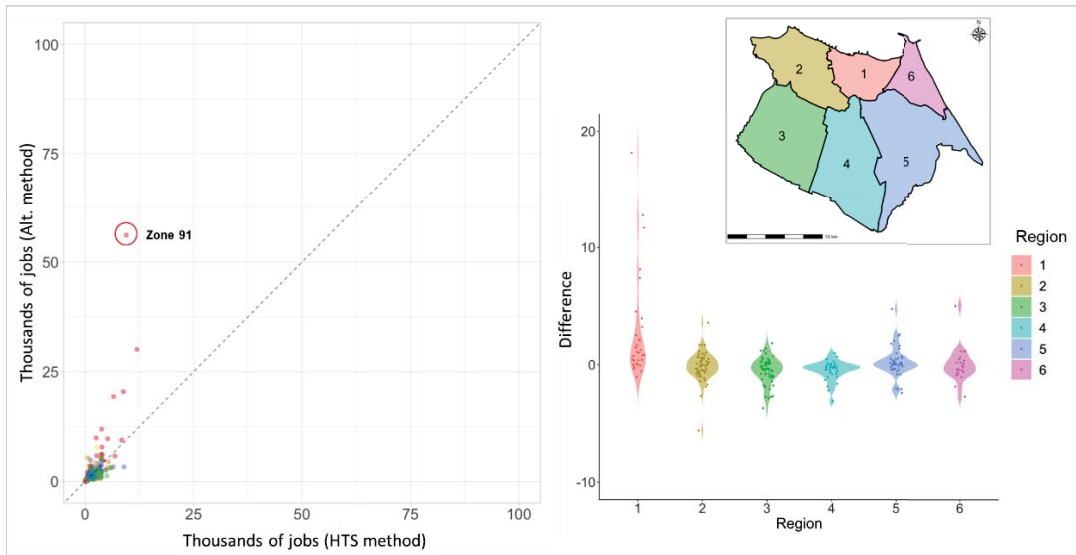


Fig. 5. Scatterplots and distributions of differences in the total number of jobs estimated by the two methods

From the scatterplots in Fig. 5, it can be noted that much of the difference between the two methods, both for formal and informal jobs, was caused by the total jobs in traffic zone 91, located in the Central region, which is highly overestimated by the Alternative method in comparison to the HTS approach. The violin plot also highlights that this overestimating trend by the Alternative method is more intensely observed in the Central region, where there is a greater number of values of positive differences, while for the other regions the differences vary more closely around zero. As described in section 4.2, the Alternative method combines information from RAIS, PNAD-C, and POF, annually available databases, to estimate jobs location. As the RAIS database only accounts for formal jobs, such differences were expected,

especially because of the way it collects data on workers location, considering only the company's head office. However, this may not be the actual location of the job, given that a company may have several branches. So, a job location indicated by the RAIS database may not correspond to the actual place of work. Besides, the results provided by the Alternative method may be facing issues related to ecological fallacy and change of support problems (Gotway and Young, 2002), due to the various scales units of the variables used to estimate jobs location. Therefore, its results must be interpreted considering these pitfalls.

Despite these limitations, which led to absolute differences in proportions of informal jobs across zones and regions, as well as in the Dissimilarity Index values observed between the two methods, it can be drawn from the results that both approaches have led to similar conclusions about inequalities on the spatial mismatch conditions for different income groups, and on the impact of including informal jobs on their account.

Therefore, we can reliably state that the Alternative method could serve as a viable tool for estimating the distribution of formal and informal jobs in Brazilian cities whenever more accurate data and robust approaches are not available. We still believe, however, that, despite its limitations, estimating jobs location from a HTS is still the best alternative to conduct accessibility analyses in the absence of a specific employment database. This is supported by its extensive use in the academic literature on this subject (Motte et al., 2016; Boisjoly et al., 2017). Hence, given the availability of a travel survey recently conducted in Fortaleza, we considered the jobs distribution estimated by the HTS method to perform the accessibility inequality analyses in the next section.

6. Accessibility inequalities

6.1. Spatial distribution of accessibility to jobs

[Fig. 6](#) shows the spatial distribution of accessibility levels to formal and informal jobs, for high- and low-income groups, considering a time threshold of 30 minutes; with [Fig. 7](#) presenting the same distribution for a 60-minute time threshold. Comparing the maps, it can be observed that high-income workers enjoy much better spatial conditions of accessibility than low-income ones. For both groups, access to formal jobs is higher in the Central region and its adjacent zones, decreasing as one gets further from there, attesting to a concentric pattern of accessibility conditions. For low-income individuals this pattern results in a city that is almost inaccessible for those living far from the Central region, since no more than 10% of jobs are

accessible by public transport in 30 min from most traffic zones, and only up to 30% of jobs are accessible by public transport in 60 min from most peripheral zones. For the high-income population, more than 70% of all formal jobs are accessible in 60 min by car from any part of the city. This situation may indicate a condition of high socio-spatial inequalities in accessibility levels to formal jobs in Fortaleza.

For informal jobs, gains in accessibility levels of the order of 10% to 20% can be observed in some peripheral zones of the Northwest and Southwest regions. This may contribute to improving the conditions of accessibility to work for low-income individuals, most of whom living in those regions. In contrast, some losses of the same order are observed in the city’s eastern regions. Thus, the overall spatial pattern of accessibility levels alone is insufficient to conclude that informal jobs have the potential to reduce socio-spatial inequalities in accessibility.

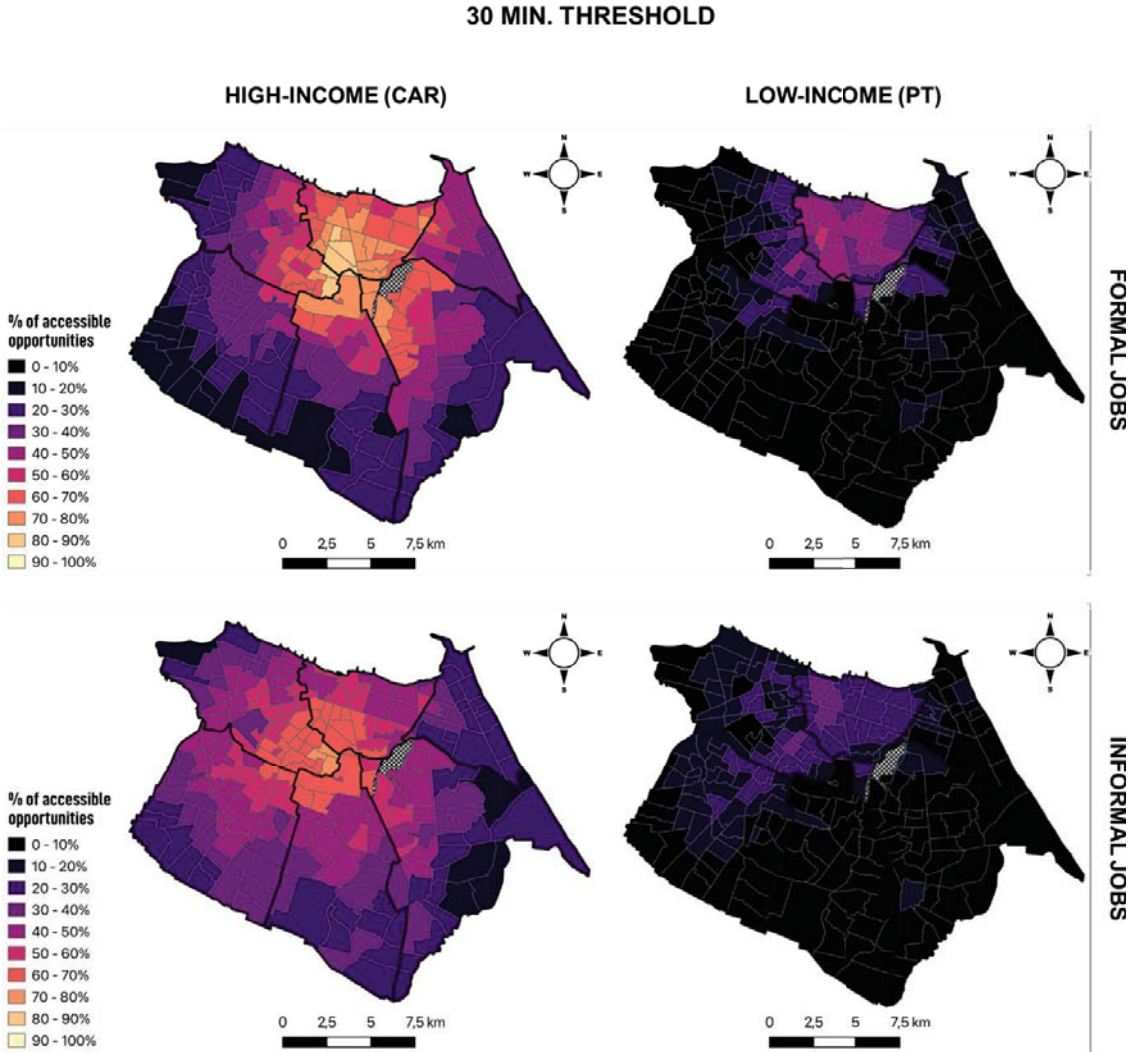


Fig. 6. Distribution of accessibility levels to formal and informal jobs for high- and low-income groups, considering a 30-min time threshold.

60 MIN. THRESHOLD

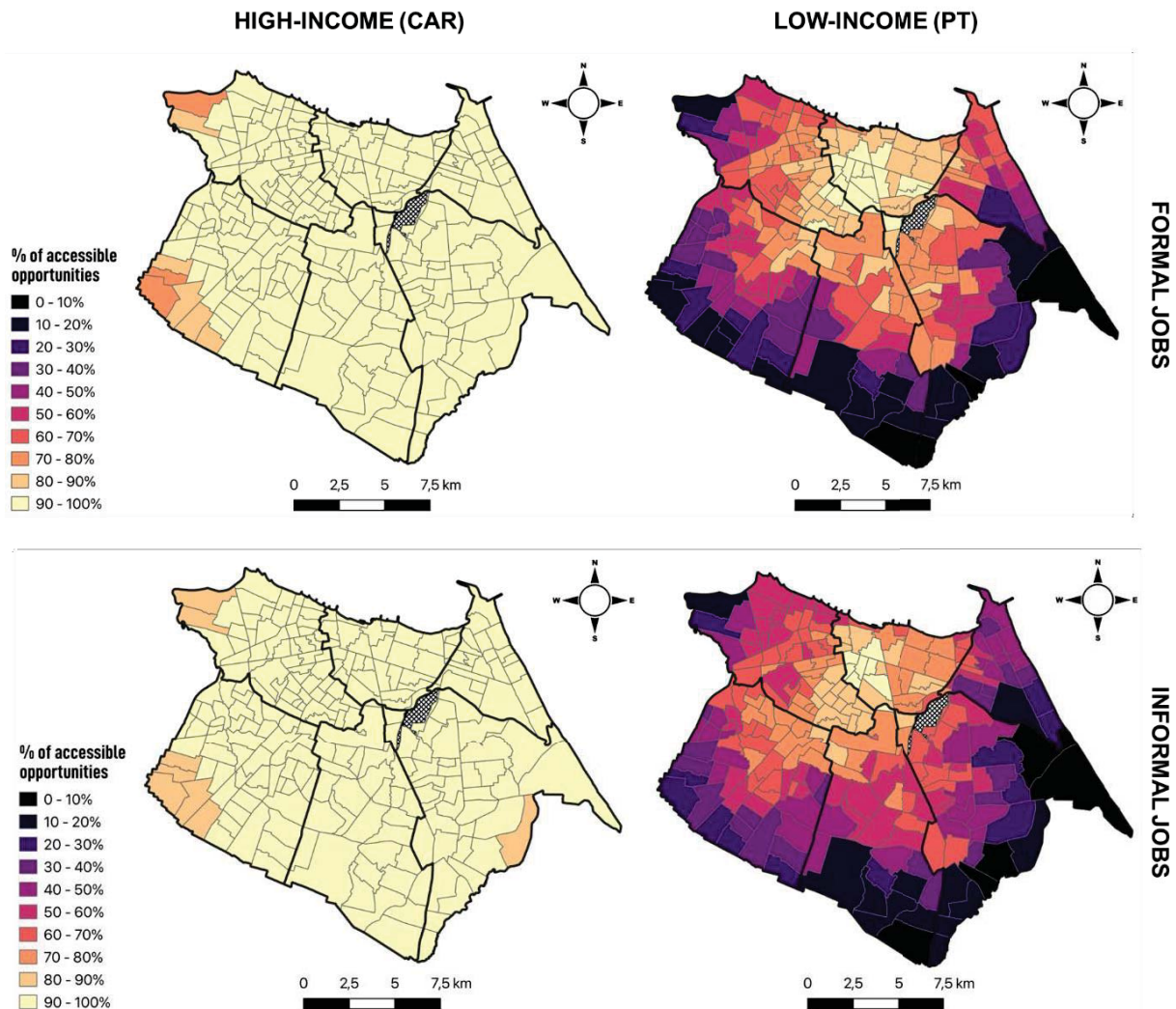


Fig. 7. Distribution of accessibility levels to formal and informal jobs for high- and low-income groups, considering a 60-min time threshold.

6.2. Distribution of accessibility by region

To have a more comprehensive view of how incorporating informal jobs impact the socio-spatial inequalities in accessibility, the weighted average of accessibility to formal and informal jobs by region were compared, considering both 30-min and 60-min time thresholds (Fig. 8). From this analysis it can be observed that, in some regions, differences in accessibility between low- and high-income workers are smaller for informal jobs, while it increases in others. For example, in region 1 (Central) high-income individuals can access 31% more formal jobs than low-income individuals in 30 minutes, while for informal jobs this difference drops

slightly to 29%. The same happens in regions 5 (Southeast) and 6 (Northeast), that is, informality seems to somewhat reduce socioeconomic inequalities. Contrarily, in region 3 (Southwest), which concentrates most of the poor population, the difference in accessibility between socioeconomic groups ranges from 21% for formal jobs to 30% for informal jobs, increasing inequalities. The same happens in regions 2 (Northwest) and 4 (South), also predominantly occupied by low-income households. When considering a 60-min time threshold, except for region 3 (Southwest), informal jobs reinforce socio-spatial inequalities in accessibility.

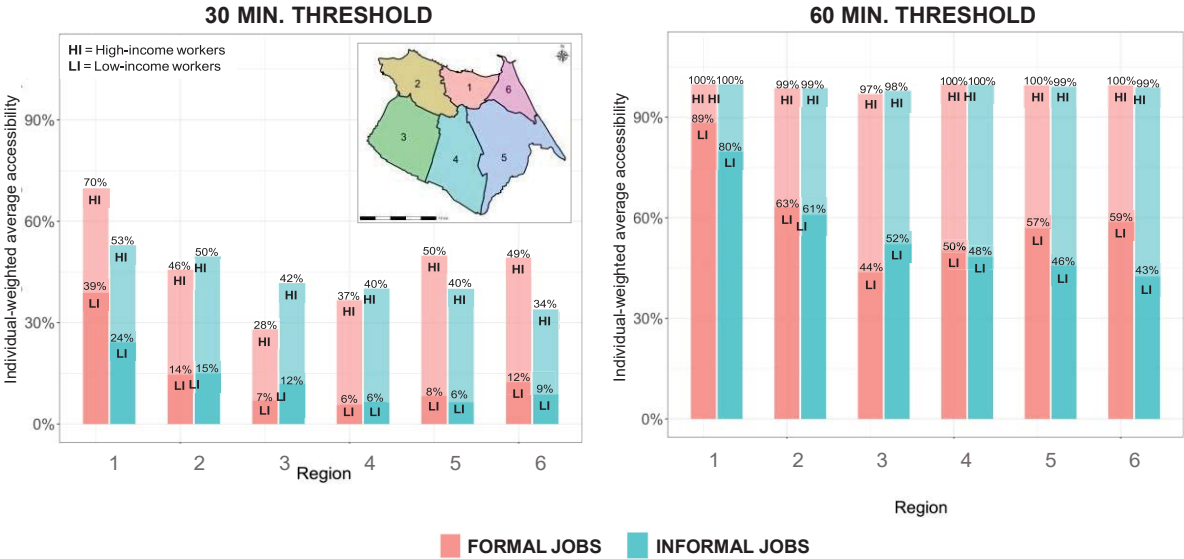


Fig. 8. Weighted average accessibility by region for low- and high-income groups, considering 30-min and 60-min time thresholds.

6.3. Distribution of accessibility among individuals

Fig. 9 presents the distribution of accessibility levels to formal and informal jobs among low- and high-income individuals, considering both 30-min and 60-min time thresholds, that is, the proportion of workers in each socioeconomic group subjected to a given level of accessibility. For the 30-min threshold, the distribution of accessibility to informal jobs showed a less unequal pattern when compared to the one obtained for formal jobs. The Gini coefficient for the low-income group reduced from 0.38 to 0.29, while for the high-income group it dropped from 0.22 to 0.15, meaning that informal jobs have the potential to reduce inequalities in accessibility within groups. Besides, the global weighted averages for both types of jobs are similar for low-income workers, while high-income individuals experience a small reduction in accessibility when considering informal jobs. This means that, from a non-spatial perspective,

informal jobs slightly reduce inequalities between low- and high-income individuals, from 36.6% to 33.0%.

Considering a 60-min threshold, informality seems to slightly reduce inequalities within the group of low-income workers, especially by improving accessibility for those with the lowest income levels (Gini coefficient reduced from 0.22 to 0.19). However, when looking at the global weighted average, the difference in accessibility between high- and low-income workers is higher for informal jobs (44.0%) than for formal jobs (42.4%).

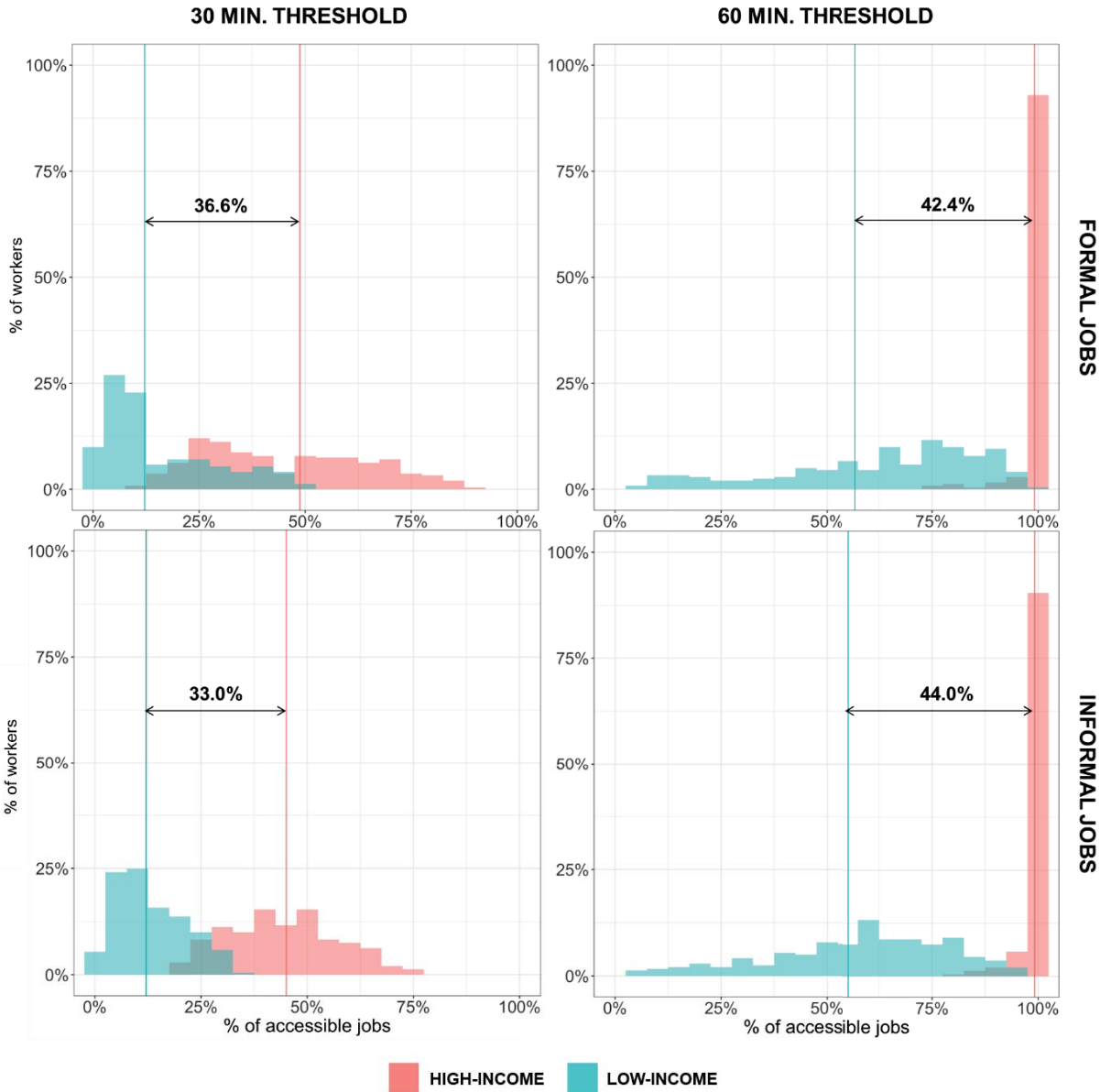


Fig. 9. Distribution of accessibility levels among low- and high-income individuals, considering a 30-min and a 60-min time threshold.

7. Conclusions and recommendations

Like most metropolises in developing countries, Fortaleza is characterized by a concentration of jobs in its central region and a peripheralization of poor workers on its outskirts, creating a form of land-use spatial mismatch between the places of residence and work, consequently generating socio-spatial inequalities in accessibility to job opportunities. Some recent empirical studies have shown that informal jobs may be more dispersed across the territory and could thus reduce these inequalities. Therefore, this study aimed at analyzing the effects of informality on spatial mismatch and on the socio-spatial inequalities in accessibility to jobs, considering Fortaleza as a representative case study of large cities in the Global South, in which informal employment represents a considerable share of job opportunities.

The initial findings indicate a greater dispersion of informal jobs over Fortaleza's territory, especially towards regions with higher densities of low-income workers. Quantitatively, it was observed a reduction in the absolute levels of jobs-population spatial mismatch for all income-decile workers, measured by a Dissimilarity Index, when informality is taken into consideration. It was also noted a slightly decrease in the gap between the poorest (1st decile) and the wealthiest (10th decile) groups. Therefore, we can firstly conclude that access to informal job opportunities tends to mitigate unequal conditions of land-use configuration to which lower income workers are subjected in Global South metropolises.

Regarding the effects of informality on socio-spatial inequalities in access to employment, accessibility levels to formal and informal jobs were measured using a cumulative-opportunity metric for both a 30-min and 60-min time thresholds, assuming that in Fortaleza high-income people travel exclusively by car (not considering other mode choices), while low-income individuals, with poor access to private vehicles, are predominantly captive of public transportation. This premise allowed us to estimate the most extreme state of social inequalities in accessibility, which we understand should be the planning target in the context of developing countries. The impact of informal jobs on these inequalities was then assessed considering the spatial distribution of accessibility, the weighted average accessibility by region, and the distribution of accessibility levels among individuals.

The results suggest that in Fortaleza informal jobs have the potential to reduce spatial inequalities in accessibility, especially for those living in its most peripheral regions. When looking specifically at the distribution of accessibility among individuals, the case study's evidence showed that informal jobs had a greater impact on reducing inequalities within each

socioeconomic group, as quantitatively demonstrated by the significant reduction in the within-group Gini coefficient, especially for the low-income individuals. The differences found in the global weighted averages of accessibility remained approximately the same for formal and informal jobs alike. Although it could be questionable to establish accessibility gains from informal job opportunities, given the inferior conditions to which these types of employees are usually submitted, we believe it is relevant within the urban planning decision-aid process to comprehend its impacts on socio-spatial inequalities, whereas informality may account for a large share of the working population, especially the most vulnerable segments in the Global South.

As a secondary contribution of this paper, and case specific to Brazilian cities, two methodological approaches for estimating the spatial distribution of formal and informal jobs were compared, aiming to validate an alternate method based on official socioeconomic data from annually available surveys, to be applied whenever a recent HTS is not available. The converging results indicate that, although the proposed alternative method provided a somewhat more concentrated distribution of informal jobs than the HTS method, it can be a valuable tool in the absence of more specific employment data, allowing time series analyses for intervals between comprehensive travel surveys. The premises and structure of the proposed approach may also contribute to the development of alternate jobs spatializing methods in countries with distinct data collection procedures. However, it is important to highlight that the Alternative Method has limitations related to the ecological fallacy and change of support problems due to the use of data at different spatial scales.

Finally, our case study's overall findings allow us to conclude that informality can have an impact on the conditions of land-use spatial mismatch and, consequently, on socio-spatial inequalities in accessibility to employment in urban areas that present a concentric pattern of jobs distribution with a strong concentration of low-income households in the peripheries. Such a spatial pattern is very common in most large cities of the Global South, like all Brazilian metropolises, reinforcing the need to consider both formal and informal jobs when analyzing problems of spatial inequalities in the distribution of accessibility among socioeconomic groups. More research on this subject is desirable, therefore, to support a solid diagnosis of such a problematic urban phenomenon, establishing the basis for a more effective integrated land-use transport planning in the context of developing countries.

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