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ANALYSIS OF SPATIAL CORRELATION BETWEEN PUBLIC TRANSPORTATION SYSTEM USERS AND COVID-19 CASES: A CASE STUDY IN RECIFE (PE)

ANÁLISE DA CORRELAÇÃO ESPACIAL ENTRE OS USUÁRIOS DE SISTEMAS DE TRANSPORTE PÚBLICO E OS CASOS DE COVID-19: UM ESTUDO DE CASO PARA RECIFE (PE)

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Abstract

Using public transport systems has been reported to be a possible vector of virus transmission during epidemics. In this context, this article aims to analyze the spatial correlation between public transportation users and COVID-19 cases, using Recife (PE) as a case study. Using spatial analysis, the Moran I Global and Local index were calculated, and global and geographically weighted regression models were estimated for the months of March to June 2020, considering neighborhoods in Recife as a spatial unit of analysis. The results indicated global and local spatial correlation between the variables considered. Nevertheless, the number of public transport users is a variable that influenced the number of COVID-19 cases, especially in April, May, and June. Finally, the public transport system may not have been the only factor that contributed to the spread of COVID-19 in Recife, given the high number of neighborhoods without an indicator of local spatial association with statistical significance. As the public transport system contributes to the mobility of people who work in essential activities to the urban life, strategies that contribute to social distance within the vehicles of the system are necessary.

Keywords: Public Transport Systems. COVID-19. Spatial Analysis. Moran's I Index. Geographically Weighted Regression.

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Resumo

O uso de sistemas de transporte público é apontado como possível vetor de transmissão de vírus durante epidemias. Nesse contexto, é objetivo deste artigo analisar a correlação espacial entre os usuários do sistema de transporte público e os casos da COVID-19, por meio de um estudo para Recife (PE). Utilizando-se da análise espacial, foi calculado o índice I de Moran global e local, e foram estimados modelos de regressão global e geograficamente ponderados, para os meses de março a junho de 2020, considerando o bairro como unidade espacial de análise. Os resultados indicaram correlação espacial global e local entre as variáveis consideradas. Ainda, o número de usuários do transporte público é uma variável que influenciou no número de casos de COVID-19, principalmente em abril, maio e junho. Por fim, o sistema de transporte público pode não ter sido o único fator que contribuiu para a disseminação da COVID-19 no Recife, visto o elevado número de bairros sem indicador de associação espacial local com significância estatística. Como o sistema de transporte público contribui para a mobilidade de pessoas que trabalham em atividades essenciais para a vida urbana, são necessárias estratégias que contribuam para o distanciamento social dentro dos veículos do sistema.

Palavras-chave: Sistemas de Transporte Público. COVID-19. Análise Espacial. Índice I de Moran. Regressão Geograficamente Ponderada.

Introduction

The first COVID-19 cases, a disease caused by the SARS-COV-2 coronavirus, occurred in China in December 2019 and spread quickly throughout the world. This disease was considered a pandemic by the World Health Organization (WHO) in March 2020 (SOHRABI *et al.*, 2020).

Among the measures to reduce the transmission of infectious diseases, we highlight the closure of public offices, commerce, and major centers that generate travel, the total or partial suspension of non-essential services, and increased remote work (HENSON *et al.*, 2017), and the suspension of public transport operation (MO *et al.*, 2020). As an example, the suspension of services was implemented to prevent the spread of the influenza virus in the years 1918, and 1919 (HENSON et al., 2017). During the COVID-19 pandemic, cities such as Wuhan and Wuxi (China), Milan (Italy) suspended the operation of Public Transport Systems (PTSs) (total or partial) to reduce the level of contagion among their users (MO *et al.*, 2020). Moreover, according to Mo et al. (2020), there seems to be a strong correlation between the dynamics of people’s mobility and the number of COVID-19 cases.

In addition to these measures, social distancing was a strategy adopted almost worldwide to prevent and reduce the number of COVID-19 cases (AINSLIE *et al.*, 2020). Social distancing consists of reducing activities outside homes to maintain physical distance between people, in addition to reducing the number of trips. As a consequence, there is a delay in the spread of contagious diseases, such as COVID-19, slowing the transmission rate, and allowing the health system to assist people infected with COVID-19, and affected by other comorbidities.

However, a city needs to maintain essential services to keep it functioning. To do this, PTSs are essential, although they can act as vectors of virus transmission during epidemics (RODRIGUE *et al.*, 2020; ANDREWS *et al.*, 2013; XU *et al.*, 2013; EDELSON *et al.* 2011). As there are several concepts, for this paper the definition of PTSs proposed by Vuchic (2002) will be used, which says that they are services provided by public or private companies, available to all those who pay a pre-determined tariff. In urban areas, typical PTSs are buses, underground trains, regional trains, and other modes that operate on prescribed routes at set times.

Contaminated people using PTSs is identified as a possible vehicle for the spread of diseases (XU *et al.*, 2019; LI *et al.*, 2019; TEIXEIRA *et al.*, 2020; ZHANG *et al.*, 2020; GUPTA; ABRAMSON, 2007), despite this being an essential system for the functioning of cities. Contact between PTS users can be a mediator in the transmission of contagious diseases (MO *et al.*, 2020; MOHR *et al.*, 2012; LEE *et al.*, 2020), largely because the systems operate with high occupancy and indoors (MOHR *et al.*, 2012). The literature reports that using PTSs contributed to the spread of contagious diseases such as Influenza (LEMEY *et al.*, 2014), and ebola (HENSON *et al.*, 2017).

There is a vast body of literature analyzing the relationship between epidemics and PTSs, but research gaps still exist. Although the literature proves that PTSs are potential vectors of contagious diseases, the results are very focused on strategies to reduce contamination by the disease. However, public transport is an essential service. Measures such as travel restrictions penalize workers in essential services, who are extremely important for pandemic times. Thus, this article contributes to this gap, analyzing the contribution of public transport in the dissemination of COVID-19, through spatial-temporal analysis.

Understanding the spread of any virus through PTSs is essential to create a strategy that allows essential services to function without impacting the public health system too much (COSNER et al., 2009; BOGOCH et al., 2020; TIRACHINI et al., 2020; LIU, 2020). Considering this, we formulated the following research question: Is there a spatial correlation between PTS users and the number of people infected with COVID-19? The research hypothesis is that there is a spatial correlation between PTS users and the number of people infected with COVID-19 in the city of Recife (PE). Thus, this paper aims to analyze the spatial correlation between PTS users and COVID-19 cases in the city of Recife. For this purpose, the spatial analysis was used to identify the correlation between using PTSs in the dissemination of COVID-19.

Epidemics and PTSs

The spread of viruses requires a physical approach from a healthy person to an infected person. It is essential to analyze individual passenger journeys and levels of travel agglomerations in PTSs (CHAN et al., 2020) to understand the spread of a virus in an urban area. Thus, understanding the population's mobility patterns is an important element for constructing epidemic dissemination models (HACKL et al., 2019), especially considering the spatial characteristics and level of occupation of PTSs in epidemiological models (COLIZZA et al., 2007; EUBANK et al., 2004), to identify the dominant ways of spreading the virus (GAUTREAU et al., 2008).

The literature on the spread of viruses due to using public passenger transport systems is vast. Mateus et al. (2014) present a literature review on the subject. Conducting simulations was also a tool used to assess the spread of viruses by PTSs (SHOGHRI et al., 2019; HADDAD et al., 2016; RAMLI; MONTEROLA, 2015; LEMEY et al., 2014), while other researchers focused on analyzing the use of public transport as a vector for virus transmissions (MO et al., 2020; QUIAN et al., 2020; DU and BAI, 2018; BÓTA et al., 2017; RAMLI; MONTEROLA, 2015; SUN et al., 2015; ANDREWS et al., 2013; XU et al., 2013).

Some studies have analyzed measures to reduce the rate of virus spread, such as making inactive PTS stations with greater virus transmission dynamics (RAMLI; MONTEROLA, 2015). This strategy is based on the fact that travel restrictions delayed the spread of the flu virus (MATEUS et al., 2014; SHOGHRI et al., 2019).

However, most studies focus on the development of models for the spread of disease by using public passenger transport systems. For Tirachini and Cats (2020), models of disease transmission by PTSs allow testing the potential consequences of various levels of system demand and characteristics of virus spread to support new pandemic control strategies.

Balcan et al. (2010) developed a model called Global Epidemic and Mobility (GLEaM), which integrates sociodemographic and mobility data. The authors used a spatially structured stochastic approach to the disease to simulate the spread of epidemics worldwide. For the case of COVID-19, Chinazzi et al. (2020) showed that the effects of travel restrictions from China delayed the spread of the disease around the world.

Moreover, conducting a literature review, López-Olmedo et al. (2020) concluded that there is an increase in the likelihood of respiratory infections associated with using public transport. The same authors stated that the incidence of influenza A or B viral contagion was 54% higher in people who frequently use public transport compared to people who do not frequently use the service. Using data regarding London, Goscé and Johansson (2018) identified that the number of people infected with influenza and other viral diseases is higher among people who use the underground train for longer journeys (therefore, with longer travel times), especially in more populous districts, with a predominance of underground users.

This section makes it clear that despite the vast literature analyzing the relationship between epidemics and public transport systems, research gaps still exist. For example, although the literature proves that PTSs are potential vectors of contagious diseases, the results are highly focused on strategies to reduce contamination by the disease. However, public transport is an essential service. Measures such as travel restrictions penalize workers in essential services, who are extremely important for pandemic times. Thus, this article contributes to this gap, analyzing the contribution of public transport in the dissemination of COVID-19, through spatial-temporal analysis. The next section describes this research method in detail.

Research method

To analyze the influence of the PTS on the spread of COVID-19, we obtained data from the number of passengers using the PTS and the number of those infected with COVID-19. As the study was developed in Recife (PE), data on the number of people infected were obtained from the Pernambuco Department of Health (PERNAMBUCO, 2020), for the period from March 12 (first case registered in Recife) to June 30, 2020. Concerning the users of the PTS based on data from the origin-destination survey conducted in 2018 (ICPS, 2020), the daily number of public transport passengers, for work reasons, was considered as a proxy in the analysis due to the unavailability of updated data for the same period in which the COVID-19 cases were collected. It should be noted that public transport users for work reasons do not vary much over time. The analyses were made for March, April, May, and June.

A spatial analysis was used as a research method. Initially, cartograms were prepared for each analyzed month to illustrate the spatial distribution of the investigated phenomenon for characterization of the study area.

The bivariate global Moran's I was calculated to identify the correlation between the variables analyzed in Recife. The bivariate Morans' I measures the spatial correlation between two variables by analyzing the relationship between the covariance and the variance of the elements analyzed for the study area (MELICIANI; PERACCHI, 2009). The pseudo-significance test provides the statistical significance of the index by the z-value and the respective p-value. The null hypothesis of spatial independence between variables is rejected if the $p\text{-value} < 0.05$. The result of the bivariate global Moran's I should be compared with the expected Moran's I for the study area. The spatial correlation is more intense when the values obtained are close to the expected Moran's I (ANSELIN, 1996; GOODCHILD, 1986). Details on the calculation of the bivariate Global Moran's I can be obtained from Moran (1974).

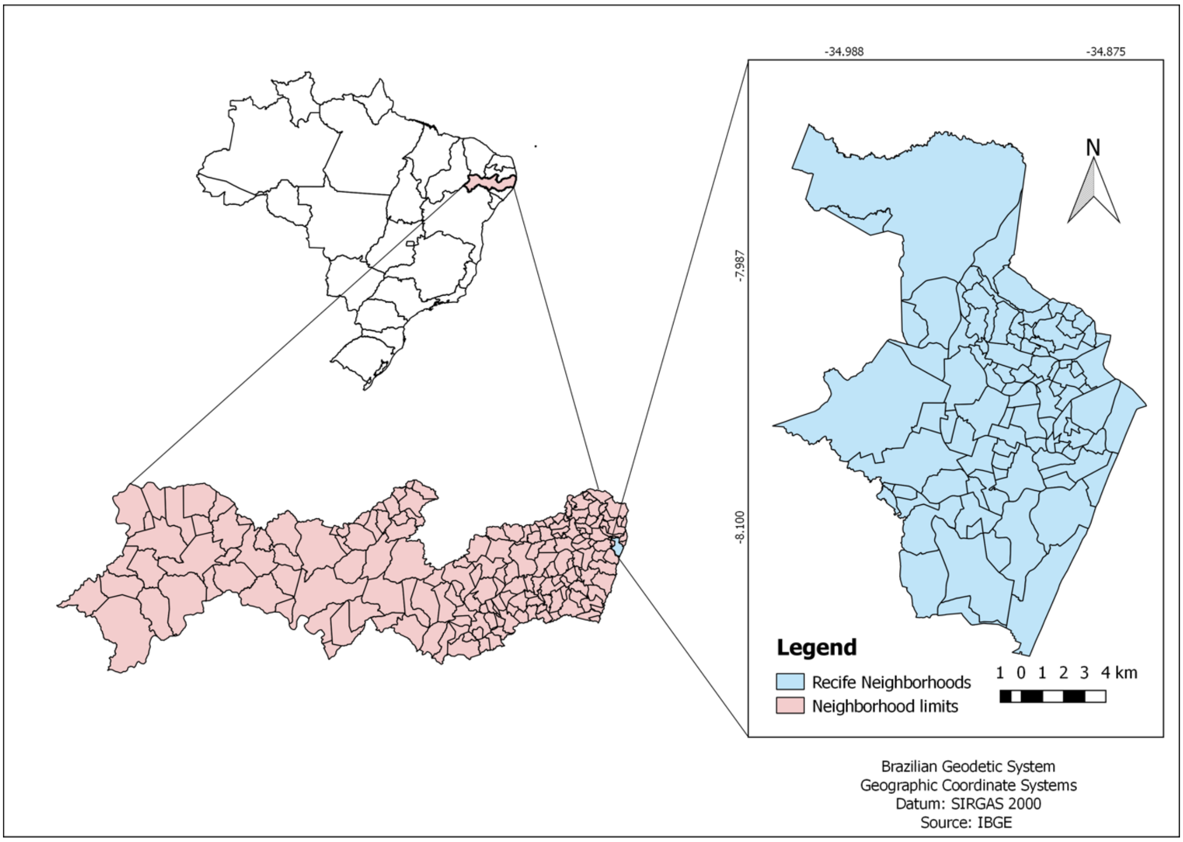
The bivariate local Moran's I was also calculated, which measures the sample's heterogeneity. It is obtained in a similar way to the global index. However, it obtains the relationship between variance and covariance for each geographical unit of the studied area. In the calculation, the queen contiguity was considered for the elaboration of the weight matrix and a 95% confidence interval. From the calculation of the bivariate local Moran's I, the Local Spatial Association Index (LISA) is obtained, whose results indicate clusters of contiguous geographical units whose LISA is significant. Clusters indicate the similarity of a geographical unit with its neighbor, based on the local correlation index grouped in a map cluster. For more information on the bivariate local Moran's I and LISA, please consult Anselin (1995). These analyses were performed using the GeoDa software.

Finally, global, and geographically weighted regression models were estimated for each of the months of analysis. In global regression models, the global parameters of the variables of the studied phenomenon are estimated. In the geographically weighted regression models, coefficients are estimated according to their location, thus enabling one to analyze the influence of the analysis variables at a local level (FORTHERINGHAM et al., 2002). In this paper, models estimated in which the number of cases was the response variable, and the number of passengers was the independent variable. These models were estimated using the spgwr package (BIVAND et al., 2020) in the R language, using the Gaussian function. The model statistics were obtained using the GWmodel package (LU et al., 2020) in the R language.

Characterization of the studied area

Recife, the capital of the state of Pernambuco, in the Northeast of Brazil (Figure 1) was chosen as the study area. The estimated population of Recife, in 2020, is 1,653,461 inhabitants, distributed over 219 km^2 (IBGE, 2020).

Figure 1: Location of Recife in the State of Pernambuco and in Brazil.

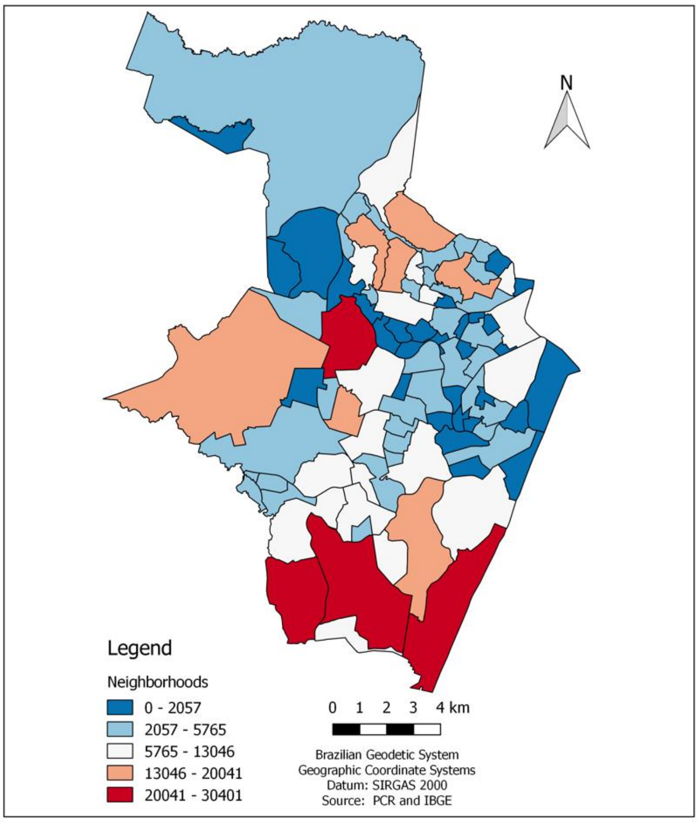


Source: IBGE (2020).

The territory of the capital of Pernambuco is characterized by extreme social inequality, observed by the value of the Gini Index (0.67 - Atlas of Human Development, 2010), which is considered the Brazilian capital with the greatest social inequality. Social inequality is reflected in the distribution of the population in the space, where part of the population lives in luxurious housing and another part does not even have adequate basic sanitation in the same neighborhood. Only 69.2% of the municipality has adequate basic sanitation, and 49.6% of the roads have adequate urbanization (IBGE, 2017). The spatial study, carried out by Cavalcanti and Avelino (2018), demonstrated how complex the urbanization of the city is. The north and west side of the city have an environmental preservation area; the eastern side, close to the coast, houses most of the material historical heritage, preserved by IPHAN; and various concentrations of Special Areas of Social Interest (ZEIS) can be found throughout the city, in which a population resides with lower income and less access to urban infrastructure. Thus, the southeastern side and the central region are those that have the highest population concentrations and have better conditions for urban density.

Figure 2 shows the cartographic representation of the number of public transport passengers in the neighborhoods of Recife. It is observed that the neighborhoods in the south, as well as the neighborhoods in the west, are the ones that concentrate the largest number of passengers. According to data from the source-destination survey (ICPS, 2020), approximately 43% of the population of Recife use the PTS for commuting to work. The PTS is managed by the Greater Recife Transport Consortium and consists of the Integrated Structural System (SEI) and the Metropolitan Complimentary Transport System (STCM). SEI, which serves most passengers, is a public transport network consisting of buses and underground train lines integrated by terminals that allow users to travel within the RMR by paying only one fare. The SEI has a spatial configuration consisting of radial and perimeter axes, with the terminals located at the intersection of these axes. This transport configuration, although it has a social function in allowing people who live farther away to have the benefit of paying only one fare, requires that many transfers are made at the terminals that end up having a large crowd. However, the problems related to the precarious conditions of this system are constant, mainly concerning the high occupation of vehicles (SILVA, 2018).

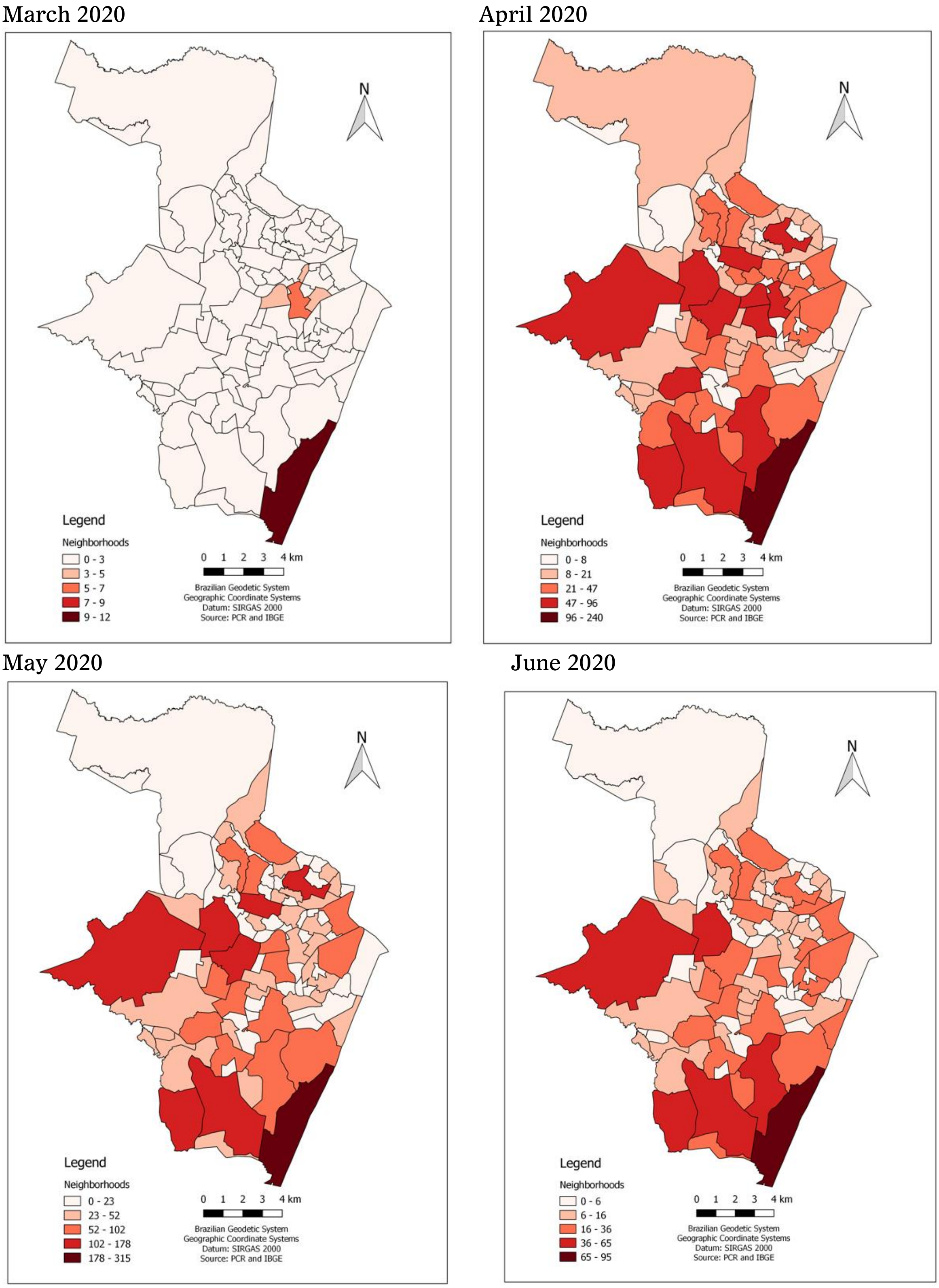
Figure 2: Cartographic representation of the number of passengers on the PTS in Recife.



Fonte: ICPS (2020).

Concerning COVID-19, the first transmission case was diagnosed on March 12, 2020. From this date on, the number of cases increased gradually, as illustrated in the cartograms shown in Figure 3. It can be observed that in March 2020, the cases were concentrated in the neighborhood located in the southern region of Recife. In April 2020, in addition to the increase in the number of cases, there was a spatial spread of the virus. In May 2020, the spatial distribution was similar to April, despite the increase in the number of cases. Finally, in June 2020, a reduction in the number of cases was observed even though there were cases in all space units. To delay the spread of COVID-19, the State Government of Pernambuco adopted social distancing. As a consequence, there was a drop in the demand of passengers in the PTS, especially in March and April 2020. Due to this reduction in passenger demand, there was also a reduction in the fleet and the frequency of bus lines to adapt to supply and demand, respecting local determinations to minimize or avoid agglomerations (NTU, 2020).

Figure 3: Cartographic representation of the number of COVID-19 cases between March and June in Recife.



Source: Pernambuco (2020).

According to FECOMÉRCIO-PE (2020), according to a survey conducted to discover the profile of public passenger transport users during the pandemic, the population considers that the greatest risk of contagion of COVID-19 is related to using the PTS at times when the system is at the highest occupancy level. The bus fleet, still reduced, has not been able to keep up with the demand for passengers who are gradually returning to work activities, following the State's reopening protocols. The survey also pointed out that the increase in waiting time between trips is the most negative point for 34% of people, followed by the high occupancy rate of buses (32%) and the reduction of lines (22%). The study considers that these difficulties increase the risk of contamination among users (FECOMÉRCIO-PE, 2020).

Results and analysis

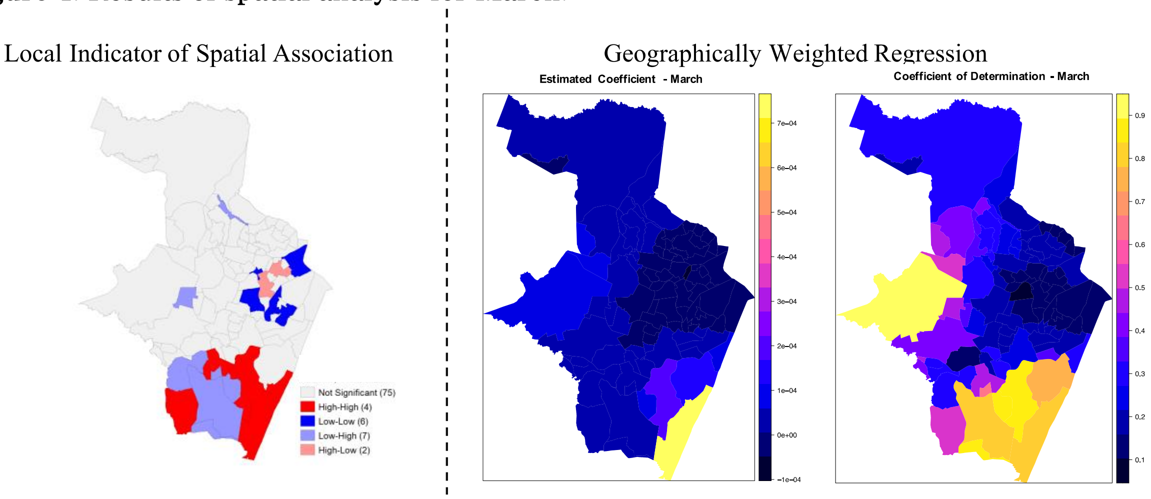
Table 1 presents the results of the global Mora's I, which assesses the existence of a global spatial correlation. For all months, the results of the pseudo-significance test indicate that there is a spatial correlation between the variables since all p-values <0.05. In this study, the expected Moran index I for the city of Recife is 0.33. Therefore, except for March, it can be concluded that the spatial correlation between the variables was more intense in April, May and June.

Table 1: Global Spatial Correlation Results - global Moran's I

Month	Moran's I	z-value (p-value)
March	0.060	1.382 (0.001)
April	0.116	2.374 (0.001)
May	0.190	3.528 (0.001)
June	0.225	4.145 (0.001)

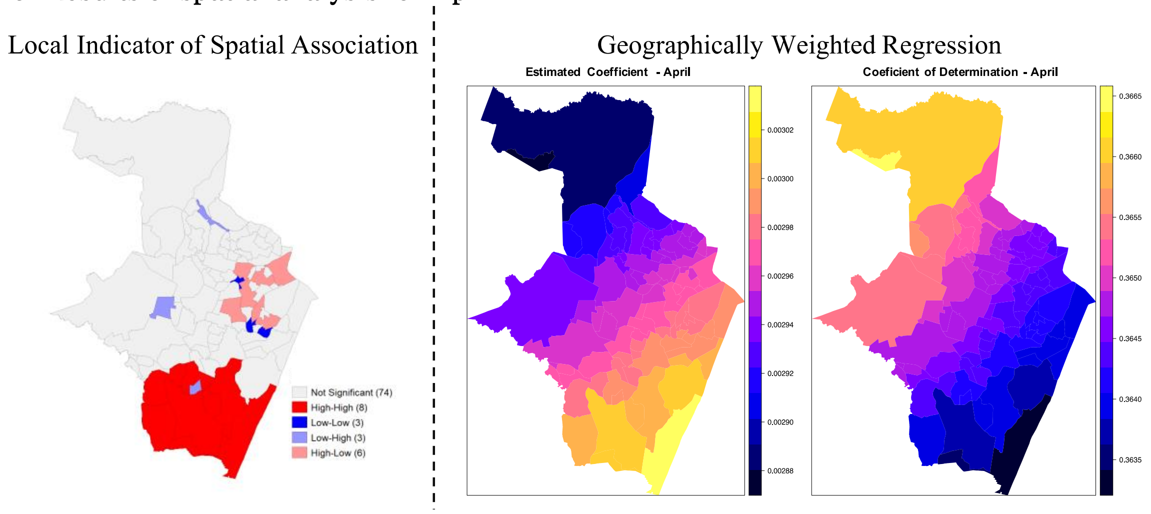
The results of the local spatial association index (LISA) and the geographically weighted regression model in March are shown in Figure 4. In March, social distance measures were introduced in Recife. The LISA results indicate that the neighborhoods with the highest incidence of cases presented clusters of the high-high or low-high type, indicating positive spatial association. In these same neighborhoods, the geographically weighted regression model showed the highest determination coefficients (R^2), despite the low values for the estimated coefficients, because of being the first stages of the spread of the virus. The highest estimated coefficient was for the neighborhood of Boa Viagem with the highest number of registered cases; this is one of the neighborhoods with the highest number of passengers on the PTS. Thus, it can be concluded that there is a spatial correlation between the PTS users and the number of people infected by COVID-19 for 10 districts in Recife in March, represented by the low-low and high-high clusters.

Figure 4: Results of spatial analysis for March.



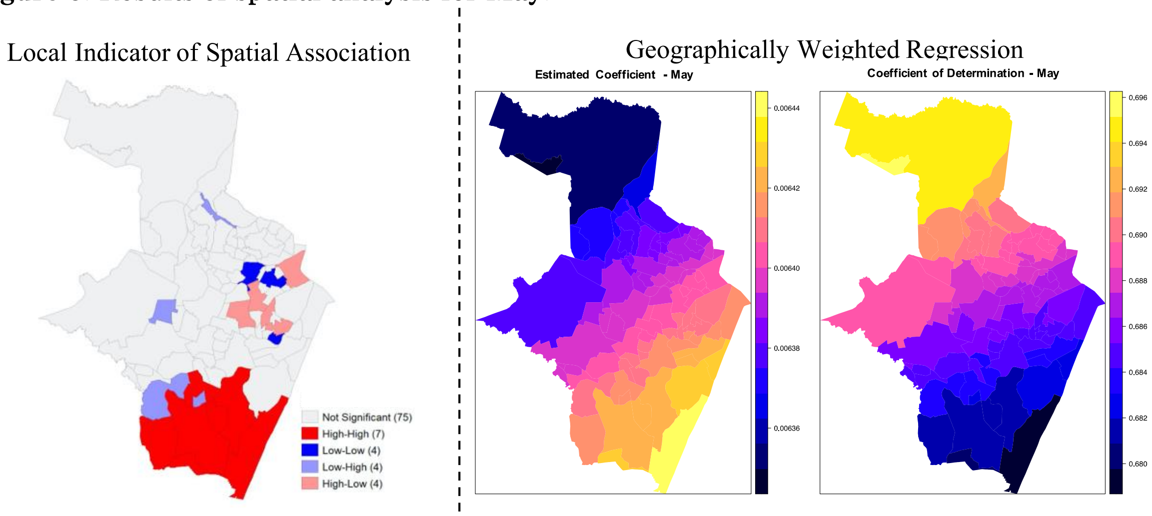
In April, the number of COVID-19 cases increased significantly, and cases were observed in all districts of Recife. The results of the LISA presented in Figure 5 show us the spread of the virus according to the increase in the number of clusters, mainly of the high-high or high-low type, which indicates a positive spatial correlation in these neighborhoods. These results are confirmed by the geographically weighted regression model, in which the neighborhoods with the highest values of the coefficient are the same as the highest numbers of PTS users. However, there are neighborhoods with lower coefficients in regions where there is a large number of passengers, such as places with a low-high cluster. Thus, it can be concluded that there is a positive local correlation between the number of PTS users and the number of those infected with COVID-10 in 11 districts of Recife in April.

Figure 5: Results of spatial analysis for April.



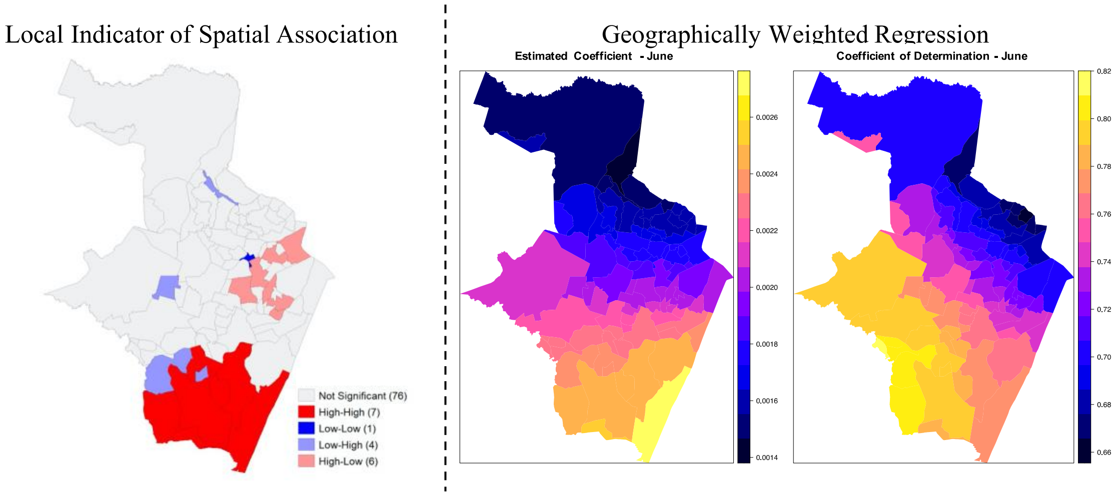
In May, LISA results indicated a reduction in the number of high-high clusters and an increase in low-low clusters (Figure 6), also showing the existence of a positive local spatial correlation, but a change in neighborhoods with this correlation. Furthermore, the estimated coefficients of the geographically weighted regression model showed a slight increase, in addition to the fact that the model had better local adjustments represented by the coefficient of determination. Thus, it can be concluded that there was a positive local correlation between the number of PTS users and the number of those infected with COVID-19 in 11 of the 94 neighborhoods in Recife in May.

Figure 6: Results of spatial analysis for May.



In June, there was a reduction in the number of COVID-19 cases in Recife, despite the occurrence in all neighborhoods in the municipality. As a consequence, the LISA result (Figure 7) shows an increase in the number of high-low clusters, suggesting that the increase in the number of cases is not necessarily associated with the number of PTS users. Despite this, the geographically weighted regression model indicates the existence of spatial correlation throughout the territory of Recife, with higher estimated values for the southern portion, which also presents the best local adjustments observed by the value of the determination coefficient. Thus, it can be concluded that despite the reduction in the number of COVID-19 cases and the identification of negative spatial correlation in some neighborhoods in Recife (observed by the high-low clusters), there is still a positive spatial correlation between the number of PTS users and the number of those infected with COVID-19 in nine districts of Recife.

Figure 7: Results of spatial analysis for June.



Analyzing the coefficients of the geographically weighted regression models, it can be observed that the spread of COVID-19 occurred in the southeast-northwest direction. These models also demonstrate the influence on neighborhood relations in the neighborhoods, which proved to be more significant in the dissemination of COVID-19 than the number of users of the PTS itself. This relationship is evident when comparing the cartograph of the number of COVID-19 cases and the results of the models, where similarities are observed in the number of cases in adjacent neighborhoods and the results of the coefficients of the GWR models in that same set of neighborhoods.

Finally, the results of the global regression are shown in Table 2. The global regression allows us to identify whether using the PTS influenced the spread of COVID-19. Although the models have statistically valid coefficients (p-value of the t-test) for all months and are statistically valid (p-value of the f-test), the estimated values for the number of PTS users varied between the months analyzed. For March, in which few cases were concentrated in a few neighborhoods, the model does not present a good global adjustment (represented by the value of R2). The best adjustments were obtained for May and June.

Table 2: Results of the global regression

	March	April	May	June
Number of users (X)	0.00005	0.00298	0.00641	0.00217
T-value (p-value)	2.16 (0.033a)	7.20 (1.6e-10b)	14.09 (<2e-16b)	14.356 (<2e-16b)
Multiple R2	0.05	0.36	0.68	0.69
R2 Adjusted	0.04	0.35	0.68	0.69
F-statistics (p-value)	4.67 (0.03)	51.88 (1.58e-10)	198.7 (< 2.2e-16)	206.1 (< 2.2e-16)
Sigma (hat)	1.46	24.32	26.74	8.88

[a] = 0,05, [b]= 0,01

The results of the global regression enable us to conclude that the number of PTS users influenced the number of COVID-19 cases in Recife, confirming the results of the global correlation obtained by the bivariate global Moran's I. However, when analyzing the phenomenon at the neighborhood level, there was a local spatial correlation in the neighborhoods located mainly in the south of Recife. As there were cases in all neighborhoods in Recife, it can be concluded that the PTS may have contributed to the spread of COVID-19, especially in neighborhoods where the number of users is more representative. However, public transport was not the only factor for the dissemination of COVID-19 in the city of Recife, since the number of neighborhoods with no incidence of local correlation clusters was representative in this study.

Conclusion

COVID-19 has proved to be a challenge for public authorities when it comes to managing the spread of the virus. Social distancing measures have reduced urban displacement and appeared to reduce the rate of dissemination. However, this hypothesis cannot be tested due to the lack of data on the movement of people during the pandemic. As an alternative, it is important to investigate the possible factors that may have contributed to the spread of infectious diseases, such as COVID-19, to identify effective strategies to prevent it from spreading. Thus, this paper analyzed the spatial correlation between the number of Recife's PTS users and the number of COVID-19 cases.

To this end, a research question was formulated to investigate whether there is a spatial correlation between the PTS users and the number of people infected with COVID-19. Results showed that there is a global and local spatial correlation, with the occurrence of clusters that indicate the existence of a spatial neighborhood relationship between the number of COVID-19 cases and the number of PTS users, from March to June, in the city of Recife, confirming the research hypothesis. Thus, it can also be said that the objectives of the article were achieved. When analyzing the contribution of public transport in the dissemination of COVID-19, through a spatial-temporal analysis, it appears that the proposal to fill this gap in the literature was also achieved.

As essential services continued to function for the maintenance of urban life, as well as the gradual resumption of activities as cases decrease and health safety protocols are created, the PTS must provide security for its users, since the level of occupation of PTS is a contributing factor for COVID-19 dissemination. As the PTS is a democratic space (by law), often people with the virus, who are seeking health care services or have a lack of knowledge about the pathology, share spaces with healthy people. Thus, it is essential to maintain social distance within the vehicles of the PTS, making them operate with a lower than expected occupancy level. To ensure access for all, it is essential to increase the offer, especially during peak hours, to reduce vehicle occupancy, guarantee social distance and maintain the city's economic activities. In addition, the incentive for active transport, including investments in infrastructure, can guarantee the displacement of the population in a safe and healthy way.

For future work, it is suggested to incorporate other factors into the spatial analysis to understand the socio-economic-spatial relations that may have influenced the dissemination of COVID-19 in Recife.

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