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Airports, highways and COVID-19: An analysis of spatial dynamics in Brazil

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ABSTRACT

Introduction: The high transmissibility and infectivity of the new coronavirus, the high proportion of asymptomatic transmitters and the rapid and continuous spatial displacement of people, by the different mechanisms of locomotion, are elements that can contribute to the dissemination of COVID-19. This study aims to describe the geographical dispersion of COVID-19 in the state of Bahia and the importance of major airports and highways in the dynamics of disease transmission.

Methods: This is an ecological study involving all cases of COVID-19 registered in the state of Bahia between March 6, date of the first registered case and May 16, 2020. After collection, an exploratory spatial analysis was performed, considering the cases accumulated on the last day of each epidemiological week.

Results: The first cases of COVID-19 were concentrated in areas served by three important airport complexes in the state, located in Salvador, Ilhéus and Porto Seguro. From week 16 – 20, there was a more intense expansion of COVID-19 to the interior of the state. A global spatial autocorrelation was observed (I Moran 0.2323; p = 0.01), with the influence of distance: positive correlation at distances less than 205.8 km (I Moran 0.040; p = 0.01) and greater than 800 km (I Moran 0.080; p = 0.01).

Conclusions: Based on the spatial dispersion pattern of COVID-19 in the state of Bahia, airports and highways that cross the state were responsible for the interiorization of the disease.

1. Introduction

COVID-19 (Coronavirus Disease - 2019), caused by SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) was first registered in December 2019 in the city of Wuhan, a Chinese metropolis of 11 million inhabitants (Zhu et al., 2020). From the Asian continent, COVID-19 spread to other parts of the world, resulting in a pandemic, declared on March 11, 2020 by the World Health Organization (WHO) (World Health Organization, 2020). As of March 03, 2021, 115.2 million cases and 2.5 million deaths have already been confirmed worldwide (COVID-19 Map, 2021).

In Brazil, the first case of the disease was registered on February 26, 2020, in the city of São Paulo. The first death was registered on March 17 of the same year (Boletim COE COVID-19 no. 13, 2020; de Souza et al., 2020a). Initially, the disease reached the large urban centers of the country and from these, it started a process of interiorization, reaching the poorest municipalities of Brazil (de Souza et al., 2020b), where the limited healthcare network soon collapsed (Rache, Rocha, Nunes, Spinola, Malik, Massuda). This process of interiorization of the disease becomes even more worrying in a country of continental dimensions, where intense socio-spatial inequality is observed (Campello et al., 2016).

In Brazil, as of March 03, 2021, 10.7 million cases and 259.2 thousand deaths as a result of the disease, representing the third highest burden of the disease on the planet (COVID-19 Map, 2021). The state of Bahia stands out as one of the ten Brazilian states with the highest number of confirmed cases, with 694,7 thousand (4671.4/100,000) cases and 12,1 thousand deaths (81.6/100,000) (CORONAVIRUS BRASIL, 2021).

Bahia is the fourth most populous state in Brazil (about 14 million inhabitants) and the fifth in territorial extension (564,000 km²). These spatial characteristics associated with local development drove the installation of a significant road and airport network in the state. There are 61 public aerodromes, of which, due to the volume of annual passengers, Salvador, Ilhéus, Porto Seguro, Barreiras,
Vitória da Conquista and Teixeira de Freiras stand out (Brasil, 2020). It is noteworthy that the municipality of Juazeiro, in the north of the state, is served by the airport of Petrolina, Pernambuco.

The emergence or reemergence of pathogens is an important challenge for global public health. The high transmissibility and infectivity of the new coronavirus, the high proportion of asymptomatic transmitters and the rapid and continuous spatial displacement of people, by the different mechanisms of locomotion, are elements that can contribute to the dissemination of COVID-19 (Li et al., 2020; Wong et al., 2020; Ahmed et al., 2020; Carmo et al., 2020).

The spatial analysis of the spread of the disease can contribute to decision making by the local government, favoring the control of the disease in the state (Arcencio, 2015). In addition, the influence of highways and the airline network has been associated with the spatial diffusion and internalization of COVID-19 in other countries and states (Carmo et al., 2020; Ramírez-Aldana et al., 2020; Zheng et al., 2020). However, in the state of Bahia there is little evidence to support this theory, already pointed out in other countries and Brazilian states.

Based on the above, this study aimed to describe the geographical dispersion of COVID-19 in the state of Bahia and the importance of major airports and highways in the dynamics of disease transmission.

2. Methods

2.1. Study design, population and period

This is an ecological study involving all cases of COVID-19 registered in the state of Bahia between March 6, date of the first registered case and May 16, 2020. This period comprises 10 epidemiological weeks, from the 10th to the 20th.

2.2. Study scenario

Bahia is a state located in the Northeast Region of the country. Comprised of 417 municipalities, the state has significant socioeconomic inequalities. Although the Human Development Index (HDI) is classified as high (HDI 0.714), 62.8% (262) of the municipalities have low human development and are subject to a broad context of social vulnerabilities (Brasil, 2021a). In addition, the high territorial dimension of the state, as already pointed out in this text, imposes challenges to political management.

2.3. Variables, data sources and collection procedures

In the study, the absolute number of COVID-19 cases and the disease prevalence rate were analyzed. The prevalence rate was calculated from the following equation:

\[
Prevalence\ rate = \frac{Number\ of\ COVID-19\ cases}{\text{Resident population in the year} \times 100,000}
\]

Data on confirmed cases were obtained from the Rede CoVida panel (https://covid19br.wcota.me/), the road network was obtained from the National Department of Land Infrastructure (http://www.dnit.gov.br/mapas-multimodais/shapefiles) and the spatial network of municipalities was obtained from the Brazilian Institute of Geography and Statistics (https://www.ibge.gov.br/geociencias/downloads.geociencias.html). It should be noted that the Rede CoVida panel is a project developed by the Oswaldo Cruz Foundation and consolidates and analyzes data made available by the Brazilian Ministry of Health. These data have intrinsic validity, since they are official statistical data from the Brazilian government.

2.4. Statistical analysis

Global and local Moran statistics were used for spatial analysis. Global Moran statistics were used to identify global spatial autocorrelation (spatial dependence). The Moran index ranges from $-1$ to $+1$, with values close to zero indicating spatial randomness; positive values suggest positive spatial autocorrelation, and negative values suggest negative spatial autocorrelation. To assess the local autocorrelation, the Gi and Gi * statistics of Getis & Ord were applied, as they are based on the distance between locations. Additionally, the Nonparametric Spatial Autocorrelation was used and an autocorrelogram based on distance elaborated (Najar and Marques, 1998).

Analyses were performed using GeoDa software, version 1.10 (Center for Spatial Data Science, Computation Institute, The University of Chicago, Chicago, IL, USA) and Qgis, version 2.14.11 (Open Source Geospatial Foundation [OSGeo], Beaverton, OR, USA).

2.5. Ethical aspects

As this study used only secondary data in the public domain, it is not possible to identify the subjects. For this reason, Research Ethics Committee approval was waived.
Fig. 1. Expansion of COVID-19 in the state of Bahia, Brazil between March 6 and May 16, 2020.
Fig. 2. Prevalence rate of COVID-19 in the state of Bahia, Brazil, between March 6 and May 16, 2020.
3. Results

The first confirmed case of COVID-19 in Bahia was registered in the municipality of Feira de Santana on March 6, 2020. Seven days later (March 13), the capital Salvador confirmed three cases. In week 12 (03/21/2020), the number of affected municipalities increased to seven: three in the Metropolitan Region of Salvador (Salvador, Lauro de Freitas and Camaçari), one in the interior (Feira de Santana) and three in the South (Prado, Porto Seguro and Itabuna) (Fig. 1).

In week 13 (03/28/2020), COVID-19 starts an interiorization process and reaches 14 more municipalities, totaling 21 affected locations (127 confirmed cases). Among the municipalities, Juazeiro (in the northern region), Barreiras (in the extreme west) and

Fig. 3. Spatial Statistics of COVID-19 in the state of Bahia, Brazil, between March 6 and May 16, 2020.
Teixeiras de Freitas (in the extreme south) stand out. On week 14, 41 municipalities (10.3%) confirmed the circulation of SARS-CoV-2 in the territory, with emphasis on Vitória da Conquista. At week 15, a total of 72 (17.3%) municipalities had confirmed cases, with a greater concentration in the south of the state (Fig. 1).

From week 16–20, there was a more intense expansion of COVID-19 to the interior of the state, increasing from 94 (22.5%) to 218 (52.3%) the number of municipalities affected (Fig. 1). On May 16, the state had confirmed 8288 cases of the disease, with an average prevalence rate of 26.73 ± 43.63 per 100 thousand inhabitants (Fig. 2). The municipalities of Urucuca (302.15/100,000), Itabuna (285.21/100,000), Ipiáu (281.21/100,000), Ilhéus (229.78/100,000) and Salvador (183.82/100,000) were the ones that had the highest prevalence rates of COVID-19 (Fig. 2).

A global spatial autocorrelation was observed (I Moran 0.2323; p = 0.01), with the influence of distance: positive correlation at distances less than 205.8 km (I Moran 0.040; p = 0.01) and greater than 800 km (I Moran 0.080; p = 0.01) (Fig. 3A). In addition, the local Gi statistic showed a cluster involving 30 municipalities in the southern region of the state and the Gî statistic showed 33 municipalities on the axis that runs from the south to the west of the state (Fig. 3B).

4. Discussion

Based on the spatial dispersion pattern of COVID-19 in the state of Bahia and the spatial autocorrelation of the prevalence rate influenced by the distance, we believe that, airports and highways that cross the state contributed to the interiorization of the disease.

The first argument in favor of this hypothesis concerns the spatial pattern. The first cases of COVID-19 were concentrated in areas served by three important airport complexes in the state, located in Salvador, Ilhéus and Porto Seguro. It is noteworthy that the first confirmed case in Feira de Santana had a history of international travel, having landed in Salvador. The airports of Porto Seguro and Ilhéus, in the southern region of the state are important ports of entry for tourism. These two airports have the highest passenger volumes in the interior of the Northeast. In 2019, these airports handled 1.8 million and 521 thousand passengers, respectively (Brasil, 2020). In the South region, a spatial cluster with a high prevalence rate was found, comprising 30 municipalities.

In the far west of the state, the first case was confirmed in Barreiras on March 22. In 2019, Barreiras airport handled 79 thousand passengers, with domestic flights available (Brasil, 2020), mainly connecting Brasília and Salvador, giving rise to an important gateway for COVID-19 in the region. In addition, Barreiras airport serves the municipalities in the Northwest of the state. The positive spatial autocorrelation observed in distances over 800km corroborates the hypothesis that air transport contributed to the arrival of the disease in this region of the state.

That same week, cases were also confirmed in Juazeiro (in the north), Vitória da Conquista (in the southwest) and Teixeira de Freitas (in the extreme south). Juazeiro is served by Senador Nilo Coelho Airport, in Petrolina/Pernambuco, an important domestic airport complex (handling 389 thousand passengers in 2019) and cargo handling, of which 71.7% refers to the export of irrigated fruit products (Brasil, 2020). In Vitória da Conquista, the local airport handled 66 thousand passengers in the second half of 2019 and, in Teixeira de Freitas, there were 33 thousand passengers in 2019 (Brasil, 2020). The displacement of people plays an important role in the dispersion of respiratory infections and has contributed to the rapid spread of COVID-19 worldwide (Zheng et al., 2020; Olsen et al., 2003).

In China, asymptomatic cases have taken the disease to other neighboring cities and person-to-person transmission has resulted in rapid spread of the virus (Zheng et al., 2020). A study carried out in China showed a significant and positive association between the frequency of flights, trains and buses and the daily and cumulative number of confirmed cases of COVID-19 recorded in neighboring cities. The authors also showed that the shortest distance was inversely associated with the highest number of cases (Zheng et al., 2020).

From the arrival of the disease in the larger municipalities of the state with airports, it is likely that the road network is responsible for the spread of the virus to neighboring municipalities. The daily displacement of people between cities has been associated with the dispersion of COVID-19 worldwide (Wong et al., 2020; Zheng et al., 2020). The corridor of priority municipalities that connect the south of the state to the west may indicate the importance of highways in the interiorization of the disease.

A Brazilian study carried out in the state of Pernambuco, bordering Bahia, showed an important contribution of highways in the spatial dispersion and interiorization of the disease, as well as the Petrolina Airport, a Pernambuco city next to Juazeiro, in the North of Bahia (Carmo et al., 2020). International studies also highlight the importance of high urban mobility and connectivity between localities as important mechanisms involved in the spatial dispersion of COVID-19 (Ramírez-Aldana et al., 2020).

Besides the aspects related to the state’s highways and airways, it is pertinent to highlight the importance of other factors that when present in the territories favor spatial dispersion, among which are the population’s living conditions and the social dynamics in different countries and regions (de Souza et al., 2020b; Biggs et al., 2020; Bamba et al., 2020; Hawkins, 2020). In Brazil, about 59% in the variation in the incidence of COVID-19 is attributed to social inequalities of income, population density, and higher lethality (Figueiredo et al., 2020). For this reason, it has been argued that the poorest populations are most severely affected by the consequences of the pandemic (de Souza et al., 2020b).

In a study carried out in Bahia, the high burden of the disease was associated with the worst living conditions of the population, whose lethality was 1.4 times higher in municipalities with high social vulnerability when compared to those with low social deprivation (de Souza et al., 2020a). This context reflects the need to consider the social determinants of health in plans for coping with the disease (de Souza et al., 2020a; de Souza et al., 2020b; Ferreira dos Santos et al., 2020).

The complexity of the transmission dynamics and the difficulties in facing the pandemic in the state of Bahia are even greater when we consider the following points: i. 66% of the workers in Bahia work in the informal market (Ferreira dos Santos et al., 2020), not only hampering the adoption of social distance measures, but demanding greater economic support from the government; ii. The high
territorial dimension of the state and the number of municipalities impose challenges to local management, both in the provision of tests for the diagnosis of the disease and in hospital beds; iii. 58.9% (246/417) of the municipalities have less than 20 thousand inhabitants and, therefore, reduced capacity for health services (Brasil, 2021b); iv. The high flow of people around the municipalities in the state, which concentrate commercial and health services. This process of daily migration between cities can contribute to the rapid spatial spread of the disease.

The migratory flow in search of medical attention has also been pointed out as responsible for the interiorization of the disease (BrasilMinistério da SaúdeFundação Oswaldo Cruz, 2020). In general, the smaller municipalities, due to their limited capacity to offer care to their population, pact with larger municipalities, which in large part, assume the responsibility for the care of medium and high complexity patients (Mello and Viana, 2012). This daily transit between cities can be another element associated with the interiorization of COVID-19.

Even considering the methodological care, the present study has limitations, among which the lack of population testing offer at the beginning of the pandemic and the incapacity of the surveillance systems of the smaller municipalities of the state stand out. In addition, the possible underreporting of COVID-19 cases also represents a limitation.

For this reason, measures, such as the partial interruption of air and road traffic, the limitation of urban mobility within or between cities and sanitary barriers can reduce the intensity as the COVID-19 spreads. Thus, for smaller municipalities that have not yet been reached by COVID-19, the government must adopt preventive measures.

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None.

5. Ethics

Approval and Consent to Participate As this study used only secondary data in the public domain, it is not possible to identify the subjects. For this reason, Research Ethics Committee approval was waived.

Availability of data and materials

All data and materials used in this work were publicly available.

Author’s contributors

Drs Souza CDF, Carmo RF, Machado MF and Silva Junior AG and designed the study. Dr. Souza CDF independently collected and analyzed the data. Drs Machado MF, Carmo RF contributed to the interpretation of the data. Drs Souza CDF, Silva Jr AG, and Machado MF drafted the manuscript. Drs Souza CDF and Carmo RF revised it critically for important intellectual content. All authors agreed to be accountable for all aspects of the work and approved the final version of the paper.

Declaration of competing interest

We declare that we have no conflicts of interest.

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