JIDC | THE JOURNAL OF INFECTION IN DEVELOPING COUNTRIES

Coronavirus Pandemic

Network analysis of socioeconomic disparities and public transport in COVID-19 spread: a case study in northeast Brazil

Taise F Cavalcante[1,2], Waneska de S Barboza[1], Cliomar A dos Santos[3], Adriano Antunes de S Araújo[2], Lucindo José Quintans-Júnior[2], Paulo Ricardo Martins-Filho[2,4]

[1] Aracaju Health Department, Aracaju City Hall, SE, Brazil
[2] Graduate Program in Health Sciences, Federal University of Sergipe, SE, Brazil
[3] Central Laboratory of Public Health (LACEN/SE), Government of Sergipe State, SE, Brazil
[4] Investigative Pathology Laboratory, Federal University of Sergipe, SE, Brazil

Abstract

Introduction: The coronavirus disease 2019 (COVID-19) pandemic has significantly impacted public transportation systems worldwide. In this study, we evaluated the rate of COVID-19 positivity and its associated factors among users of public transportation in socioeconomically disadvantaged regions of Brazil during the pre-vaccination phase of the pandemic.

Methodology: This ecological study, conducted in Aracaju city in Northeast Brazil, is a component of the TestAju Program. This initiative was designed to expand COVID-19 testing to asymptomatic individuals in public spaces such as squares and bus terminals. Using logistic regression, we examined the relationship between COVID-19 positivity and factors such as demographics, socioeconomic status, and travel frequency. The Fruchterman-Reingold algorithm was used to explore transmission pathways across neighborhoods with varying living conditions.

Results: Of the 1,420 public transport users tested via real time reverse transcriptase polymerase chain reaction (RT-PCR), 249 were positive, indicating a 17.5% positivity rate (95% CI: 15.7–19.6). Our findings revealed a higher positivity rate during periods of increased viral spread (OR = 4.3, 95% CI: 3.1–5.9) and in neighborhoods with poorer conditions (OR = 1.5, 95% CI: 1.1–2.1). Network analysis revealed affluent neighborhoods as significant transmission hubs of the disease.

Conclusions: Our study highlights the vital role of urban mobility patterns in the spread of COVID-19. Neighborhoods with better living conditions that serve as hubs of activity and movement, enable gatherings and interactions among people from diverse regions, including those from areas with higher infection rates.

Key words: COVID-19; SARS-CoV-2; environment; epidemiology.

J Infect Dev Ctries 2024; 18(12.1):S305-S309. doi:10.3855/jidc.19843

(Received 13 January 2024 – Accepted 11 June 2024)

Introduction

The coronavirus disease 2019 (COVID-19) pandemic has posed unprecedented challenges for the public transportation systems, especially in developing countries such as Brazil. Public transport, notably buses, have been identified as a key vector for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) spread due to factors such as the close proximity of passengers, limited air circulation, and frequently touched surfaces including seat handles, door open/close buttons, and handrails [1,2]. Moreover, the inadequate infrastructure of public transport in these countries may lead to excessive passenger density, thus increasing the risk of infection [3]. Implementing mitigation strategies, enforcing hygiene practices, limiting vehicle capacity, and improving ventilation, are crucial but encounter obstacles due to the constraints of resources and infrastructure [4]. Consequently, comprehending the transmission dynamics of COVID-19 in the realm of public transportation in developing countries is vital for devising effective public policies and safeguarding both the passengers and the sector employees. This study evaluated the COVID-19 positivity rate and its associated factors among users of the public transportation system in Aracaju, Sergipe, Northeast Brazil.

Methodology

Aracaju, a coastal city and the capital of Sergipe state, is characterized by a population of approximately 602,000 inhabitants, with an average minimum wage of 2.8 Brazilian Reals per hour, and an employment rate of 35%. Situated in a region facing economic challenges, the city is administratively divided into 42 neighborhoods and operates a public transport network comprising 596 buses across 118 routes, serving 200,000 daily users [5]. This cross-sectional ecological study, a part of the TestAju Program, was conducted from April to August 2021 [6]. This timeframe, marked by the prevalence of the SARS-CoV-2 Gamma and Delta variants [7], coincided with the period before widespread COVID-19 vaccination in Brazil. The initiative was spearheaded by the Aracaju Health Department and aimed to expand COVID-19 testing to asymptomatic individuals across various neighborhoods of the city. Real time reverse transcriptase polymerase chain reaction (RT-PCR) tests using nasal swab samples were administered by health officials in public areas, including squares and bus terminals, based on spontaneous requests. Data gathered included demographic and logistical details. These encompassed each participant's gender, age, residential neighborhood, and frequency of public transport usage. The distance in kilometers between their residential neighborhood and the testing site was also recorded. Additionally, the neighborhoods, both residential and testing sites, were categorized by the living conditions index (LCI) [8,9], which assesses factors like education, income, and housing, thereby classifying neighborhoods into high, intermediate, low, or very low LCI categories. Of the 42 neighborhoods in Aracaju, 20 were classified as high/intermediate LCI and 22 as low/very low LCI.

In addition to calculating the COVID-19 positivity rate with a 95% confidence interval (CI), we executed a logistic regression analysis to investigate factors associated with a positive COVID-19 outcome among public transport users. The independent variables included gender (male and female), age, the LCI of the testing neighborhood (categorized as high/intermediate and low/very low), and the frequency of public transport utilization (1–2 times/week, 3–4 times/week, and 5 or more times/week), as well as the month of sample collection. In the logistic regression analysis, the category representing the least frequent use of public transport (1–2 times/week) was used as a baseline for comparison with the other categories, with adjustments made for the distance between the participants' residence and the testing site. We also segmented the sample collection period for RT-PCR in the statistical model based on the city's COVID-19 case trends: a period with an increasing number of cases (April–May), and a period with a decreasing number (June–August) [10]. In addition to the main analysis, an interaction analysis was performed to determine if the relationship between the frequency of public transport use and the RT-PCR results varied with other variables. The findings were presented as odds ratios (OR) with 95% CI, and all analyses were conducted using the R software (R Foundation for Statistical Computing, Vienna, Austria).

In this analysis, the Fruchterman-Reingold algorithm [11] was additionally employed to investigate interactions between neighborhoods based on residence and testing locations, considering the LCI as a socioeconomic stratifier. The database was processed to create a directed graph in a random layout, where the nodes symbolized neighborhoods, and the edges denoted interactions derived from testing data and the residences of individuals. Degree centrality and betweenness centrality metrics were applied to identify nodes with the highest number of direct connections and those acting as pivotal transit points in the network, respectively. These metrics were computed using the NetworkX library in Python. The quantitative analysis focused on the count of edges and the proportion of positive versus negative RT-PCR results, allowing for a detailed understanding of interaction and testing dynamics within and between different socioeconomic strata. All data used in this study were de-identified and sourced secondarily from the microdata catalog of the Aracaju Health Department.

Results

A total of 80,166 individuals were tested for COVID-19 in Aracaju between April and August 2021, of whom 38,340 tested positive (47.8%, 95% CI 47.5–48.2%). During this period, the TestAju Program conducted 5,346 tests, including 1,420 among public transport users. Out of these, 249 were positive, indicating a positivity rate of 17.5% (95% CI 15.7–

Figure 1. Monthly trends in coronavirus disease 2019 (COVID-19) positivity rates. A, positive cases among the general population and B, among public transport users in Aracaju, Sergipe, April–August 2021.

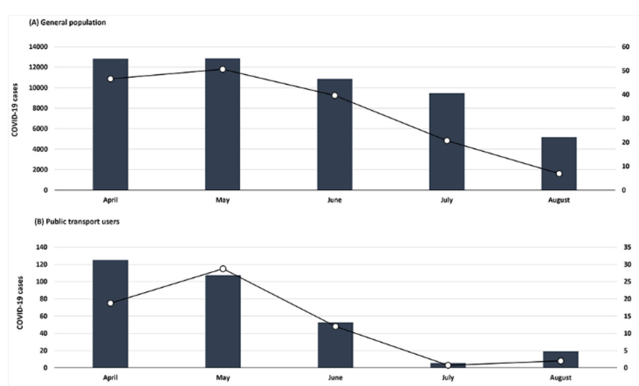


Table 1. Factors associated with coronavirus disease 2019 (COVID-19) among public transport users in Aracaju, Sergipe, Brazil (April–August 2021).

Variable	Total (%)	COVID-19 positivity rate (%)	OR (95% CI)	*p* value
Gender				
Male	514 (36.2)	19.7	1.29 (0.96–1.74)	0.086
Female	906 (63.8)	16.3	Ref	
Age (years)	43.6 (± 15.6)		0.99 (0.98–1.00)	0.314
Period				
April–May	668 (47.0)	28.4	4.29 (3.11–5.92)	< 0.001
June–August	752 (53.0)	7.9	Ref	-
LCI				
Low/very-low	782 (55.1)	21.7	1.53 (1.12–2.10)	0.008
High/intermediate	638 (44.9)	12.4	Ref	-
Frequency of public transport use				
1–2 times/week	777 (54.7)	16.6	Ref	
3–4 times/week	214 (15.1)	20.1	1.30 (0.87–1.95)	0.203
≥ 5 times/week	429 (30.2)	17.7	1.10 (0.78–1.53)	0.591
Interaction analysis				
3–4 times/week * gender			0.96 (0.42–2.19)	0.924
* age			1.00 (0.97–1.03)	0.948
* period			1.02 (0.42–2.49)	0.961
* LCI			0.74 (0.31–1.74)	0.485
≥ 5 times/week * gender			0.90 (0.46–1.77)	0.757
* age			0.99 (0.97–1.01)	0.326
* period			1.10 (0.53–2.29)	0.803
* LCI			0.74 (0.36–1.49)	0.393

LCI: Living Conditions Index; Ref: reference; OR: odds ratio; CI: confidence interval; * indicates interaction analysis between variables.

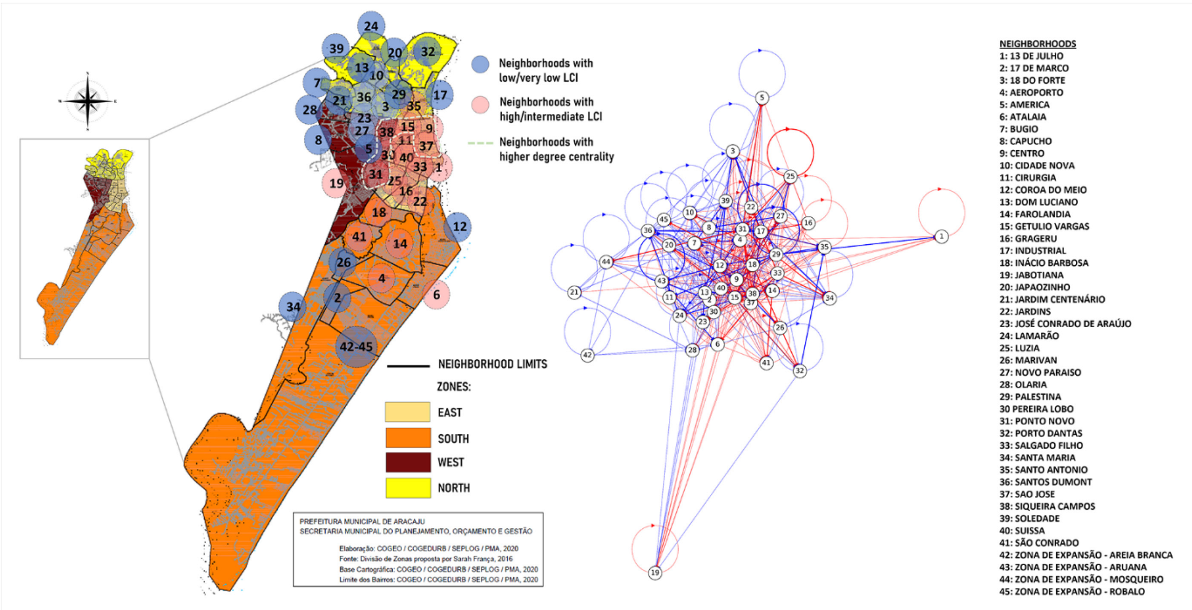
19.6) as shown in Figure 1. Among the public transport users tested, the majority were women (63.8%), with average age of 43.6 years. Usage patterns revealed that 777 users (54.7%) used public transport 1–2 times per week, 214 (15.1%) used it 3–4 times per week, and 429 (30.2%) used it at least 5 times per week. Logistic regression analysis indicated a higher likelihood of a positive COVID-19 test among public transport users during periods of increased viral spread in the city (OR = 4.3, 95% CI 3.1–5.9, $p < 0.001$) and in neighborhoods with poorer living conditions (OR = 1.5, 95% CI 1.1–2.1, $p = 0.008$). A higher weekly frequency of public transport use was not associated with an increased chance of COVID-19, as detailed in Table 1.

Quantitative analysis of network topology and data-derived graphs showed an asymmetric distribution in RT-PCR results and in the connections between neighborhoods, distinguished by their LCI. Neighborhoods with low living conditions exhibited a higher rate of positive RT-PCR tests (21.01%) compared to those with high living conditions (10.21%). Centrality analysis identified the Centro neighborhood as a pivotal hub within the network, boasting a degree centrality of 95.5% and a betweenness centrality of 8.7%. This highlights its dual role as both a densely connected area and a strategic transit point in the urban layout, potentially serving as a key vector in COVID-19 transmission dynamics. Furthermore, neighborhoods like São José, Siqueira Campos, Getúlio Vargas, and Ponto Novo emerged as critical nodes in the network, exhibiting significant degree centrality. Simultaneously, neighborhoods such as Siqueira Campos, Farolândia, Coroa do Meio, and Getúlio Vargas were notable for their high betweenness centrality, suggesting their potential roles as transmission channels or interconnecting links across diverse city areas. These results suggest a potential influence of these neighborhoods on the dynamics of disease spread (Figure 2).

Discussion

In this study, the implementation of a novel street testing approach in Aracaju not only distinguished itself from other national strategies [12,13] by including asymptomatic individuals in public and transportation areas, but also shed light on the unique dynamics of COVID-19 transmission. This approach revealed a significantly lower positivity rate for COVID-19 among public transport users compared to the city's general population, which can be explained by the differences in the COVID-19 testing model between these two populations. While the official data from local authorities primarily involve testing individuals who seek health services for respiratory symptoms, a practice that naturally skews towards higher positivity rates, the TestAju Program's methodology includes the spontaneous testing of asymptomatic individuals in public areas. Additionally, these findings might have

Figure 2. Integrated visualization of coronavirus disease 2019 (COVID-19) positivity mapping in Aracaju, Sergipe, and Fruchterman-Reingold force-directed network diagram depicting disease transmission dynamics among neighborhoods according to the living conditions index (LCI).



been influenced by the preventive measures initiated by the Aracaju City Hall at bus terminals in March 2021, which included regular disinfection of the bus fleet, organization of boarding and disembarking queues, provision of hand sanitizer for passengers, and enforcement of mask-wearing guidelines. These initiatives were focused on high-density and high-mobility environments [14,15], and may have been important in reducing the spread of the virus among public transport users, pointing to important pathways for public health strategies in similar urban contexts.

Consequently, the absence of a direct relationship between the frequency of public transport usage and an elevated probability of testing positive for COVID-19 illustrates the intricate nature of viral transmission dynamics. Although this observation could be influenced by preventative measures implemented at bus terminals, it is important to consider individual risk behaviors that are not captured by this study, such as mask usage and hand hygiene. Additionally, the data analyzed here might exhibit autocorrelation, suggesting that individuals who use public transportation more frequently could be more cognizant and compliant with preventative measures. However, in an ecological perspective, our study reveals a multifaceted panorama of COVID-19 transmission dynamics in Aracaju. Although a higher incidence of COVID-19 has been observed in poorer communities in Northeast Brazil [16,17], the network analysis revealed a central role for neighborhoods with better socioeconomic conditions, characterized by intense commercial and service activities. This finding emphasizes the intricate interplay among various socioeconomic layers within urban dynamics, where affluent areas, despite better living conditions, become critical nodes in the virus's transmission network. Such a central role may be driven by multiple factors, including increased human flow for business and employment purposes [18], fostering heightened interactions among residents from diverse city sectors, irrespective of their socioeconomic status.

Conclusions

This study highlights the vital role of urban mobility patterns in the spread of COVID-19. Neighborhoods with better living conditions, serving as hubs of activity and movement, enable gatherings and interactions among people from diverse regions, including those from areas with higher infection rates. This convergence of populations creates an environment conducive to the virus's dissemination, transcending socioeconomic boundaries, and emphasizing the need to consider urban mobility and meeting points in developing public health strategies to tackle future COVID-19 waves. These findings are particularly crucial in formulating responses to pandemics, notably in urban settings and developing countries, where the challenges are exacerbated by infrastructural limitations and socioeconomic inequalities. Therefore, the experience of Aracaju is a valuable case study, offering lessons that could shape global public health management strategies in times of health crises.

Acknowledgements
LJQJ, AASA, and PRMF are research productivity fellows at the National Council for Scientific and Technological Development (CNPq), Brazil.

Authors' contributions
Conception/design: TFC, WdSB, AAdSA, LJQ-J, PRM-F; data collection: TFC, WdSB, CAdS, PRM-F; data analysis/interpretation: TFC, PRM-F; supervision: PRM-F; drafting the manuscript, intellectual contributions on text/revisions, final approval of manuscript: TFC, WdSB, CAdS, AAdSA, LJQ-J, PRM-F.

References
1. Bertone M, Mikszewski A, Stabile L, Riccio G, Cortellessa G, d'Ambrosio FR, Papa V, Morawska L, Buonanno G (2022) Assessment of SARS-CoV-2 airborne infection transmission risk in public buses. Geosci Front 13: 101398. doi: 10.1016/j.gsf.2022.101398.
2. Ou C, Hu S, Luo K, Yang H, Hang J, Cheng P, Hai Z, Xiao S, Qian H, Xiao S, Jing X, Xie Z, Ling H, Liu L, Gao L, Deng Q, Cowling BJ, Li Y (2022) Insufficient ventilation led to a probable long-range airborne transmission of SARS-CoV-2 on two buses. Build Environ 207: 108414. doi: 10.1016/j.buildenv.2021.108414.
3. Basso F, Frez J, Hernández H, Leiva V, Pezoa R, Varas M (2023) Crowding on public transport using smart card data during the COVID-19 pandemic: new methodology and case study in Chile. Sustain Cities Soc 96: 104712. doi: 10.1016/j.scs.2023.104712.
4. Deb S, Hinge G (2023) Passenger's perception about city buses in the aftermath of COVID 19: experience from Guwahati city, India. Int J Disaster Risk Reduct 85: 103489. doi: 10.1016/j.ijdrr.2022.103489.
5. Sindicato das Empresas de Transporte de Passageiros de Aracaju (2024) Industry data. [Article in Portuguese]. Available: https://setransp-aju.com.br/dados-do-setor/. Accessed: 20 January 2024.
6. Barboza WS, Cavalcante TF (2022) TestAju project — strengthening health surveillance in monitoring COVID-19 in Aracaju/SE. [Article in Portuguese]. Available: https://portal.conasems.org.br/brasil-aqui-tem-sus/experiencias/287_projeto-testaju-fortalecimento-da-vigilancia-em-saude-no-monitoramento-da-covid-19-em-aracaju-se. Accessed: 20 January 2024.
7. Martins-Filho PR, de Souza Araújo AA, Quintans-Júnior LJ, Soares B dos S, Barboza W de S, Cavalcante TF, Santos VS (2022) Dynamics of hospitalizations and in-hospital deaths from COVID-19 in northeast Brazil: a retrospective analysis based on the circulation of SARS-CoV-2 variants and vaccination coverage. Epidemiol Health 44: e2022036. doi: 10.4178/epih.e2022036.
8. Martins-Filho PR, de Souza Araújo AA, Quintans-Júnior LJ, Santos VS (2020) COVID-19 fatality rates related to social inequality in Northeast Brazil: a neighbourhood-level analysis. J Travel Med 27: taaa128. doi: 10.1093/jtm/taaa128.
9. Carvalho RA da S, Santos VS, Melo CM de, Gurgel RQ, Oliveira CC da C (2015) Inequalities in health: living conditions and infant mortality in Northeastern Brazil. Rev Saude Publica 49: 5. doi: 10.1590/S0034-8910.2015049004794.
10. Prefeitura de Aracaju (2024) COVID-19 epidemiological bulletins. [Article in Portuguese]. Available: https://transparencia.aracaju.se.gov.br/prefeitura/covid19/covid19-boletins-2/. Accessed: 20 January 2024.
11. Fruchterman TMJ, Reingold EM (1991) Graph drawing by force-directed placement. Softw - Pract Exp 21: 1129–1164. doi: 10.1002/spe.4380211102.
12. Boschiero MN, Palamim CVC, Ortega MM, Mauch RM, Marson FAL (2021) One year of coronavirus disease 2019 (COVID-19) in Brazil: a political and social overview. Ann Glob Health 87: 44. doi: 10.5334/aogh.3182.
13. Martins-Filho PR, Barberia LG (2022) The unjustified and politicized battle against vaccination of children and adolescents in Brazil. Lancet Reg Health Am 8: 100206. doi: 10.1016/j.lana.2022.100206.
14. Zhu P, Guo Y (2021) The role of high-speed rail and air travel in the spread of COVID-19 in China. Travel Med Infect Dis 42: 102097. doi: 10.1016/j.tmaid.2021.102097.
15. Wang CT, Xu JC, Fu SC, Chao CYH (2022) Airborne infection risk of nearby passengers in a cabin environment and implications for infection control. Travel Med Infect Dis 47: 102285. doi: 10.1016/j.tmaid.2022.102285.
16. Martins-Filho PR, Santos VS (2022) Relationship between living conditions in neighborhoods in the Northeast Brazil and COVID-19 estimates during the third wave associated with the Omicron variant. Biodemography Soc Biol 67: 224–228. doi: 10.1080/19485565.2022.2149464.
17. Alencar do Nascimento CM, Freire De Souza CD, De Oliveira Silva LE, Oliveira Silva W, Amaro Barbosa N, do Carmo RF, Andrade EL, Teixeira SHO, Rocha TJM (2022) COVID-19 risk areas associated with social vulnerability in northeastern Brazil: an ecological study in 2020. J Infect Dev Ctries 16: 1285–1293. doi: 10.3855/jidc.15214.
18. Chen Y, Chen M, Huang B, Wu C, Shi W (2021) Modeling the spatiotemporal association between COVID-19 transmission and population mobility using geographically and temporally weighted regression. GeoHealth 5: e2021GH000402. doi: 10.1029/2021GH000402.

Corresponding author
Paulo Ricardo Martins-Filho, PhD.
Universidade Federal de Sergipe, Hospital Universitário,
Laboratório de Patologia Investigativa,
Rua Cláudio Batista, s/n. Sanatório.
Aracaju, Sergipe, Brasil. CEP: 49060-100.
Tel: +55 79 3194-6600
Fax:+55 70 3194-6837
E-mail: prmartinsfh@gmail.com

Conflict of interests: No conflict of interests is declared.