Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Short Communication

Spatial clustering of low rates of COVID-19 vaccination among children and adolescents and their relationship with social determinants of health in Brazil: a nationwide population-based ecological study

V.S. Santos a, b, c, *, T.S. Siqueira c, J.R.S. Silva d, R.Q. Gurgel c, e

a Department of Medicine, Federal University of Sergipe, Lagarto, Brazil
b Applied Health Sciences Program, Federal University of Sergipe, Lagarto, Brazil
c Health Sciences Graduate Program, Federal University of Sergipe, Aracaju, Brazil
d Department of Statistics and Actuarial Science, Federal University of Sergipe, Aracaju, Brazil
e Department of Medicine, Federal University of Sergipe, Aracaju, Brazil

Article history:
Received 21 September 2022
Received in revised form 16 October 2022
Accepted 21 October 2022
Available online 2 November 2022

Keywords:
COVID-19 vaccination
Spatial clusters
Social determinants of health
Brazil

ABSTRACT

Objective: This study aimed to investigate the spatial clusters of high and low COVID-19 vaccination rates among children and adolescents across Brazilian municipalities and their relationship to social determinants of health.

Study design: This is a nationwide population-based ecological study.

Methods: We have obtained for each of the 5570 Brazilian municipalities data on the COVID-19 vaccination rate of children and adolescents by August 16, 2022, the Gini index, the social vulnerability index and the municipal human development index. A Bayesian empirical local model was used to identify fluctuations in the COVID-19 vaccination rates. Spatial clusters were identified using scan spatial statistic tests. The relationship among COVID-19 vaccination rates and social determinants of health was explored by using multiple linear regression models.

Results: Overall, 52.1% of children aged 5–11 years and 72.8% of adolescents aged 12–17 years have been fully vaccinated against COVID-19 in Brazil by mid-August 2022. There was spatial dependence on the smoothed rates for both children (I Moran 0.66; P < 0.001) and adolescent (I Moran 0.65; P < 0.001) groups. The lowest rates occurred in municipalities in the North and Northeast regions. Municipalities with a higher Gini index, higher social vulnerability index and lower municipal human development index were more likely to have a lower COVID-19 vaccination rate for both children and adolescent groups.

Conclusion: COVID-19 vaccination of children and adolescents was heterogeneously distributed, with spatial clusters of the lowest vaccination rates occurring mainly in municipalities with marked socioeconomic disparities and social vulnerability, especially in the North and Northeast regions.

© 2022 The Royal Society for Public Health. Published by Elsevier Ltd. All rights reserved.

Introduction

COVID-19 vaccines are recommended in Brazil since January 2022 for individuals over 5 years of age. As of August 16, 2022, 61.8% of children and adolescents aged 5–17 years have been fully vaccinated against COVID-19 in Brazil.1 Since the country has marked social and health inequities, vaccination rates are expected to vary geographically. Furthermore, there is currently limited information on the vaccination distribution and on the existence of spatial clusters of low COVID-19 vaccine coverage among children and adolescents and their relationship to sociodemographic characteristics. Thus, we examined spatial clusters of high and low COVID-19 vaccination rates among children and adolescents across Brazilian municipalities and their relationship to social determinants of health.

* Corresponding author. Federal University of Sergipe, Campus Lagarto, Av. Gov. Marcelo Dédia, s/n, São José, Lagarto, Sergipe 49400-000, Brazil.
E-mail address: santosvictor19@gmail.com (V.S. Santos).

https://doi.org/10.1016/j.puhe.2022.10.024
0033-3506/© 2022 The Royal Society for Public Health. Published by Elsevier Ltd. All rights reserved.
Methods

Study design

We conducted a population-based ecological analysis of the spatial distribution of all children and adolescents fully vaccinated against COVID-19 until August 16, 2022. The geographic units of analysis were the municipalities, and we included all the municipalities of the country. We examined the relationship between the municipalities’ COVID-19 vaccination rate and social determinants of health. All analyses were performed considering the children and adolescents’ residence data.

Data sources and measures

Data were obtained from a variety of publicly available databases. Data on COVID-19 vaccination were obtained from OpenData SUS.1 This database has the vaccination records per municipality for all children (aged 5–11 years) and adolescents (aged 12–17 years). The number of children and adolescents for 2021 by age and municipalities was obtained from the Brazilian Ministry of Health’s estimate. This population estimate is the same one used by municipal health departments to plan vaccine doses for the target population. Gini Index and Municipal Human Development Index (MHDI) by municipality were obtained from the 2010 Brazilian Census. The Gini index measures the degree of income concentration in a population group and ranges from 0 to 1, with values closer to 1 representing higher income concentration. The MHDI is composed of well-established indicators to quantify three dimensions of human development: longevity, education and income; and it is adapted to the national context and uses local indicators available for the calculation. The MHDI ranges from 0 to 1, with values closer to 1 indicating higher human development.

Social Vulnerability Index (SVI) was obtained from the Institute of Applied Economic Research.3 This index estimates the degree of vulnerability and social exclusion of a population and is composed of 16 social indicators comprising domains of urban infrastructure, human capital and income and work. The SVI scores range from 0 to 1, and higher values indicate higher social vulnerability.

Data analysis

We calculated the full scheme (second or single dose) immunisation rates (percentage) for each of the 5570 Brazilian municipalities. Crude rates were smoothed using the Local Empirical Bayesian Estimator. Spatial autocorrelation was measured using the Moran’s Global Index and the Local Index of Spatial Association (LISA).2 Scattering diagrams were generated to position the municipalities into quadrants (Q) and calculated the neighbouring municipalities average into Q1 (high/high: positive values and positive averages), Q2 (low/low: negative values and negative averages); Q3 (high/low: positive values and negative averages); Q4 (low/high: negative values and positive averages).

Assumptions of normality were assessed by using the Kolmogorov–Smirnov test and homoscedasticity by the Levene test, and both children and adolescents’ vaccination rates showed a symmetrical distribution. Multiple linear regression models were fitted to relate the proportion of vaccinated people to the socio-economic indicators (Gini Index, SVI and MHDI). The analyses were performed in R, version 4.2.0, with a significance level of 5%.

Ethical considerations

Institutional review board approval and informed consent were not required because all data were obtained from public domain databases and were deidentified.

Results

Overall, 52.1% of children aged 5–11 years and 72.8% of adolescents aged 12–17 years have been fully vaccinated against COVID-19 in Brazil by mid-August 2022. COVID-19 vaccination rates for both children and adolescents’ groups varied across municipalities. There was spatial dependence on the smoothed rates for both children (I Moran 0.66; P < 0.001) and adolescent (I Moran 0.65; P < 0.001) groups. The highest rates of COVID-19 vaccination for both children and adolescent groups occurred in municipalities in the Southeast and South regions, whereas the lowest rates occurred in municipalities in the North and Northeast regions (Fig. 1). Municipalities with a higher Gini Index, higher SVI and lower MHDI were more likely to have a lower COVID-19 vaccination rate for both children and adolescents (Table 1 in Supplementary Material).

Discussion

Although Brazil has a National Immunization Program (NIP) integrated to and based on primary healthcare facilities, with more than 35,000 vaccination rooms disseminated throughout the country,4 COVID-19 vaccination of children and adolescents was heterogeneously distributed, with spatial clusters of the lowest vaccination rates occurring mainly in municipalities with marked socio-economic disparities and social vulnerability, especially in the North and Northeast regions.

The World Health Organization global COVID-19 vaccination strategy targets 100% coverage for all older adults (aged ≥60 years), health workers and other priority risk groups with primary series and booster doses; and 70% of total population (irrespective of age group) for international benchmarking and against context-specific country targets.5 In Brazil, the Ministry of Health recommends a COVID-19 vaccination coverage of 90% of the population regardless of the age group for the complete primary schedule (dose 1 and dose 2 or single dose) and boosters.6 This study found a COVID-19 vaccination coverage of 52.1% for children aged 5–11 years and 72.8% for adolescents aged 12–17 years, both below the targets recommended. Furthermore, our findings highlighted a heterogeneous distribution of low coverage across the country.

The geographical distribution of lower COVID-19 vaccination coverage clusters resembles the distribution of cases and deaths among children and adolescents in Brazil.7 This shows that people living in socio-economically disadvantaged communities are substantially affected by COVID-19 not only in terms of incidence and mortality but also in vaccination access. In fact, people living in areas with large social inequalities often have difficult access to education and health services.

In addition, Brazil has suffered from misinformation campaigns about the COVID-19 vaccines,8 which would cause vaccine hesitancy, especially among people with low access to scientifically based information. This demonstrates the need for awareness and information campaigns by official government agencies about the safety and efficacy of the COVID-19 vaccines for the paediatric populations.9
The southeast region had the highest COVID-19 vaccination coverage rates, especially the state of São Paulo. This may be related to two important aspects. São Paulo state concentrates on the municipalities with the highest MHDI in Brazil, with a well-structured health services network, providing greater opportunity for access to vaccination. In addition, COVID-19 vaccination in Brazil was started by São Paulo state by governmental initiative of importation and production of the adsorbed inactivated COVID-19 vaccine (Sinovac/Butantan), which later became part of the Brazilian NIP and after, also distributed to the other states.6

This study assessed a large sample size of children and adolescents fully vaccinated against COVID-19 and how social determinants of health are associated with lower COVID-19 vaccination rates in a country with marked social inequalities. Nevertheless, the results presented here need to be interpreted according to the study limitations. The secondary data and ecological studies are unsuitable to establish disease causality; and therefore, our analyses only provide evidence of statistically significant relationships between COVID-19 vaccination rates, poverty, and social inequalities. Also, our findings are only applied to children and adolescents aged 5–17 years.

Although low vaccination rates of children and adolescents occurred in all regions of Brazil, the main clusters of low COVID-19 vaccination occurred in municipalities in the North and Northeast, which are the regions with the worst socio-economic indicators and greatest health disparities. Identifying areas with lower

---

**Fig. 1.** Spatial distribution of the percentage of children and adolescents fully vaccinated against COVID-19 in Brazil on August 16, 2022. (A) Local Empirical Bayesian Estimator and (B) Moran Map for the vaccination rate for children aged 5–11 years. (C) Local Empirical Bayesian Estimator and (D) Moran Map for the vaccination rate for adolescents aged 12–17 years.
vaccination coverage against COVID-19 may assist policymakers in the allocation of resources (as information campaigns and mass immunisation) to localities with the lowest vaccination rates for children and adolescents.

Author statements

Ethical approval

Institutional review board approval and informed consent were not required because all data were obtained from public domain databases and were deidentified.

Funding

There was no funding source for this study. The corresponding author has full access to all the data in the study and had final responsibility for the decision to submit for publication.

Competing interests

There is no conflict of interest.

Author contributions

V.S., T.S. and J.R.S. contributed to concept and design. All authors contributed to acquisition, analysis, or interpretation of the data; and critical revision of the article for important intellectual content. V.S. and T.S. drafted the article. J.R.S. contributed to statistical analysis. V.S. and J.R.S. contributed to administrative, technical, or material support. V.S. contributed to supervision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2022.10.024.

References

1. Brazil. Ministério da Saúde. OpenDataSUS. Brasília, DF: Ministério da Saúde; 2022.
2. Instituto de Pesquisa Econômica Aplicada | IPEA. Atlas da Vulnerabilidade Social nos Municípios Brasileiros. IPEA; 201577 p.
3. Anselin L. Local indicators of spatial association-LISA. Geogr Anal [Internet] 2010 Sep 3;27(2):93–115. Available from: https://doi.org/10.1111/j.1538-4632.1995.tb00338.x.
4. Domingues CMAS, Maranhão AGK, Teixeira AM. Domínguez RAS. The Brazilian national immunization Program: 46 years of achievements and challenges. Cad Saúde Pública; 2020. p. 36.
5. WHO. Global COVID-19 vaccination strategy in a changing world: July 2022 update. Glob COVID-19 Vaccin Strateg a Chang World July 2022 Updat [Internet]. 2022 [July]. Available from: https://www.who.int/publications/m/item/global-covid-19-vaccination-strategy-in-a-changing-world–july-2022-update.
6. Brasil. Ministério da Saúde. Secretaria de Vigilância em Saúde. Departamento de Imunizações e Doenças Transmissíveis. Plano Nacional de Operacionalização da Vacinação contra a COVID-19 [Internet]. Brasília/DF: Ministério da Saúde; 2022. p. 171. Available from: http://bvsms.saude.gov.br/bvs/publicacoes/plano_nacional_operacionalizacao_vacinacao_covid19.pdf.
7. Santos VS, Siqueira TS, Cubas Atienzar AI, da Rocha Santosantos MAR, Vieira SCF, de Siqueira Alves Lopes A, et al. Spatial clusters, social determinants of health and risk of COVID-19 mortality in Brazilian children and adolescents: a nationwide population-based ecological study. Lancet Reg Heal - Am [Internet] 2022 Sep;13:100311. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2667193X22001284.
8. Barberia LG, Boing A, Santana L, Cota W, Bastos LS. Government inaction on COVID-19 vaccines contributes to the persistence of childism in Brazil. Lancet Reg Heal - Am [Internet] 2022 Sep;13:100346. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2667193X22001635.
9. World Health Organization (WHO). Interim statement on COVID-19 vaccination for children and adolescents. 2021. Geneva,