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Original Article

Spatial-temporal analysis of COVID-19 cases in the state of Alagoas

Análise espaço-temporal dos casos de COVID-19 no estado de Alagoas

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Abstract

The COVID-19 pandemic has severely impacted Brazil, highlighting significant gaps in public health infrastructure. This study aims to analyze the spatial-temporal distribution of COVID-19 cases in Alagoas. The study covers all 102 municipalities in Alagoas, using official data from the Alagoas COVID-19 Panel. It is observational and retrospective with an ecological and quantitative approach. Data were collected up to July 2, 2022, totaling 305,806 cases. Spatial analysis was performed using R Statistical software, with Global Moran's Index (GMI) and Local Indicators of Spatial Association (LISAs) identifying spatial clusters. In 2020, municipalities showed significant but weak spatial autocorrelation (GMI = 0.2084; $p < 0.05$). High-High clusters appeared in Maceió and nearby municipalities. In 2021, spatial autocorrelation remained weak (GMI = 0.2344; $p < 0.05$). High-High clusters persisted in Satuba and Maceió, while Low-Low clusters expanded into northeastern Alagoas by 2022. The reduction in High-High clusters in Maceió in 2022 likely resulted from early vaccination efforts. The spatial distribution pattern of COVID-19 in Alagoas reveals significant insights into regional pandemic dynamics. Stable infection rates in the center-west and south of Alagoas may be due to lower population density and less movement. The dynamic nature of COVID-19 spread highlights the need for continuous monitoring and adaptive public health strategies. The study underscores the importance of targeted interventions and future research to refine spatial models and incorporate additional variables to enhance predictive accuracy and inform public health strategies.

Keywords: coronavirus, respiratory infection, COVID-19, public health.

Resumo

A pandemia de COVID-19 impactou severamente o Brasil, destacando lacunas significativas na infraestrutura de saúde pública. Este estudo visa analisar a distribuição espaço-temporal dos casos de COVID-19 em Alagoas. O estudo abrange todos os 102 municípios de Alagoas, utilizando dados do Painel COVID-19 da Secretaria de Estado da Saúde de Alagoas. É observacional e retrospectivo, com caráter ecológico e abordagem quantitativa. Os dados foram coletados até 2 de julho de 2022, totalizando 305.806 casos. A análise espacial foi realizada com o software R Statistical, usando o Índice de Moran Global (GMI) e Indicadores Locais de Associação Espacial (LISAs) para identificar clusters espaciais. Em 2020, os municípios mostraram autocorrelação espacial significativa, mas fraca (GMI = 0,2084; $p < 0,05$). Clusters High-High surgiram em Maceió e municípios vizinhos. Em 2021, a autocorrelação espacial permaneceu fraca (GMI = 0,2344; $p < 0,05$). Clusters High-High persistiram em Satuba e Maceió, enquanto clusters Low-Low se expandiram para o nordeste de Alagoas em 2022. A redução de clusters High-High em Maceió em 2022 provavelmente resultou dos esforços iniciais de vacinação. O padrão de distribuição espacial da COVID-19 em Alagoas revela insights significativos sobre a dinâmica regional da pandemia. Taxas de infecção estáveis no centro-oeste e sul de Alagoas podem ser devido à menor densidade populacional e menor movimento. A natureza dinâmica da disseminação da COVID-19 destaca a necessidade de monitoramento contínuo e estratégias de saúde pública adaptativas. O estudo enfatiza a importância de intervenções direcionadas e pesquisas futuras para refinar modelos espaciais e incorporar variáveis adicionais para aumentar a precisão preditiva e informar estratégias de saúde pública.

Palavras-chave: coronavírus, infecção respiratória, COVID-19, saúde pública.

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1. Introduction

The COVID-19 pandemic has severely impacted Brazil, which has reported some of the highest infection and mortality rates globally (Mathieu et al., 2020). The health system has been overwhelmed, with hospitals and ICU units often operating beyond capacity (Zeiser et al., 2022). This crisis has highlighted significant gaps in public health infrastructure and resources (Noronha et al., 2020). These high numbers underscore the urgent need for comprehensive public policies to address the immediate health crisis and promote long-term socio-economic recovery (Bigoni et al., 2022; Sott et al., 2022).

The situation has been particularly dire in Brazil's poorer and more unequal regions, where the pandemic's effects have been exacerbated by existing socio-economic vulnerabilities (Souza et al., 2020). Overcrowded living conditions and limited access to healthcare have contributed to higher infection and mortality rates in these areas (Almeida et al., 2023). Additionally, many residents in these communities work in informal sectors and lack social safety nets, which has led to severe economic hardship and instability (Garcia et al., 2021). The shift to remote learning has further widened educational disparities, as access to digital resources is often limited (Previtali and Fagiani, 2023).

In the state of Alagoas, the socio-economic challenges have been starkly evident. With one of the highest poverty rates in Brazil (PNUD, 2023), Alagoas has seen its healthcare system stretched to the limit, struggling to manage the surge in COVID-19 cases (Sales et al., 2022). The disease further deepened existing socio-racial inequalities (Villar et al., 2023). Economic impact has been profound, as many Alagoanos rely on informal work and have faced significant income losses during the pandemic (Bridi, 2020).

This study aims to conduct a spatial analysis of the distribution of COVID-19 cases in Alagoas. By mapping the cases across the state, we hope to identify the areas most affected and provide insights that can inform targeted public health interventions and policies to mitigate the ongoing crisis and support long-term recovery.

2. Methods

2.1. Study area

The research area encompasses all 102 municipalities in Alagoas, which had an estimated population of 3,337,357 in 2019 and a population density of 121 individuals per km^2 (IBGE, 2023).

2.2. Study design

This is an observational and retrospective study with an ecological character and a quantitative approach.

2.3. Inclusion criteria

Patients with confirmed COVID-19 diagnoses from March 2020 to June 30, 2022, will be included in the analysis, while cases marked as negative, not performed, ongoing, or left blank on the COVID-19 notification/investigation form will be excluded.

2.4. Data and variables

All COVID-19 data were extracted from the latest update of the Alagoas State Secretary of Health database, from the Covid-19 Panel in Alagoas – a platform developed by the State Secretariat for Planning, Management, and Heritage (SEPLAG) – which systematizes the official pandemic information (Alagoas, 2022). The last data collection was conducted on July 2, 2022, and recorded a total of 305,806 cases.

Based on COVID-19 cases, the following rates were calculated: prevalence (number of confirmed cases per 100,000 inhabitants) and the Global Moran's Index (GMI) for enhanced spatial analysis.

2.5. Statistical analysis

Spatial analysis was also performed using R Statistical 4.0.5 software. To estimate spatial autocorrelation, the Global Moran's Index (GMI) was used, ranging from -1 to +1, providing its statistical significance (p-value). Following this analysis, spatial clusters were evaluated using Local Indicators of Spatial Association (LISAs). Cartograms illustrated the delineation of spatial clusters into four types:

- **High-High:** Regions where municipalities with high frequencies of the incidence rate variable are surrounded by similar high-frequency regions;
- **Low-Low:** Regions where municipalities with low frequencies of the incidence rate variable are surrounded by similar low-frequency regions;
- **High-Low:** Regions where municipalities with high frequencies of the incidence rate variable are surrounded by low-frequency regions;
- **Low-High:** Regions where municipalities with low frequencies of the incidence rate variable are surrounded by high-frequency regions.

The correlation values generated by the GMI and local Moran's index (LMI) could be evaluated as positive or negative and as weak (< 0.3), moderate (0.3-0.7), or strong (> 0.7) (Moran, 1950; O'Sullivan and Unwin, 2010).

2.6. Ethical considerations

As this study was conducted using secondary data obtained through publicly accessible information systems, it was not necessary to submit it to the Research Ethics Committee for approval. Additionally, the use of an Informed Consent Form was not required. The data utilized were already available in the public domain, ensuring that individual privacy and confidentiality were maintained.

3. Results

Figure 1 shows the cluster maps for the incidence rate. In the spatial correlation analysis for COVID-19 in 2020, municipalities exhibited significant but weak spatial autocorrelation (GMI = 0.2084; p-value < 0.05). The majority

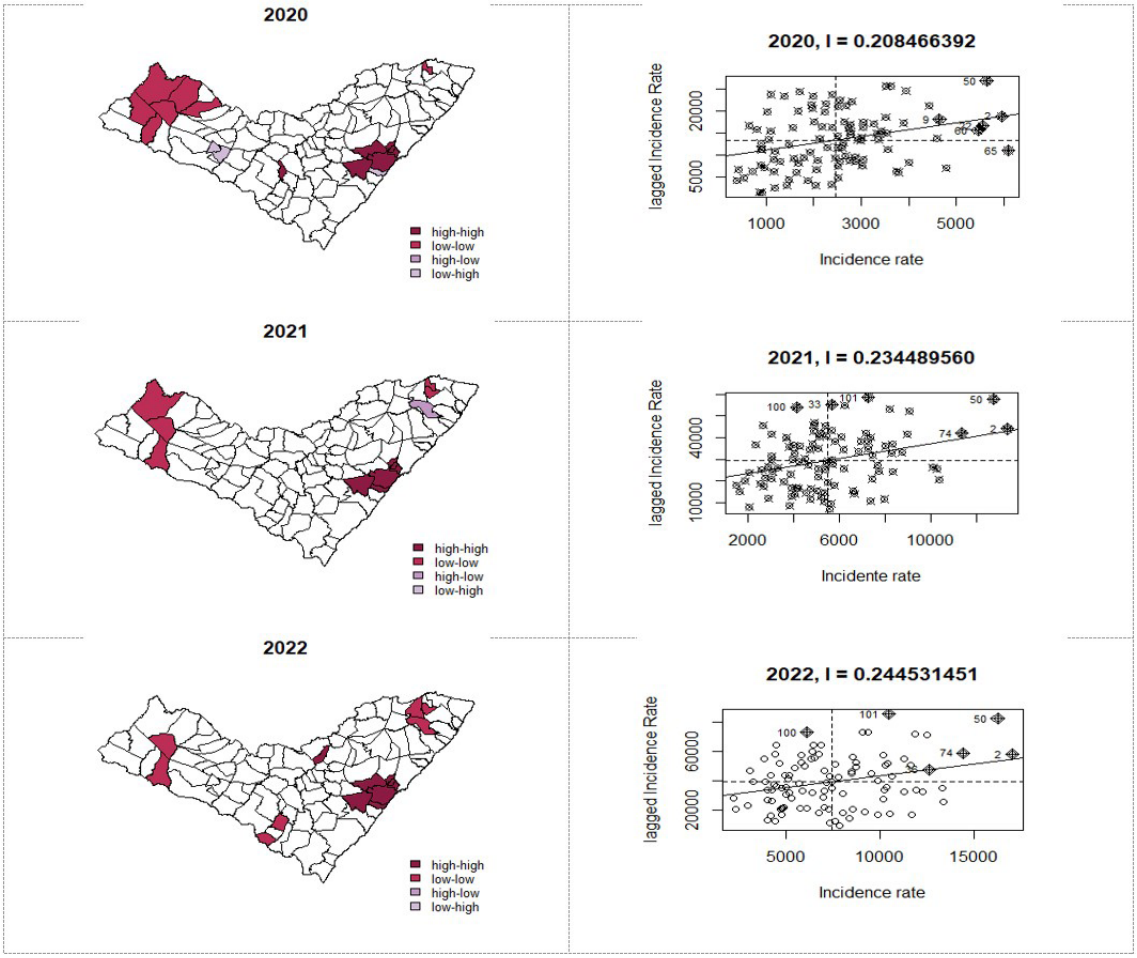

Figure 1. Cluster map and Moran quadrant for cumulative cases per 100,000 inhabitants.

of municipalities, including those in the "sertão alagoano", "agreste alagoano", and the southern coast, formed insignificant spatial clusters. However, High-High clusters emerged in municipalities within the metropolitan region of Maceió, extending to Satuba, Santa Luzia do Norte, São Miguel dos Campos, Barra de São Miguel, Coqueiro Seco, Marechal Deodoro, and Pilar.

In 2021, the spatial autocorrelation of COVID-19 remained positive and weak (GMI = 0.2344; p-value < 0.05). High-High clusters persisted in the Satuba region and the metropolitan area of Maceió. The Low-Low clusters shrank to municipalities in the sertão alagoano, while in 2022, these clusters extended into the northeast of Alagoas.

Some regions consistently exhibited Low-Low and High-High clusters. Notably, there was a reduction in High-High clustering in the metropolitan region of Maceió. This reduction could be attributed to Maceió's status as a commercial hub with high daily commuting and integration into the federal road network, leading to increased human movement and virus transmission. Additionally, Maceió was the first city in the state to begin vaccination in early 2021. Insignificant clusters predominated in the center-west and south of Alagoas during both phases.

4. Discussion

The spatial distribution pattern of COVID-19 in Alagoas, as detailed in this study, reveals significant insights into the regional dynamics of the pandemic. The results presented indicate both temporal and spatial variations that are crucial for understanding the transmission and control of the virus, reinforcing previous findings in the literature (Nascimento et al., 2022).

The predominance of insignificant clusters in the center-west and south of Alagoas during both phases suggests that these areas experienced relatively stable and lower infection rates. These regions' lower population density and possibly less human movement compared to the metropolitan regions might have contributed to their lesser involvement in significant clustering (Martins-Filho, 2021).

The temporal analysis highlights the dynamic nature of COVID-19 spread, with regional variations influenced by factors such as population density, mobility patterns, and public health measures, including vaccination (Carozzi et al., 2022). The persistent yet weak spatial autocorrelation throughout the study period emphasizes the necessity for continuous monitoring and adaptive

public health strategies tailored to local epidemiological conditions (Silk et al., 2023).

Spatial analysis is essential for comprehending the spread of COVID-19, as it reveals the geographical patterns and dynamics of the pandemic. The spatial distribution of disease has been extensively investigated worldwide. Studies indicate that the pattern of confirmed cases often follows a power-law distribution, maintaining a consistent spreading center in various cities over time (Zhang et al., 2023).

In Brazil, there is evidence of spatial dependence among micro-regions concerning incidence and mortality rates, with different patterns of spatial autocorrelation observed in states such as São Paulo and Minas Gerais (Garcia Filho et al., 2023). In India, analyses of hotspots and outliers at the district level have demonstrated the evolving nature of COVID-19 hotspots and coldspots across different regions over time (Guchhait et al., 2023). Furthermore, research in the United States has outlined the temporal progression of the epidemic through various phases, showing spatial clustering and distinct trajectories of the epidemic's center of gravity (He et al., 2022).

These insights highlight the critical need to comprehend spatial patterns and their evolution to implement effective control and prevention strategies. Additionally, such analyses can forecast the future trajectory of the pandemic, highlight high-risk zones, improve resource distribution, and strengthen public health responses.

This study shares limitations typical of those utilizing secondary databases, where the accuracy and completeness of the data may restrict the findings due to potential errors in typing, recording, omissions in filling fields, and possible underreporting of the disease. Despite these limitations, the study prompts a discussion on the public policies implemented to improve COVID-19 control, illustrating the impact and progression of the virus in a Brazilian state using official data from the state agency responsible for health monitoring and surveillance.

5. Conclusion

In conclusion, this study provides a comprehensive understanding of the spatial distribution of COVID-19 in Alagoas, highlighting critical areas for targeted intervention. Future research should focus on refining spatial models and incorporating additional variables such as socio-economic factors, healthcare infrastructure, and detailed mobility data to enhance predictive accuracy and inform public health strategies effectively.

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