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SPATIAL ANALYSIS OF POLIOMYELITIS VACCINATION COVERAGE IN THE STATE OF MINAS GERAIS: AN ECOLOGICAL STUDY

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ABSTRACT
Objective: to evaluate the poliomyelitis vaccination coverage rate in the state of Minas Gerais and its spatial dynamics in the period from 2016 to 2021. Methods: Ecological study, with the collection of vaccination coverage rates in the municipalities of Minas Gerais in the period 2016- 2021, obtained from the Department of Informatics of the Unified Health System of Brazil. The analysis was performed using geoprocessing and autocorrelation techniques using Moran's Global Index and the Local Spatial Association Index. Results: The spatial analysis showed the existence of specific spatial clusters in the distribution of vaccination coverage rates among the municipalities of Minas Gerais. Clusters of municipalities with high vaccination coverage rates (High-High) and clusters with low coverage rates (Low-Low) were identified, indicating areas with similar vaccination performances. Spatial autocorrelation, in some years, indicated that the vaccination coverage rates of neighboring municipalities influence the vaccination coverage rates. Conclusion: The spatial dynamics point to the influence of socioeconomic and cultural factors on poliomyelitis vaccination coverage in Minas Gerais.

Keywords: Immunization. Moran's index. Polio.

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INTRODUCTION

Low titers of antibodies against poliomyelitis in young adults, associated with low adherence to vaccination, rekindle concern about the reintroduction of poliovirus in countries where the disease has been eradicated[1,2]. In Brazil, the Ministry of Health has adopted a vaccination schedule for poliomyelitis that includes three doses of the Inactivated Vaccine (IPV) at two, four, and six months of age, followed by one dose of the Attenuated Vaccine (OPV) at 15 months, with a booster at four years[2]. Despite the established vaccination schedule, there was a downward trend in vaccination coverage, including IPV and PWV, between 2006 and 2016, although with variations among Brazilian municipalities[3-5].

In certain regions of Minas Gerais, this downward trend in polio vaccination coverage was observed between 2015 and 2020[6]. In this context, it is essential to consider the particularities of municipalities and administrative units when formulating immunization plans and strategies, aiming to identify unmet demands manifested as pockets of individuals in certain locations[6-8].

Therefore, the present study seeks to evaluate the poliomyelitis vaccination coverage rate in the state of Minas Gerais and its spatial dynamics in the period from 2016 to 2021. From this perspective, the scientific importance of this study is justified to identify areas of greater vulnerability to poliomyelitis and to direct health interventions.

METHOD

This is an ecological study developed with secondary data obtained from the database of the Department of Informatics of the Unified Health System (DATASUS) of Brazil. This study was developed considering the vaccination coverage rate of the poliomyelitis vaccine, available in the National Vaccination Calendar, in children < 1 year old for each of the 854 municipalities of Minas Gerais, Brazil. The time frame used was the period from 2016 to 2021.

The calculation of the vaccination coverage rate was performed by type of vaccine, as a numerator the total number of doses applied, data extracted from the Computerized Information System of the National Immunization Program (SI-PNI). The denominator was composed of data on live births by municipality in Minas Gerais, obtained from the National Information System for Live Births (SINASC), provided by the Ministry of Health. In addition, to obtain a real view of vaccination coverage in the municipalities, the calculation

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was carried out by type of antigen and grouped to include vaccines applied in the public and private network. The definition of adequate vaccination coverage followed the goals recommended by the National Immunization Program (PNI), 95% for Poliomyelitis[9].

The analysis of spatial dynamics was calculated by vaccination coverage by municipality between 2016 and 2021, and based on the established categories, thematic maps were constructed. The maps were prepared using geoprocessing with the aid of the Geographic Information System (GIS), spatial analysis techniques, and thematic cartography. The cartographic database of the municipalities was obtained from the Brazilian Institute of Geography and Statistics10, with geographic projection and the SIRGAS 2000 Geodetic Reference System. The QGIS software (version 3.10) was used, with the files inserted in the shapefile format of the municipalities.

The Analysis of Spatial autocorrelation was performed using Moran's Global Index to perform a comprehensive assessment of the global status and to demonstrate spatial autocorrelations between municipalities. $P > 0.05$ indicate the absence of autocorrelation, while $p \leq 0.05$ indicate the presence of spatial autocorrelation [5].

In addition, the Local Spatial Association Index was calculated, which allows the identification of specific patterns of spatial autocorrelation at the local level and reveals how vaccination coverage rates in each municipality relate to the rates of its neighbors. For this identification, the LISA Map, the Moran scatter plot, and the Moran Map11 were created.

The data were presented in a descriptive way, in figures and tables with the aid of *the Microsoft Office Word* version 2010 software. The discussion of the results took place in an analytical and interpretative way based on the current public health literature.

The study was guided by *the Strengthening the Reporting of Observational studies in Epidemiology* (STROBE) guide, according to Resolution No. 510/2016 of the National Health Council. Because this was a study with secondary data, it was not necessary to approve the research ethics committee.

RESULTS

The analysis of vaccination coverage from 2016 to 2021 points to the existence of variability in the pattern of immunization coverage. Despite showing good vaccination patterns for most polygons, there is persistence of areas with low (≥50%) or very low (<50%) coverage, which was accentuated in 2021 (FIGURE 1).

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FIGURE 1 - Spatial distribution of poliomyelitis vaccination coverage from 2016-2021 by municipality in the state of Minas Gerais, Brazil. Source: Estimates based on data from SI-PNI, SINASC, and DATASUS.

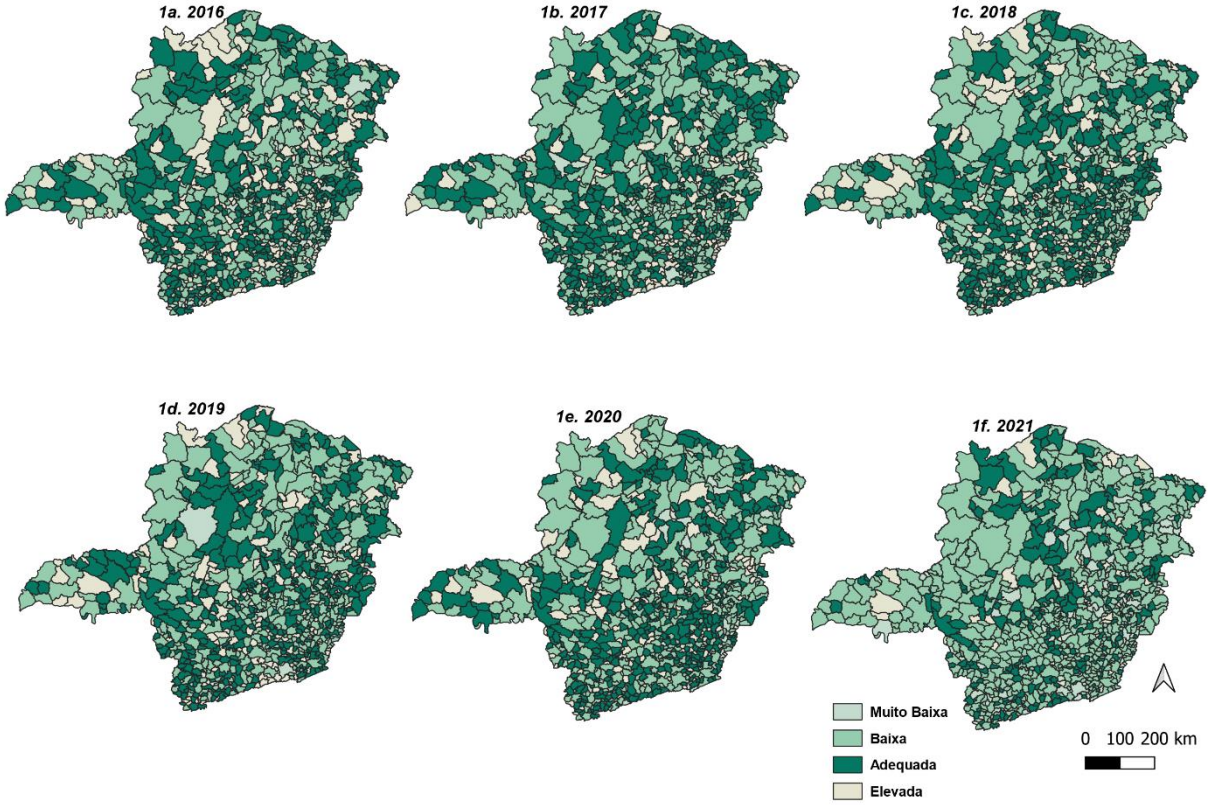

Figure 1 shows the spatial distribution of poliomyelitis vaccination coverage in green, showing the progressive reduction in the number of municipalities with adequate vaccination coverage during the years 2016-2021. There are patterns of spatial distribution with clusters or concentrations in certain areas.

In the presentation of the Global Moran Index by the first-order queen weighting matrix (TABLE 1), it is observed that the years 2016, 2018, and 2021 did not present spatial autocorrelation ($p > 0.05$) and in the years 2017, 2019, and 2020 it presented spatial autocorrelation ($p \leq 0.05$). Vaccination coverage rates did not present a spatially dependent distribution, and therefore, there was no consistent trend of clustering or dissemination of high or low vaccination coverage in nearby areas.

Table 1 - Global Moran Index by year based on poliomyelitis vaccination coverage from 2016 to 2021, by municipality, in the state of Minas Gerais, Brazil.

Polio	Moran Global	p value
2016	0,018	0,199
2017	0,092	0,002

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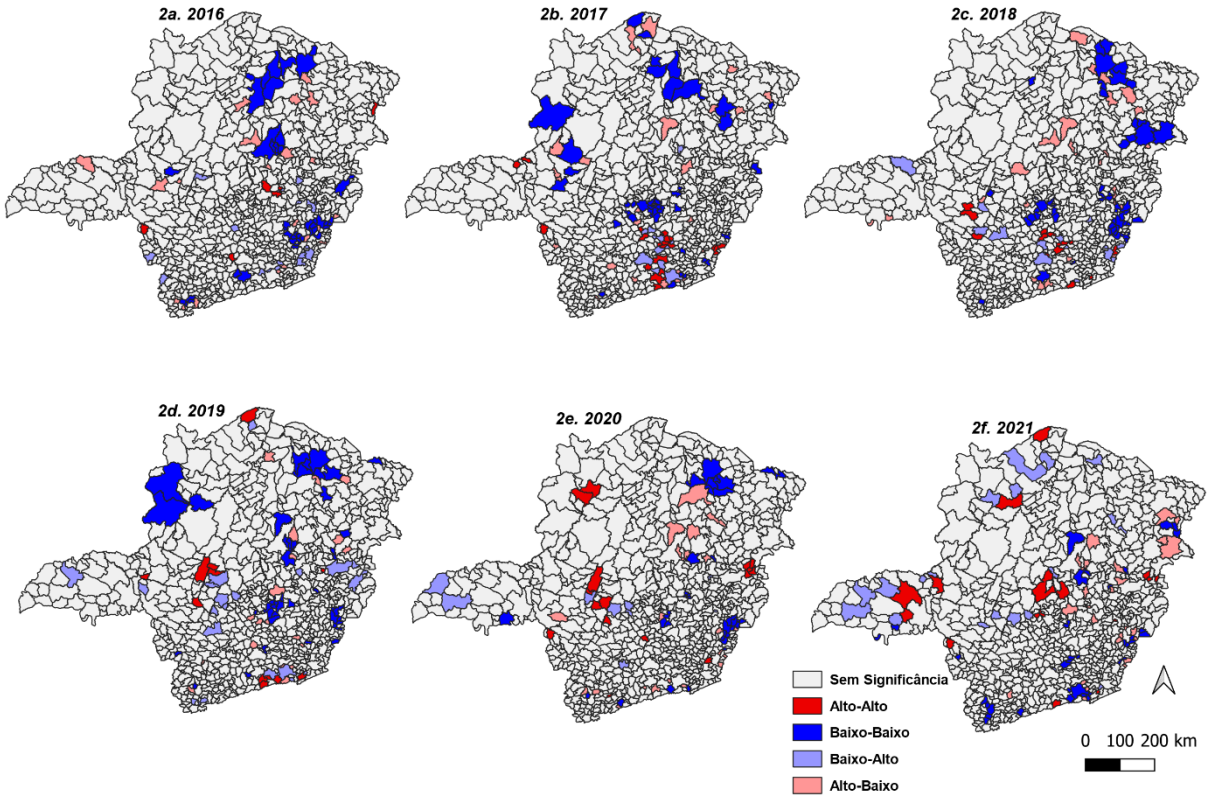
2018	0,028	0,077
2019	0,035	0,050
2020	0,041	0,024
2021	-0,004	0,444

Source: Estimates based on data from SI-PNI, SINASC, and DATASUS

FIGURE 2 - Moran Map - areas with autocorrelation of poliomyelitis vaccination coverage in the years 2016-2021 in the municipalities of the State of Minas Gerais, Brazil. Source: Estimates based on data from SI-PNI, SINASC, and DATASUS.



The Moran Map (FIGURE 2) shows that over the years analyzed, there is a low number of municipalities classified as High-High (red). In 2016, only 06 municipalities were in the Alto-Alto cluster. Over the other years, there is a tendency to increase the number of these municipalities, but it is still limited. In 2017, 20 municipalities were involved, while in the other years, it varied between 14 and 16 municipalities.

In the Moran Map, clusters of municipalities with low vaccination coverage were also observed, located close to municipalities with an average vaccination coverage rate of Low-Low (blue). These clusters indicate the existence of geographically concentrated areas with insufficient vaccination coverage rates.

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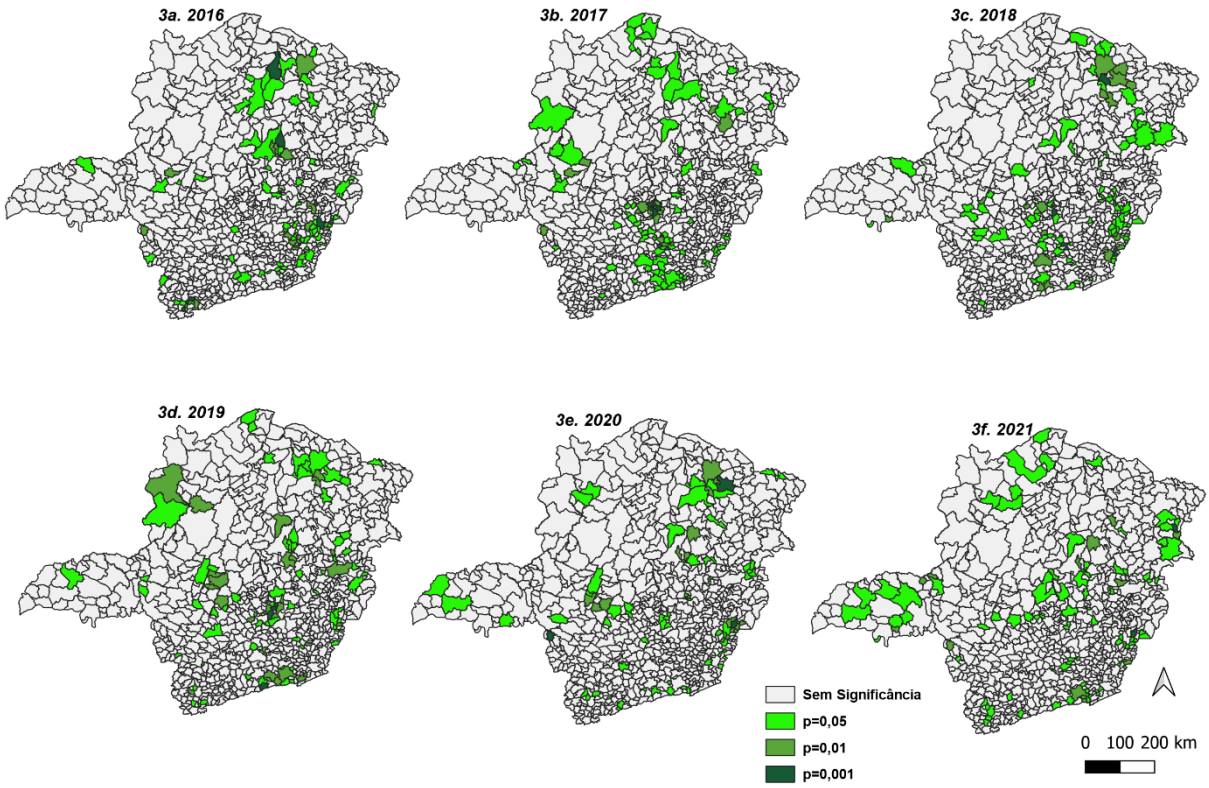
FIGURE 3 - Lisa Map - areas with autocorrelation of poliomyelitis vaccination coverage in the years 2016-2021 in the municipalities of the State of Minas Gerais, Brazil. Source: Estimates based on data from SI-PNI, SINASC, and DATASUS.



In the Lisa Map (FIGURE 3), different types of clusters can be observed that indicate the presence of specific spatial patterns. The municipalities in dark green represent the clusters with the highest levels of significance (p-value < 0.001). The lighter green corresponds to the significance level at 5% (p-value < 0.05), and the intermediate green color indicates a significance level at 1% (p-value < 0.01). It is noteworthy that the identified clusters point to spatial patterns that reflect the significant spatial dependence between the vaccination coverage rates of the neighboring municipalities.

In this analysis, areas with a high vaccination coverage rate were identified surrounded by municipalities with the same pattern (High-High clusters). These clusters indicate a concentration of municipalities with good vaccination performance, forming islands of protection against Poliomyelitis. On the other hand, the municipalities in the Low-Low clusters indicate municipalities with a low vaccination coverage rate surrounded by municipalities with the same pattern. These clusters highlight geographically close areas with similar challenges regarding immunization, requiring special attention.

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DISCUSSION

The results of this study indicate a declining trend in adherence to poliomyelitis vaccination in the municipalities of Minas Gerais between 2016 and 2021. The progressive decrease in the categories of adequate and high vaccination coverage is accompanied by an increase in the absolute number of municipalities classified as low and very low. This change indicates a reduction in collective protection against Poliomyelitis.

To address the challenges related to immunization, multifaceted approaches are needed due to the complexity of the topic. In Brazil, vaccination coverage is influenced by factors such as limited access to health services, lack of information about vaccines, and distrust of immunizers12. Given this, in the analyses, it is essential to consider the factors that impact adherence and vaccination coverage, such as geographic contexts, temporal contexts, and socioeconomic factors13,14.

In addition to these challenges, the National Immunization Program, one of the most successful health policies in the country, faces difficulties in terms of financial resources12. Underfunding of the program results in vaccine shortages and disruption in immunization programs. Therefore, strengthening the program is crucial to ensure that Brazil continues to advance in the immunization of its population, especially in geographic areas with low vaccination coverage.

In this aspect, a study that carried out a spatial analysis of vaccination coverage in Minas Gerais revealed geographic clusters with a risk of low vaccination coverage. The critical factors that emerged were the socioeconomic ones, especially the per capita income of up to half a minimum wage. Thus, the improvement of the Social Responsibility Index of Minas Gerais and the proportion of the population that is poor or extremely poor are also determinants in achieving vaccination coverage goals15.

The Global Moran Index varied over the years analyzed, indicating the presence of specific spatial patterns in different periods and priority geographic areas for the investment of resources and the implementation of actions that improve vaccination coverage. In addition, the local autocorrelation, identified by LISA Map, revealed High-High and Low-Low clusters, highlighting the need for differentiated approaches adapted to each geographic area, considering that there are regions of greater vulnerability about vaccination coverage, as well as others where immunization strategies have shown success.

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The clusters identified in the analyses indicate geographically concentrated areas with similar patterns of vaccination coverage and suggest the need for specific interventions in certain regions. These findings reinforce the need to include awareness campaigns aimed at specific regions. In addition, improvements in health infrastructure and strategies to overcome possible logistical barriers of the National Immunization Program[12].

In this sense, spatial analysis associated with spatial statistics techniques are fundamental tools to understand the dynamics of vaccination coverage and its disparities and to identify vulnerable areas called "pockets of non-vaccination". These analyses enable public health managers to effectively direct resources and professionals to implement intervention strategies that achieve the goals (95% vaccination coverage) of the National Immunization Program. In addition, the ability to analyze the homogeneity of vaccination coverage at scale contributes to the formulation of targeted policies, promoting health protection in an equitable manner[16].

Considering poliomyelitis in other regions of Brazil, a study on the spatial analysis of vaccination coverage in children under one year of age, carried out by mesoregions of Paraíba, revealed an alarming trajectory: less than 50% of the communities in Paraíba were adequately vaccinated during the two years analyzed. In the Mata Paraíba mesoregion, 63.3% of the municipalities were in the category of low vaccination coverage in 2016 and 73.3% in 2017. It is observed that the percentages increased during the years investigated, except the Meso region of the Sertão Paraíba, where the percentages decreased by [16].

The temporal analysis of the data indicates that the trend of decline in vaccination coverage intensified in 2021, making the situation even more critical. Likely, the COVID-1917 pandemic has negatively impacted vaccination coverage. According to Lopes Júnior et al.[18], this problem occurred due to the disruption of health services and social distancing measures, which created obstacles to access to vaccines and resulted in lower vaccination uptake. Such situations require immediate action by health authorities and public managers.

The data presented highlights the importance of spatial analyses to identify regions that need special attention and effective interventions. Emergency strategies, such as intensive local vaccination campaigns and effective risk communication, are needed to reverse this trend. To ensure the success of intervention strategies, it is essential to involve local communities, listen to their concerns and needs, and build solid partnerships between

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health authorities, professionals in the field, and community leaders. The population's confidence in vaccines is an essential component to achieve high vaccination coverage rates.

In addition, there are significant challenges in predicting the needs for polio vaccines, which are: deviations in the execution of the plans that underlie these predictions; lack of alignment on strategies and objectives among Global Polio Eradication Program partners and other key stakeholders; financing issues and uncertainty regarding the development and licensing deadlines of new polio vaccines; and performance characteristics in the field19.

The difficulties exposed in the text contribute to the divergences over time between the supply and demand of vaccines, resulting in negative impacts, such as excess and scarcity of supplies, which lead to additional costs and potentially preventable cases of polio. Based on our findings and recent literature19, it is crucial to improve coordination, planning, and financing to ensure an adequate supply of vaccines.

CONCLUSION

The spatial distribution patterns of vaccination coverage rates in Minas Gerais show clusters in specific areas of the state. The need to develop predictive models of the evolution of vaccination coverage rates and to compare the results of vaccination coverage in Minas Gerais with other regions of Brazil and the world is highlighted in order to identify good practices in immunization against poliomyelitis and to plan immunization strategies.

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