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Original Research

Spatial and spatio-temporal distribution of infant mortality in the state of Sergipe, Brazil: An ecological study, 2019–2023

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ABSTRACT

Objectives: To analyze the spatial and spatiotemporal distribution of infant mortality in the state of Sergipe from 2019 to 2023.
Study design: Ecological study.
Methods: This ecological study used publicly available data on infant deaths in Sergipe between 2019 and 2023, obtained from the Mortality Information System. Variables related to the child, mother, and healthcare factors were considered. Bayesian mortality rates were calculated and mapped across municipalities. Moran's Index was applied to assess spatial correlation.
Results: Between 2019 and 2023, Sergipe recorded 2547 infant deaths. The leading causes were perinatal conditions (Chapter XVI) and abnormal findings in examinations (Chapter XVIII), predominantly in the northern region. Higher mortality was observed among Black female infants with very low or low birth weight, as well as clusters of deaths among adolescent mothers in the Itabaiana region, and adult or late-age mothers in Propriá, which also showed higher mortality among preterm infants. The municipalities of Propriá and Nossa Senhora do Socorro reported more deaths associated with cesarean deliveries. Aracaju, São Cristóvão, and Nossa Senhora do Socorro formed high-mortality clusters, with a risk 641.77 times greater; conversely, Nossa Senhora da Glória, Lagarto, and Estância exhibited a 66 % lower risk.
Conclusion: Infant mortality in Sergipe is unevenly distributed, concentrated in high-risk clusters, and reflects regional disparities as well as specific maternal and neonatal factors.

1. Introduction

Infant mortality is defined as the death of children under one year of age and is subdivided into neonatal and post-neonatal components. It is an important indicator of the health level and socioeconomic development of a population. One of the targets of the Millennium Development Goals (MDGs) for maternal and child health was to achieve, by 2015, an infant mortality rate (IMR) below 15.7 deaths per 1000 live births.[1] In Latin America, these rates were considerably high, with one in every twelve children born in the region not surviving to their first year of life until 1970. In the following decades, there was a marked decline, dropping from 80 deaths per 1000 live births in 1970 to 14 in 2020.[2]

Brazil recorded 15.3 deaths per 1000 live births in 2011, well before the MDG deadline.[1] Currently, infant and fetal mortality from preventable causes in Brazil is the lowest in 28 years, corresponding to a 62 % reduction in deaths between 1996 and 2023.[3] In Northeastern Brazil, mortality rates decreased by approximately 3.9 % per year between 2001 and 2015, declining from 23.91 deaths per 1000 live births to 13.97/1,000, a trend also observed in some states of the region. Sergipe was one of the few states to show stability in late mortality rates beginning in 2010.[4]

Infant mortality rates in Brazil decreased significantly until 2010, as did those in Sergipe. However, an increase was observed from 2015 onward, peaking at 17.63 deaths per 1000 live births in 2022. Deaths were more frequent among mothers identified as mixed-race and White, aged 15–24 years, with 8–11 years of schooling, single pregnancies, and gestational ages of 37–41 weeks. The leading causes were conditions originating in the neonatal period, accounting for more than half of deaths, followed by congenital malformations, deformities, and chromosomal abnormalities.[5]

Infant mortality is an essential indicator of the quality of life and the performance of health services, as it reflects socioeconomic,

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environmental, and basic healthcare access conditions.[6] Spatial analysis of this indicator not only enables the identification of patterns of concentration and dispersion of deaths but also reveals potentially more vulnerable areas, facilitating the implementation of more targeted and effective public policies. Understanding the geographic dynamics of infant deaths can assist in the proper allocation of resources and the prioritization of actions, making efforts to reduce infant mortality more efficient and sustainable. Therefore, this study aimed to analyze the spatial and spatiotemporal distribution of infant mortality in the state of Sergipe from 2019 to 2023.

2. Methods

2.1. Study design

This was an exploratory and analytical ecological study with a quantitative approach to infant mortality. The study followed the guidelines of the Reporting of Studies Conducted Using Observational Routinely-Collected Health Data (RECORD).[7]

2.2. Context

Public data on infant deaths in the state of Sergipe from January 2019 to December 2023 were used. Sergipe is in Northeastern Brazil and is the smallest federative unit of the country, covering a total area of 21,938 km^2, equivalent to 0.26 % of the national territory and 1.4 % of the region. The state comprises 75 municipalities divided into three mesoregions: East, Agreste, and Sertão. In 2021, Sergipe had an estimated population of 2,338,474 inhabitants, of which 33,878 were under one year of age, with a population density of 100.74 inhabitants/km^2.[8] Currently, Sergipe is subdivided into seven health regions (HRs): Aracaju, Estância, Itabaiana, Lagarto, Nossa Senhora da Glória, Nossa Senhora do Socorro, and Propriá.

2.3. Participants

All infant deaths occurring in children under one year of age, as recorded on death certificates, were considered.

2.4. Variables

The variables selected from the infant death certificate included those related to the child, mother, and healthcare factors. Child-related variables comprised sex (male, female); age group (0–6 days early neonatal, 7–27 days late neonatal, 28–364 days post-neonatal); race/skin color (White, Black, Yellow, Mixed-race, Indigenous); and birth weight (<500 g, 500–999 g, 1000–1499 g, 1500–2499 g, 2500–2999 g, 3000–3999 g, ≥4000 g). Maternal variables included maternal age (10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54 years) and education (none, 1–3 years, 4–7 years, 8–11 years, ≥12 years). Healthcare-related variables included type of delivery (vaginal, cesarean); type of pregnancy (single, twin, triplet); ICD-10 chapter (Chapter I: Certain infectious and parasitic diseases; Chapter II: Neoplasms; Chapter III: Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism; Chapter IV: Endocrine, nutritional, and metabolic diseases; Chapter V: Mental and behavioral disorders; Chapter VI: Diseases of the nervous system; Chapter VII: Diseases of the eye and adnexa; Chapter VIII: Diseases of the ear and mastoid process; Chapter IX: Diseases of the circulatory system; Chapter X: Diseases of the respiratory system; Chapter XI: Diseases of the digestive system; Chapter XII: Diseases of the skin and subcutaneous tissue; Chapter XIII: Diseases of the musculoskeletal system and connective tissue; Chapter XIV: Diseases of the genitourinary system; Chapter XV: Pregnancy, childbirth, and the puerperium; Chapter XVI: Certain conditions originating in the perinatal period; Chapter XVII: Congenital malformations, deformations, and chromosomal abnormalities; Chapter XVIII: Symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified; Chapter XX: External causes of morbidity and mortality); gestational age (<22 weeks, 22–27 weeks, 28–31 weeks, 32–36 weeks, 37–41 weeks, ≥42 weeks); and municipality of residence.

All variables described in this study are available in both SIM and SINASC, except for death-specific information—such as the ICD-10 chapter of the underlying cause—which is recorded exclusively in SIM.

Infant mortality rates were calculated using the following formula: oi/ni*1,000, where oi represents the number of infant deaths in a given location, year, and group, and ni represents the number of live births in the exact location, year, and group. Rates were smoothed using the local empirical Bayes estimator to reduce random fluctuation.[9]

2.5. Data source and measurement

Data on infant deaths were extracted from the Mortality Information System (SIM), while data on live births were obtained from the Live Birth Information System (SINASC). Brazil maintains these two essential epidemiological information systems under the Ministry of Health's Secretariat of Health Surveillance. SIM provides microdata on deaths stratified by age, sex, cause, and place of residence, whereas SINASC compiles microdata on live births. Both systems are fundamental for assessing population health and monitoring temporal and geographic trends across the country.

The Mortality Information System (SIM) is responsible for the standardized registration of deaths in Brazil, including those occurring within the first year of life. Data collection is carried out through the Death Certificate, a document that must be completed by healthcare professionals and is standardized according to Ministry of Health regulations. Municipal health departments collect the certificates, enter the records, and verify inconsistencies. Subsequently, the data are validated and coded at the state level according to the International Classification of Diseases, 10th Revision (ICD-10), and then integrated into the national database. Deaths are categorized by demographic and epidemiological characteristics, such as age, sex, place of residence, and underlying cause of death. Access to these databases is provided through DATASUS, the official repository of the Unified Health System (SUS) (https://datasus.saude.gov.br/).

All data were accessed in October 2024 using TabWin as follows: (1) download of the annual databases of infant deaths from 2019 to 2023 from the website of the Department of Informatics of the Unified Health System, in.dbc format; (2) import of the downloaded data into TabWin for decompression into.dbf files; (3) import of auxiliary files; (4) tabulation of data by municipality of residence and variables of interest; and (5) export of data to Microsoft Excel® spreadsheets.

2.6. Quantitative variables

Several modifications were made to the variables of interest: (1) race/skin color: Black and Mixed-race categories were grouped as "Black"; (2) birth weight: very low weight (<1500 g), low weight (1500–2500 g), and adequate weight (≥2500 g); (3) maternal age: adolescents (<20 years), adults (20–34 years), and late-age adults (≥35 years); (4) education: categories "1–3 years" and "4–7 years" were grouped as "1–7 years"; (5) type of pregnancy: twin and triplet were grouped as multiple (≥2); (6) gestational age: <22–36 weeks (preterm), 37–41 weeks, and ≥42 weeks.

In Brazil, race/skin color is routinely collected in health information systems following the official classification of the Brazilian Institute of Geography and Statistics (IBGE), which includes the categories White, Black, Mixed-race ("Pardo"), Asian ("Amarelo"), and Indigenous. In this study, the race/skin color variable obtained from the Live Birth Information System (SINASC) refers to the mother's self-reported classification at the time of birth registration, as standardized in the national vital statistics system.

For analytical purposes, two adaptations were applied. First, the categories Black and Mixed-race ("Pardo") were combined into a single group ("Black"), consistent with epidemiological practices widely used in Brazil, given the shared patterns of social vulnerability and health inequities historically observed in these populations. Second, the categories White, Asian, and Indigenous were kept as originally recorded.

This reclassification approach follows established procedures in Brazilian public health research and strengthens the statistical analysis by reducing sparse categories while preserving the interpretability of racial/ethnic disparities.

2.7. Bias

Two main strategies were adopted to mitigate potential biases in this study. First, the distribution of deaths may be uneven across municipalities, and the absence of events in some areas can influence the analyses. To reduce this bias, a five-year aggregation was applied to stabilize the counts. Second, crude and specific infant mortality rates may be affected by random variability between municipalities. This issue was minimized through the use of spatial empirical Bayesian estimates, which smooth rates by incorporating information from neighboring areas.

2.8. Data analysis

The spatial distribution of infant mortality rates—previously smoothed using the local empirical Bayes estimator—was mapped using the Natural Breaks (Jenks) classification method. In this study, the local empirical Bayes estimator was implemented directly in GeoDa, using the number of deaths and live births to compute raw rates and a first-order contiguity spatial weights matrix to determine each municipality's neighborhood structure. The estimator adjusts each observed rate toward the regional mean while incorporating information from adjacent municipalities, thereby reducing instability caused by small population sizes. This procedure generated more reliable and stable municipal estimates for subsequent spatial analyses.[10] Municipalities with no recorded occurrences were excluded.

The Global Moran's Index (GMI) was used to assess spatial dependence across the state of Sergipe, while the local index measured dependence within each municipality. Clusters were classified as direct autocorrelation (high–high and low–low) or inverse correlation (high–low and low–high). Cartographic representation was performed using the Local Indicators of Spatial Association (LISA). A pseudo-significance test with 99,999 permutations and a 1 % significance level was adopted to reduce bias from multiple comparisons.[11] The analysis was conducted in GeoDa version 1.20.

The cartographic base was obtained from the Brazilian Institute of Geography and Statistics (IBGE), 2021 version.[12] The Universal Transverse Mercator (UTM) system was applied using the Geocentric Reference System for the Americas (SIRGAS 2000).

To identify municipalities at potential high or low risk for infant mortality, the space–time scan statistic was applied.[13] All deaths in Sergipe municipalities were included, by year of occurrence, along with the corresponding live births for the same period. A Poisson model was adopted with 99,999 Monte Carlo permutations, planar coordinates (X, Y), elliptical scanning windows, and a maximum population size of 20 %, the latter defined by a prior purely spatial model.

The scan statistic results were expressed as relative risk (RR) of the clusters, where RR $<$ 1 indicated low-risk municipalities and RR $>$ 1 indicated high-risk municipalities. The analysis was performed using SaTScan version 10.1.2.[14] All maps were produced in QGIS version 3.40.[15]

2.9. Ethical considerations

The data used in this study are open-access, publicly available, and contain no personal identifiers, thereby exempting the research from approval by an Ethics Committee.

3. Results

Between 2019 and 2023, a total of 2547 infant deaths occurred in the state of Sergipe. Chapter XVI, concerning certain conditions originating in the perinatal period, and Chapter XVIII, concerning symptoms, signs, and abnormal findings in examinations, showed the highest rates, particularly in municipalities in the northern part of the state. Higher mortality rates were identified in peripheral municipalities of Sergipe among Black male infants with very low and low birth weight (Fig. 1).

Higher rates among adolescent mothers were concentrated in municipalities within the Itabaiana health region, whereas higher rates among adult and late-age mothers were observed in the Propriá region. These regions also showed higher mortality rates among preterm infants. Deaths associated with cesarean delivery were more frequent in municipalities of the Propriá and Nossa Senhora do Socorro regions (Fig. 2).

Spatial correlation revealed clusters of low infant mortality rates in municipalities in the southern part of the state, corresponding to the Lagarto and Estância health regions. Clusters of high rates were identified in the Propriá, Nossa Senhora do Socorro, and Nossa Senhora da Glória health regions, particularly among Black male post-neonatal infants with adequate birth weight (Fig. 3).

The spatial correlation of maternal and delivery-related characteristics revealed clusters of high infant mortality rates among adolescent mothers in the Itabaiana health region. The Propriá region concentrated municipalities with high mortality rates among mothers with eight or more years of schooling, as well as those with single pregnancies and cesarean deliveries (Fig. 4).

High-risk municipalities included Aracaju (the capital), São Cristóvão, and Nossa Senhora do Socorro, where the likelihood of death was 641.77 times higher compared to other locations. Conversely, municipalities in the Nossa Senhora da Glória, Lagarto, and Estância health regions were identified as having up to a 66 % lower risk of infant death (Fig. 5).

4. Discussion

The findings of this study highlight significant spatial and spatiotemporal inequalities in the distribution of infant mortality in Sergipe. Characteristics related to the child's profile (such as being Black, male, and having very low birth weight), maternal factors (particularly among adolescent mothers and women with higher levels of schooling), and birth conditions (for example, cesarean deliveries) were concentrated in disadvantaged areas of the state, such as the Propriá, Nossa Senhora do Socorro, and Nossa Senhora da Glória regions. The presence of higher rates in peripheral municipalities, as well as the correlation with perinatal factors (Chapters XVI and XVIII), underscores the relevance of social determinants and healthcare services in the occurrence of deaths.

Municipalities in the Lagarto and Estância health regions were consistently identified as having low infant mortality rates and presented a lower risk compared to other areas of the state. The reduction in infant mortality rates may explain the observed decrease in Lagarto between 2006 and 2015, or it may be due to potential underreporting of deaths.[16] It is also possible that the number of live births contributes to this scenario, as both regions have the second and third highest concentrations of live births in the state, surpassed only by the Aracaju region.[17] Evidence from national data indicates that municipalities with shorter travel distances to childbirth facilities tend to present lower infant mortality, especially due to fewer early neonatal and preventable deaths. Regions with closer access to intermediate and critical neonatal care also show consistently lower risk. Considering that Lagarto and Estância do not require long-distance travel for most births and have access to structured maternal-childcare services, this geographic

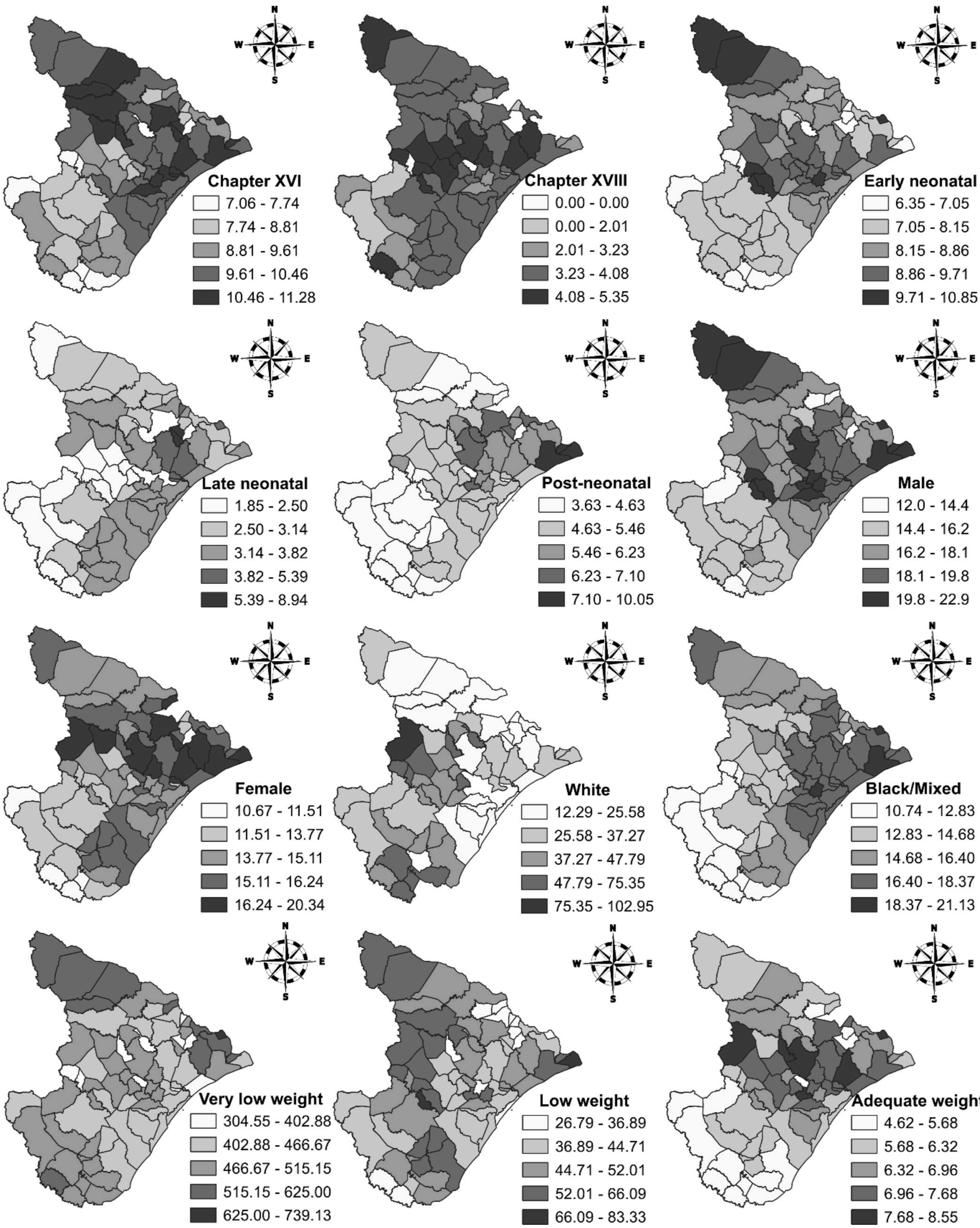

Fig. 1. Spatial distribution of Bayesian infant mortality rates in the municipalities of the state of Sergipe according to child-related variables, 2019–2023.

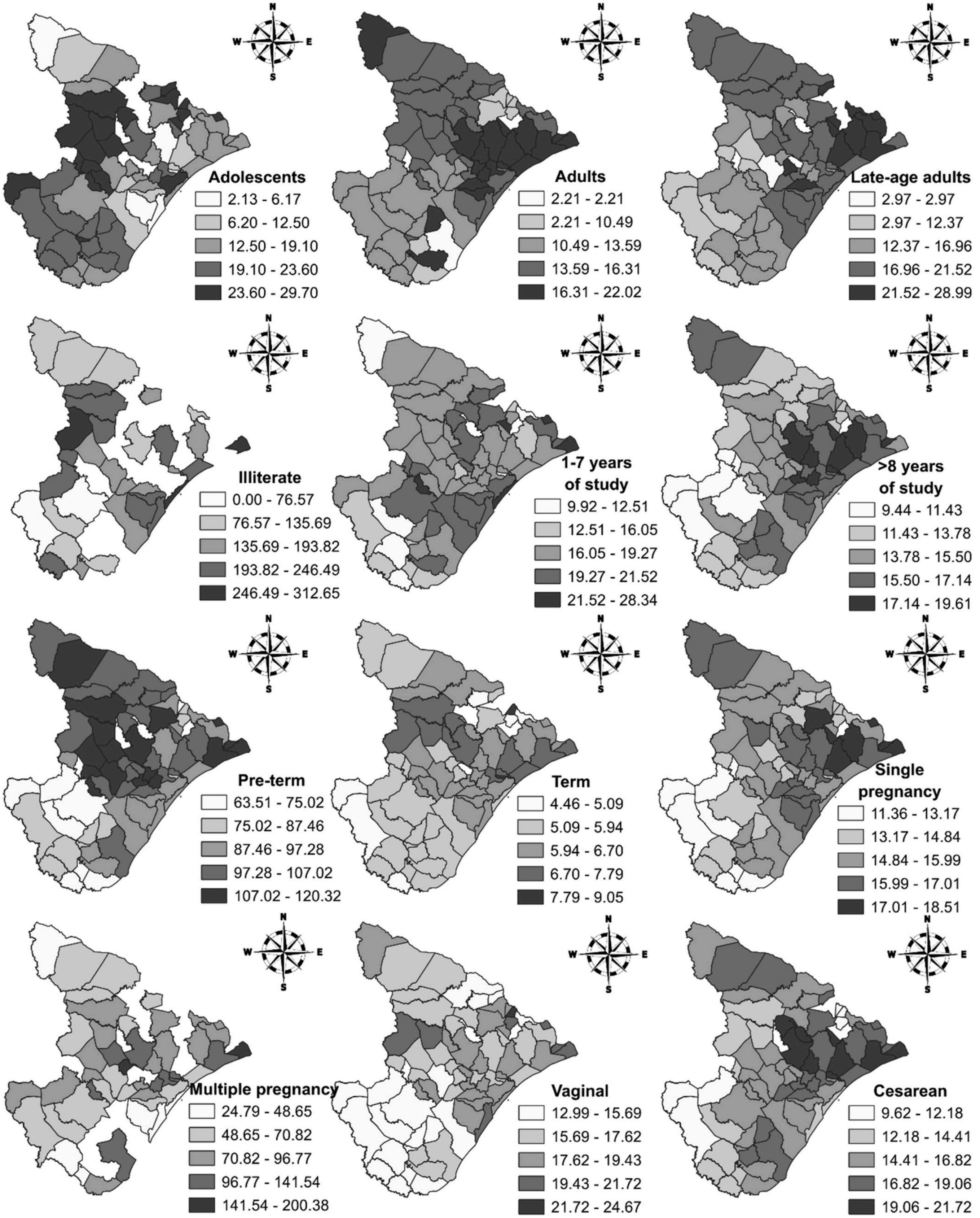

Fig. 2. Spatial distribution of Bayesian infant mortality rates in the municipalities of the state of Sergipe according to maternal and delivery-related variables, 2019–2023.

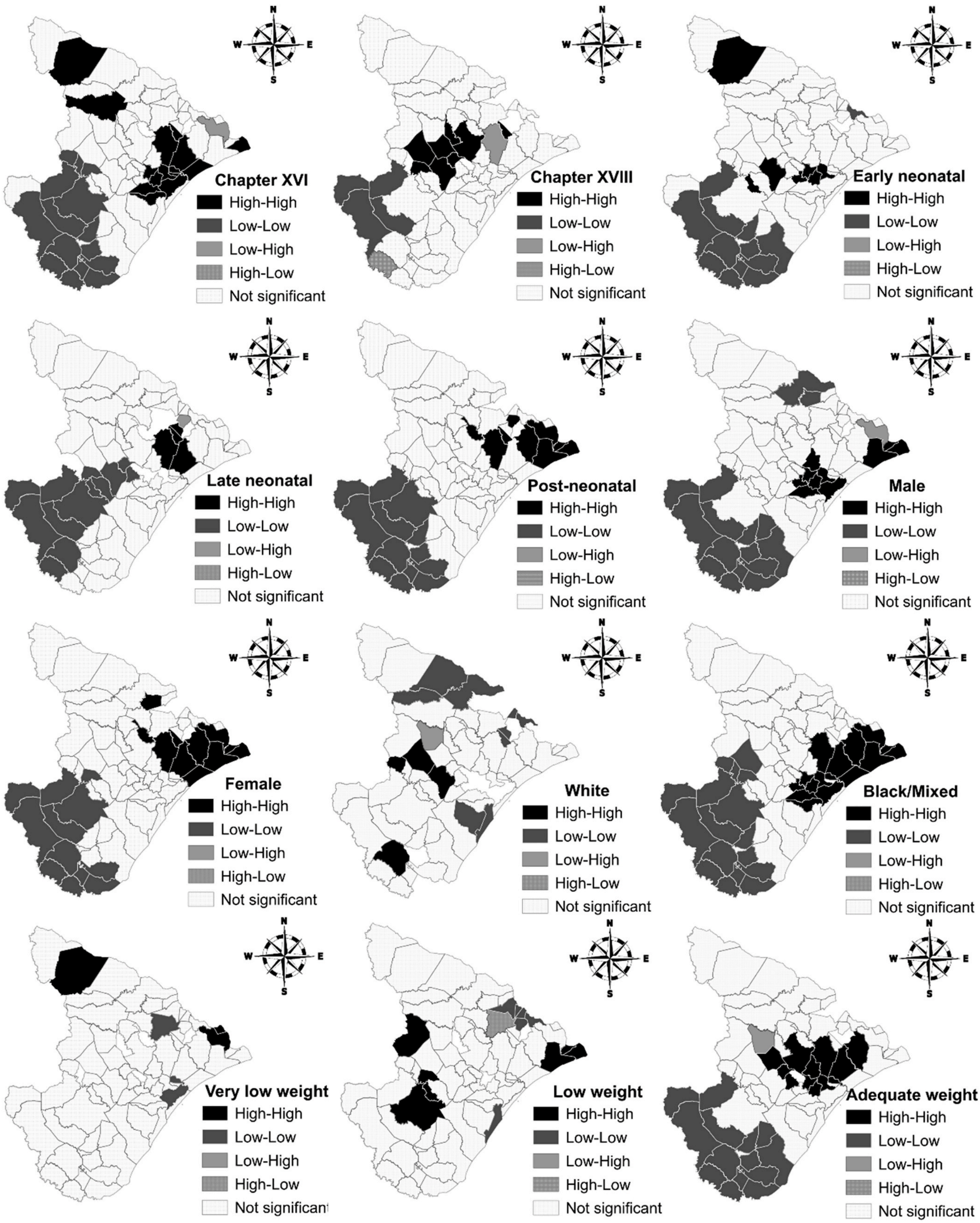

Fig. 3. Spatial correlation of Bayesian infant mortality rates in the municipalities of the state of Sergipe according to child-related variables, 2019–2023.

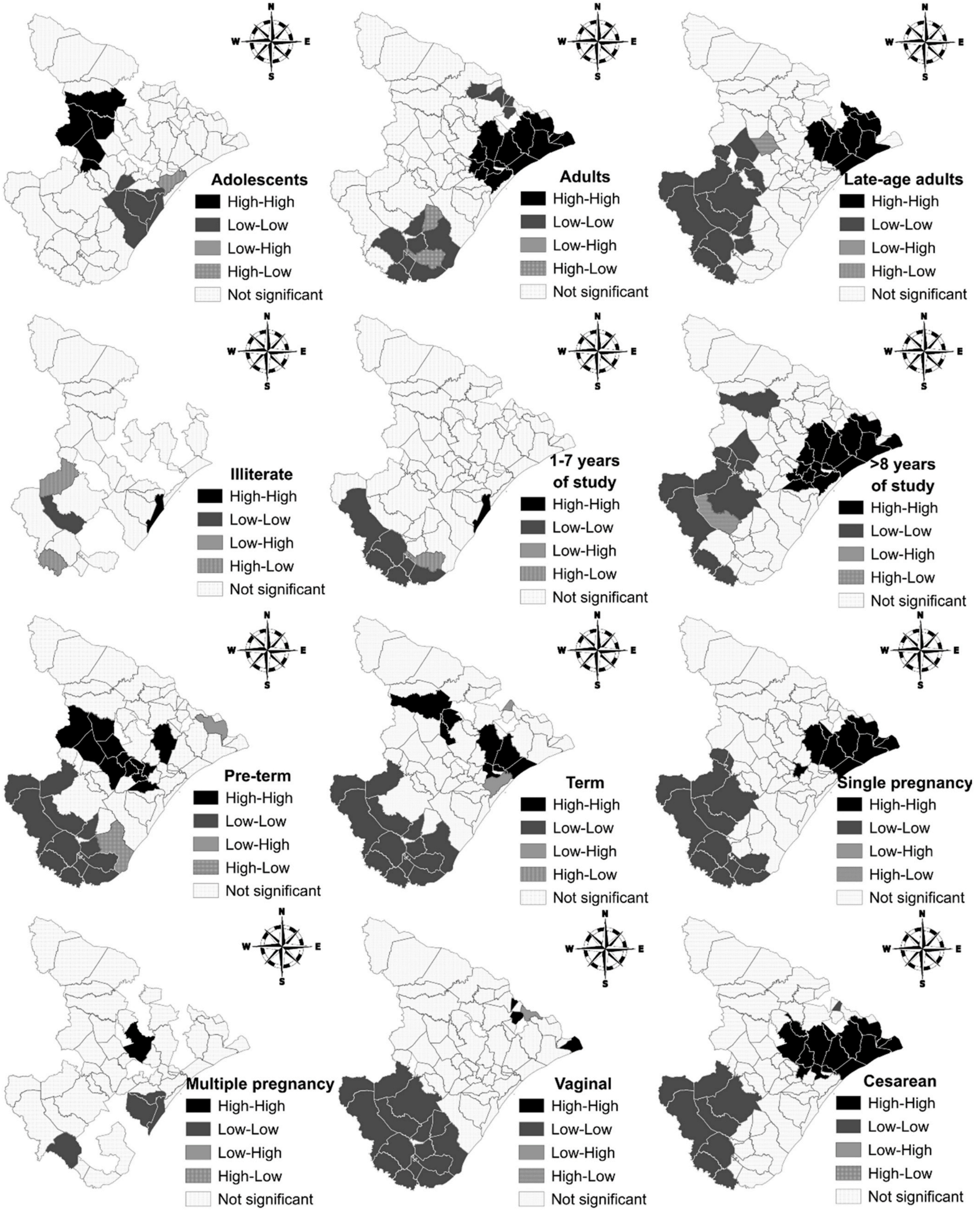

Fig. 4. Spatial correlation of Bayesian infant mortality rates in the municipalities of the state of Sergipe according to maternal and delivery-related variables, 2019–2023.

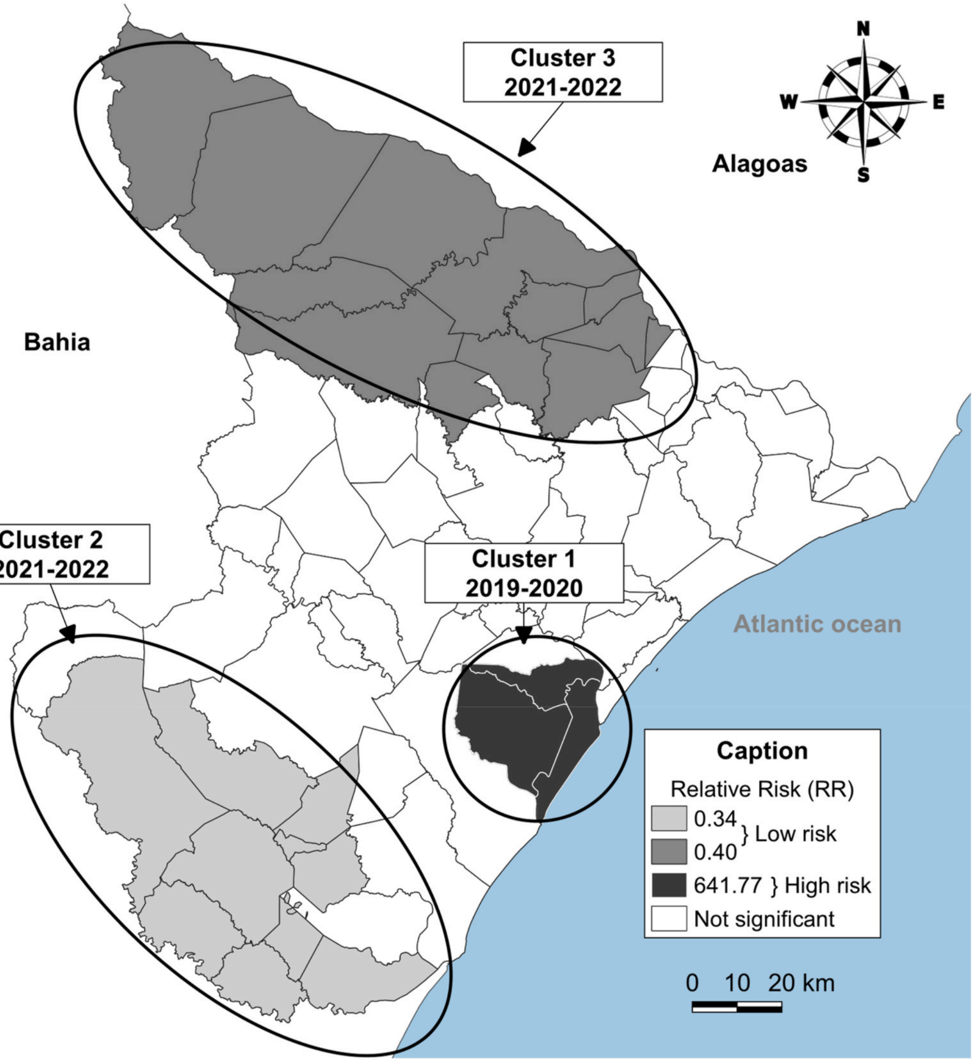

Fig. 5. Relative Risk (RR) of infant mortality in the municipalities of the state of Sergipe, 2019–2023.

advantage may contribute to their persistently low infant mortality levels.[18,19] Additionally, the effectiveness of healthcare services and greater efficiency in maternal and newborn care in these regions should also be considered. Furthermore, the presence of a maternity hospital in the Estância region is another plausible hypothesis.

Clusters of high infant mortality rates among adolescent mothers were identified in municipalities of the Itabaiana health region. The literature indicates that young mothers (<19 years of age) are 3.75 times more likely to experience neonatal death in their newborns (95 % CI: 1.40–10.02).[20] Infants of adolescent mothers generally present with lower birth weight and poorer anthropometric indicators at the beginning of life, although they show similar growth patterns up to six months of age. Nevertheless, they have a higher probability of mortality from all causes during this period when compared with infants born to adult mothers.[21] Evidence also shows that infant mortality is substantially higher among children born to adolescent mothers, particularly those under 20 years of age. Large multi-country analyses from sub-Saharan Africa and South Asia have demonstrated a strong age-gradient, with infants of very young mothers presenting mortality risks two to four times higher than those born to women aged 23–25.[22] This scenario may be associated with social vulnerability, limited access to adequate healthcare services,[23] and a higher prevalence of pregnancy-related complications among adolescent mothers—factors that can affect both prenatal care and birth and developmental conditions of the infant. In addition, aspects such as reduced maternal experience, limited family support, and deficiencies in reproductive planning guidance further contribute to the elevated risk of neonatal and post-neonatal deaths, reinforcing the need for public policies and targeted interventions focused on reproductive health and obstetric care during adolescence.

In this study, clusters of high infant mortality rates associated with cesarean delivery were observed in municipalities in the northwest of the state, specifically in the Propriá and Nossa Senhora do Socorro health regions. Several studies have reported that cesarean delivery is associated with increased odds of neonatal and infant mortality.[24–26] A systematic review and meta-analysis conducted in Brazil identified cesarean delivery as a significant risk factor for neonatal mortality, with an adjusted odds ratio of 1.55 (95 % CI: 1.20–2.00), reinforcing the vulnerability of newborns delivered by this route when not clinically indicated.[27] In Brazil, mortality among neonates born via cesarean delivery increased by 2.58 % per year between 2007 and 2017.[28] The rise in cesarean sections, often performed without strict clinical indication, may reflect deficiencies in the organization of maternal and child healthcare, as well as socioeconomic and cultural pressures influencing the choice of delivery type.

In this study, the municipalities of São Cristóvão, Aracaju, and Nossa Senhora do Socorro were identified as high-risk areas for infant mortality in Sergipe. A similar result was found in Mato Grosso, where the risk was also elevated in municipalities near the state capital, Cuiabá.[29] This scenario may be attributed to socioeconomic and structural factors, including income inequality, precarious urban infrastructure, and limited access to postnatal care.[30,31] Another plausible hypothesis is that, due to their proximity to the capital and the concentration of maternity hospitals—including high-risk facilities—these municipalities receive a greater volume of pregnant women and newborns with more complex clinical conditions, which may increase mortality statistics.

4.1. Strengths and limitations

Concerning limitations, the ecological design does not allow for inferences at the individual level or the establishment of causality. Secondary data are subject to underreporting or errors in completing death and/or live birth certificates. Municipalities with few records or small populations may mask local weaknesses; however, the spatial smoothing technique helped mitigate this issue. The aggregation of five years may also be a limitation, as it can obscure spatial or temporal fluctuations that might occur. Nevertheless, this grouping is essential for generating more robust results, as it increases the size of the population studied. Finally, external factors that may influence the observed patterns, such as social and economic determinants, were not considered.

This study provides a comprehensive overview of the spatial and spatiotemporal distribution of infant mortality in Sergipe, highlighting maternal and neonatal factors that may guide health managers and professionals in adopting preventive and interventional strategies. To the best of our knowledge, this is the first study to conduct a comprehensive analysis of demographic and clinical characteristics in the state. This aspect, combined with spatialization methods, may contribute to understanding the current scenario of infant mortality in Sergipe. Accordingly, the findings may inform the formulation of more effective public policies, such as strengthening prenatal care and improving childbirth and delivery conditions. These actions can mitigate health inequities and strengthen efforts to reduce infant mortality.

4.2. Conclusions

Infant mortality in Sergipe presents a heterogeneous spatial and temporal pattern, with a higher concentration of deaths in peripheral areas, particularly in the northern part of the state. Maternal factors, such as early age and type of delivery, and newborn characteristics, such as male sex and low birth weight, were significantly associated with higher mortality. Spatial analysis revealed high-risk clusters in municipalities of the Metropolitan Region, in contrast to lower-risk areas in other health regions, highlighting the persistence of regional inequalities influenced by socioeconomic, biological, and healthcare determinants.

Despite the reduction in infant mortality rates, substantial inequalities remain, requiring equitable public policies focused on strengthening prenatal, obstetric, and neonatal care, particularly in socially vulnerable areas. This study contributes to advancing knowledge on the spatial distribution of infant mortality in Sergipe. It provides a basis for future investigations aimed at understanding its multicausal determinants, including socioeconomic and biological factors, as well as those related to the structure and quality of healthcare services. Thus, this study reinforces the importance of integrating surveillance systems, high-quality databases, and epidemiological research as a fundamental axis for formulating effective and sustainable interventions, aligned with the principles of equity and social justice, with the goal of accelerating the reduction of infant mortality in the state.

Ethical statement

The data used in this study are open-access, publicly available, and contain no personal identifiers, thereby exempting the research from approval by an Ethics Committee.

CRediT authorship contribution statement

Maria Fernanda de Sá Camarço: Conceptualization, Methodology, Investigation, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jefferson Felipe Calazans Batista:** Conceptualization, Methodology, Data curation, Formal analysis, Software, Supervision, Validation, Writing – review & editing. **Sonia Oliveira Lima:** Conceptualization, Investigation, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

Artificial Intelligence tools (ChatGPT, OpenAI) were used exclusively for spelling and grammar review of the manuscript.

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Declaration of competing interest

None declared.

Data availability

Data will be made available on request.

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