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Maternal mortality in Brazil: an analysis of temporal trends and spatial clustering

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Abstract *This article aims to analyze spatial and temporal patterns of maternal mortality in Brazil during the period 2010-2020 and identify related socioeconomic indicators. We conducted an ecological study of the maternal mortality ratio (MMR) in Brazil's municipalities using secondary data. Temporal analysis was performed using the joinpoint method. Bayesian statistics, spatial autocorrelation, the Getis Ord Gi* technique and the scan statistic were used to identify spatial clusters, and multiple non-spatial and spatial regression models were used to assess the association between factors and the MMR. There was an increase in the MMR in 2020 and an increase in deaths in the North and Southeast. Clusters were found in Amazonas, Tocantins, Piauí, Maranhão, Bahia and Mato Grosso do Sul. The following indicators were negatively associated with the MMR: cesarean section rate, Municipal Human Development Index, and per capita household income of people who are vulnerable to poverty. The MMR was stable up to 2019, followed by a sharp rise in 2020 coinciding with the onset of the Covid-19 pandemic in the country. It is essential that efforts to reduce maternal mortality in Brazil extend beyond the promotion of improvements in antenatal, childbirth and postpartum care to address the social determinants of the problem.*

Key words *Maternal mortality, Epidemiology, Spatial analysis, Time series studies*

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Introduction

Maternal mortality (MM) is defined as the death of a woman while pregnant or within 42 days of termination of pregnancy from any cause related to or aggravated by the pregnancy or its management but not from unintentional or incidental causes[1].

Globally, around 99% of maternal deaths occur in developing countries. The risk of dying from maternal causes is approximately 120 times greater among women living in low-income countries than in those in high-income countries[1]. One of the millennium development goals (MDGs) was to reduce the maternal mortality ratio (MMR) by 75% between 1990 and 2015, irrespective of the duration and site of the pregnancy. However, a significant proportion of countries have not managed to meet this target, including Brazil, which has reduced the ratio by around only 50.0%[1,2].

There was a significant increase in the MMR in Brazil between 2018 and 2020, when there were 2,039 maternal deaths. In the states of Amazonas, Roraima, Pará, Amapá, Maranhão and Piauí, there were more than 100 deaths per 100,000 live births in 2020. A little over 9% of these deaths were associated with COVID-19, which in turn may be related to the fact that some infected pregnant women were too scared to seek health care during the pandemic, compromising their health and aggravating the condition and leading to the development of pneumonia, respiratory failure, sepsis, septic shock and ultimately death[3]. A study in Sweden revealed that the risk of being admitted to an intensive care unit was higher among pregnant women with COVID-19 than in other women due to worsening of symptoms[4].

In the light of the above, the assessment of deaths during pregnancy and the puerperium is important to identify social and regional disparities in Brazil and worldwide[5-7]. Amidst the increase in the MMR, spatial and temporal analyses are needed to identify clusters of maternal mortality and related socioeconomic indicators to inform specific public policies targeting areas where the problem is most severe. It is also important to emphasize the originality of this study, given that we did not find national studies investigating maternal mortality using geoprocessing techniques in the literature. The aim of this first-of-its-kind study was to analyze spatial and temporal patterns of maternal mortality in Brazil during the period 2010-2020 and identify related socioeconomic indicators.

Materials and methods

We conducted an ecological study using Brazil's municipalities as the unit of analysis. Brazil has an area of approximately 8.5 million sq km divided into five regions (North, Northeast, Midwest, Southeast and South), 27 states and 5,570 municipalities, and a population of 215 million[8].

We used secondary data from the Mortality Information System (SIM, acronym in Portuguese) and Live Birth Information System (SINASC, acronym in Portuguese) for the period 2010-2020, available on the website of the national health system's Department of Informatics, DATASUS. For the temporal analysis, the data were aggregated by region using the Joinpoint Regression Program version 4.6.0.0, calculating annual percentage change (APC) adopting a 95% confidence interval (95%CI).

The program models rates using piecewise linear segments on a log scale, testing whether one or more change points should be added to the linear model using the Monte Carlo permutation test. For this reason, the method is also known as change point regression, where each added point represents a change in the linear trend. The independent variable was year of occurrence of maternal death and the dependent variable was the MMR in each year. A negative APC indicates a decreasing trend, while a positive APC indicates an increasing trend, adopting a significance level of 0.05. When there is no statistical significance ($p > 0.05$), the trend is stationary[9].

For the spatial analysis of crude rates, we first calculated mean municipal MMRs using indirect standardization. The numerator was the total number of maternal deaths divided by the total number of years (11 years) and the denominator was the population of newborns in 2015 (the middle year of the study period) multiplied by 100,000 live births. To minimize the instability of the crude rates, the latter were smoothed using local Bayesian empirical analysis to correct for random fluctuations[10].

To identify spatial clusters, we used the spatial autocorrelation methods scanning and the Getis-Ord Gi* technique, adopting a significance level of 0.05. The Global Moran's Index was used to test the hypothesis of spatial dependence across the study area. When global autocorrelation was detected, we used the Local Moran's Index (Local Indicator of Spatial Autocorrelation - LISA) to detect spatial clusters in each municipality. The results were depicted using a Moran Map. High/high and low/low patterns indicate a positive

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spatial association, where neighboring areas have similar values, while high/low and low/high patterns show a negative spatial association, where neighboring areas have differing values[11].

$$MMR = \frac{\text{Total number of maternal deaths/number of years (11 years) x 100,000 live births}}{\text{Population of NBs in the middle year (2015)}}$$

The Getis-Ord Gi* technique creates z-scores that allow the identification of clusters. High z-scores indicate clustering of high values (hotspots), while low z-scores show clustering of low values (cold spots)[11]. Finally, for the purely spatial scan statistic, the scanning window encompassed 50% of the population at risk using the Poisson probabilistic model. The scan statistic was used to calculate relative risk (RR), where the risk of death in municipalities with a RR of > 1 is higher than the national rate[10].

The influence of socioeconomic indicators on the MMR was assessed using univariate ordinary least squares (OLS) regression. Indicators potentially linked to the MMR were selected based on epidemiological criteria after a comprehensive review of the literature on the topic. The following sources were used for the indicators: website of the Industry Federation of the State of Rio de Janeiro (FIRJAN), which measures local socioeconomic development[12]; SINASC, to obtain birth data[13]; and the Institute of Applied Economic Research's Atlas of Social Vulnerability, which enabled the analysis of inequalities through the identification of social vulnerabilities[14]. The following indicators from these sources were used: the Gini index, per capita household income, municipal human development index (MHDI), social vulnerability index, FIRJAN's index of municipal development (IFDM, acronym in Portuguese), primary health care coverage and cesarian section rate.

The explanatory variables for the OLS regression model were selected using the backward selection technique and the presence of multicollinearity was tested using the Variance Inflation Factor (VIF). The variables that were retained in the final OLS multiple regression model ($p < 0.10$) were also included in the global geographic models (spatial lag and spatial error models). The spatial lag model assigns spatial autocorrelation to the dependent variable, while the spatial error model assumes that observed spatial dependence is due to the influence of variables not included in the model[13].

We then adjusted the spatial regression model (geographically weighted regression – GWR), including the explanatory variables that obtained a p value of < 0.10 in the OLS model, as it was not possible to map the phenomenon using the previously used global spatial models. The results of the GWR are presented in two thematic maps for each socioeconomic indicator: one showing the regression coefficient and the other depicting the statistical significance of each municipality, adopting a significance level of 0.05. The results of the four regression methods were compared to select the model with the best fit based on the highest adjusted coefficient of determination (R^2) and lowest Akaike information criterion (AIC) value.

Scanning was performed using SatScan v.9.6. OLS regression analysis was performed using Stata v.12. Bayesian analysis, the Gertis-Ord Gi* technique, spatial lag and spatial error were performed using GeoDa 1.6.7. GWR regression was conducted using GWR v.4.0.9 and the maps were created using QGis v.2.14.17®.

The study was conducted in accordance with the ethical and legal norms and standards set out in National Health Council Resolution 510/16. The study did not require ethical approval as it was conducted using exclusively secondary data available in the public domain.

Results

There were 18,662 maternal deaths in Brazil during the period 2010-2020. The 30-39 and 20-29 year age groups accounted for the largest proportion of deaths (n = 7,391; 39.6% and n = 7,295; 39.1%, respectively). A large proportion of deaths were among brown women (n = 9,729; 54,0%), single women (n = 9,128; 53.0%) and women with between 8 and 11 years of schooling (n = 6,746; 43.2%). The overwhelming majority of deaths occurred in a hospital (n = 16,963; 90.9%).

The mean MMR in Brazil over the study period was 58.6 maternal deaths per 100,000 live births. The MMR remained relatively stable between 2010 and 2019, followed by a sharp increase in 2020 (from 55.31 deaths per 100,000 live births in 2019 to 71.97 deaths per 100,000 live births in 2020). The highest mean MMR was in the North (72.47 deaths per 100,000 live births), followed by the Northeast (69.27 deaths per 100,000 live births). In the other regions, mean MMR was above 40 deaths per 100,000 live births (Figure 1).

According to the results of the joinpoint regression analysis, there was an annual increase in the MMR of 3.0% (95%CI: 1.1-4.9; p = 0.006) in the North and 2.0% (95%CI: 0.5-3.7; p = 0.017) in the Southeast. These increases were statistically significant. The only region that showed a negative APC was the South; however, this result was not statistically significant. In the other regions and the country as a whole, trends were stationary (Table 1).

Figure 2 shows the results of the spatial clustering techniques. The distribution of crude MMRs (Map A) across the country was uneven. However, the distribution of rates was more even after smoothing (Map B), with MMRs ranging between 0.01 and 100.00 deaths per 100,000 live births in most municipalities. Clustering of deaths was observed in municipalities in the states of Amazonas, Tocantins, Maranhão, Piauí, Bahia and Mato Grosso do Sul.

Global Moran's I for crude rates showed a statistically significant positive spatial autocorrelation (I = 0.0682; p = 0.001). Map C shows clustering based on Local Moran's I. The dark gray areas represent municipalities with high/high patterns, most of which are in Tocantins, the north of Mato Grosso do Sul and in northeastern states, except for Pernambuco and Alagoas. Municipalities with low/low patterns are located mainly in the Sout and Southeast.

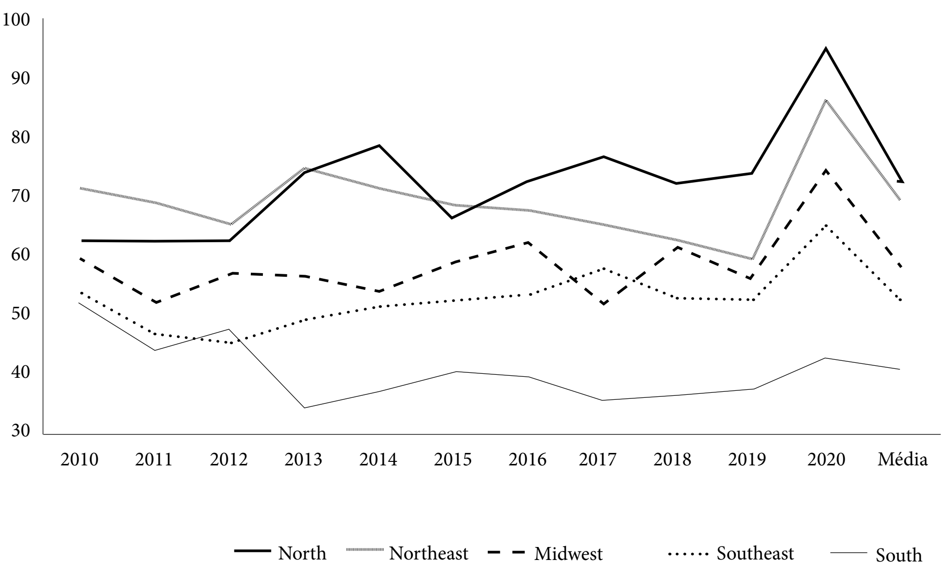

Figure 1. Maternal mortality ratio by region, 2010-2020.

Source: Authors based on data from the Mortality Information System, 2010 a 2020.

Table 1. Annual percent change in maternal mortality in Brazil, 2010-2020.

Region	Period	APC[a]	95%CI[b]	p-value	Trend
North	2010-2020	3.0[c]	1.1-4.9	0.006	Increasing
Northeast	2010-2020	0.2	-2.0-2.4	0.878	Stationary
Midwest	2010-2020	1.6	-0.4-3.7	0.107	Stationary
Southeast	2010-2020	2.0[c]	0.5-3.7	0.017	Increasing
South	2010-2020	-2.2	-4.5-0.2	0.064	Stationary
Brazil	2010-2020	1.1	-0.5-2.7	0.168	Stationary

[a] APC: Annual Percent Change. [b] 95%CI: 95% confidence interval. [c] p-value < 0.05.

Source: Authors based on data from the Mortality Information System, 2010-2020.

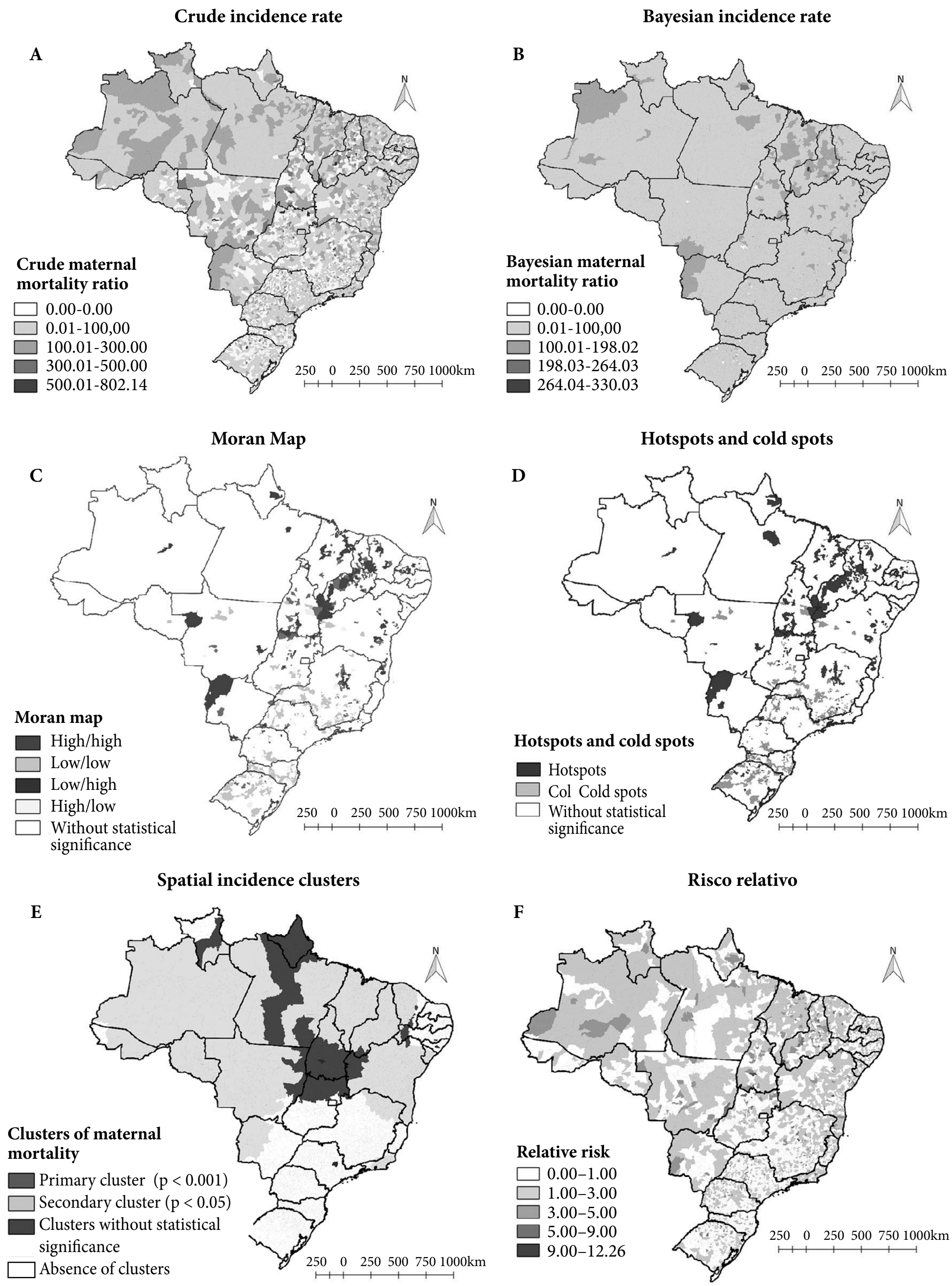

Figure 2. Crude maternal mortality ratio (A), rate smoothed using local Bayesian empirical analysis (B), Moran map (C), hotspots and cold spots (D), clusters of maternal mortality (E) and relative risk[a] based on the scan statistic (F). Brazil. 2010-2020.

[a] Relative risk: rate of maternal death in municipalities with RR > 1 higher than the national rate.

Source: Authors based on data from the Mortality Information System, 2010-2020.

The results of the Getis-Ord Gi* technique revealed practically the same spatial pattern shown on the Moran Map, with hotspots in almost all states in the Northeast, except Pernambuco and Alagoas, and in Tocantins, Roraima, Mato Grosso do Sul and Minas Gerais (Map D). It is worth highlighting that a large proportion of municipalities in Piauí had high/high patterns of deaths (Map C) and hotspots (Map D), and that the South and Southeast were cold spots.

Maps E and F show clusters and relative risk (RR) calculated using the purely spatial scan statistic. Eleven clusters were identified, five of which were statistically significant ($p < 0.05$). The primary cluster, obtained from the distribution of an event in a geographic space without a defined pattern, included 1,150 municipalities, located mainly in Amapá, Roraima, Pará, Tocantins and Goiás. The secondary clusters, which were also statistically significant, were found in practically all states in the North, Northeast and Midwest (Map E). Map F shows that the risk of MM is one to three times higher than the national rate in most municipalities.

To assess the influence of socioeconomic indicators on municipal MMRs, we compared the analysis parameters from the OLS regression ($R^2 = 0.041$; AIC = 63705.7), spatial lag ($R^2 = 0.042$; AIC = 64960.2), spatial error ($R^2 = 0.041$; AIC = 64962.2) and GWR ($R^2 = 0.068$; AIC = 64896.7) models. The models that with the best fit (lowest AIC value and highest R^2) were OLS regression and GWR, respectively.

Table 2 shows the indicators that influenced MM. The following independent variables were negatively associated with the outcome in the OLS model: cesarean-section rate ($\beta = -0.14$; $p = 0.08$), Municipal Human Development Index (MHDI) ($\beta = -151.87$; $p < 0.001$) and mean household per capita income of people who are vulnerable to poverty ($\beta = -0.17$; $p = 0.03$).

Figure 3 shows the spatial distribution of the estimated coefficients and statistical significance of the independent variables associated with the MMR in the GWR model. Maps A and B show that there was a negative association between cesarian-section rate and the dependent variable in states in the North (Amazonas, Acre, Rondônia), and in Mato Grosso, Mato Grosso do Sul and Minas Gerais.

In addition, in a large proportion of municipalities in Tocantins, Goiás and Paraná, the MMR increased with decreasing MHDI (Maps C and D). In municipalities in the south of Tocantins and west of Paraná there was a negative association between per capita income of people who are vulnerable to poverty and the MMR (Maps E and F).

Table 2. OLS, spatial lag, spatial error and GWR models including socioeconomic indicators influencing the maternal mortality ratio in Brazil, 2010-2020.

	OLS[a]			**Spatial lag[b]**			**Spatial error[c]**			**GWR[d]**	
Indicators	**Coefficient**	**Standard error**	**p**	**Coefficient**	**Standard error**	**p**	**Coefficient**	**Standard error**	**p**	**Coefficient**	**Standard error**
Constant	-0.14	0.08	0.08	-0.17	0.07	0.021	-0.20	0.08	0.012	-0.18	0.08
Cesarean-section rate	-151.87	32.07	<0.001	-94.29	30.35	0.001	-96.56	31.20	0.001	-99.34	30.42
MHDI	-0.17	0.08	0.03	-0.20	0.07	0.006	-0.23	0.07	0.003	-0.24	0.08
Income vulnerability to poverty	NA[g]	NA[g]	NA[g]	0.09	0.02	<0.001	NA[g]	NA[g]	Na[g]	NA[g]	NA[g]
Lag W[e] (spatial lag)	NA[g]	NA[g]	NA[g]	NA[g]	NA[g]	NA[g]	0.09	0.02	<0.001	NA[g]	NA[g]
LAMBDA[f] (Spatial error)											

[a] OLS: ordinary least squares regression, linear regression method. [b] spatial lag: dependent variable spatial autocorrelation model. [c] Spatial error: spatial error model influenced by independent variables. [d] GWR: geographically weighted regression, spatial regression model. [e] Lag W: spatially-correlated error coefficient. [f] LAMBDA: spatial dependence inherent in sample data. [g] NA: not applicable.

Source: Authors based on data from the Industry Federation of the State of Rio de Janeiro, Live Birth Information System and 2017 Atlas of Social Vulnerability.

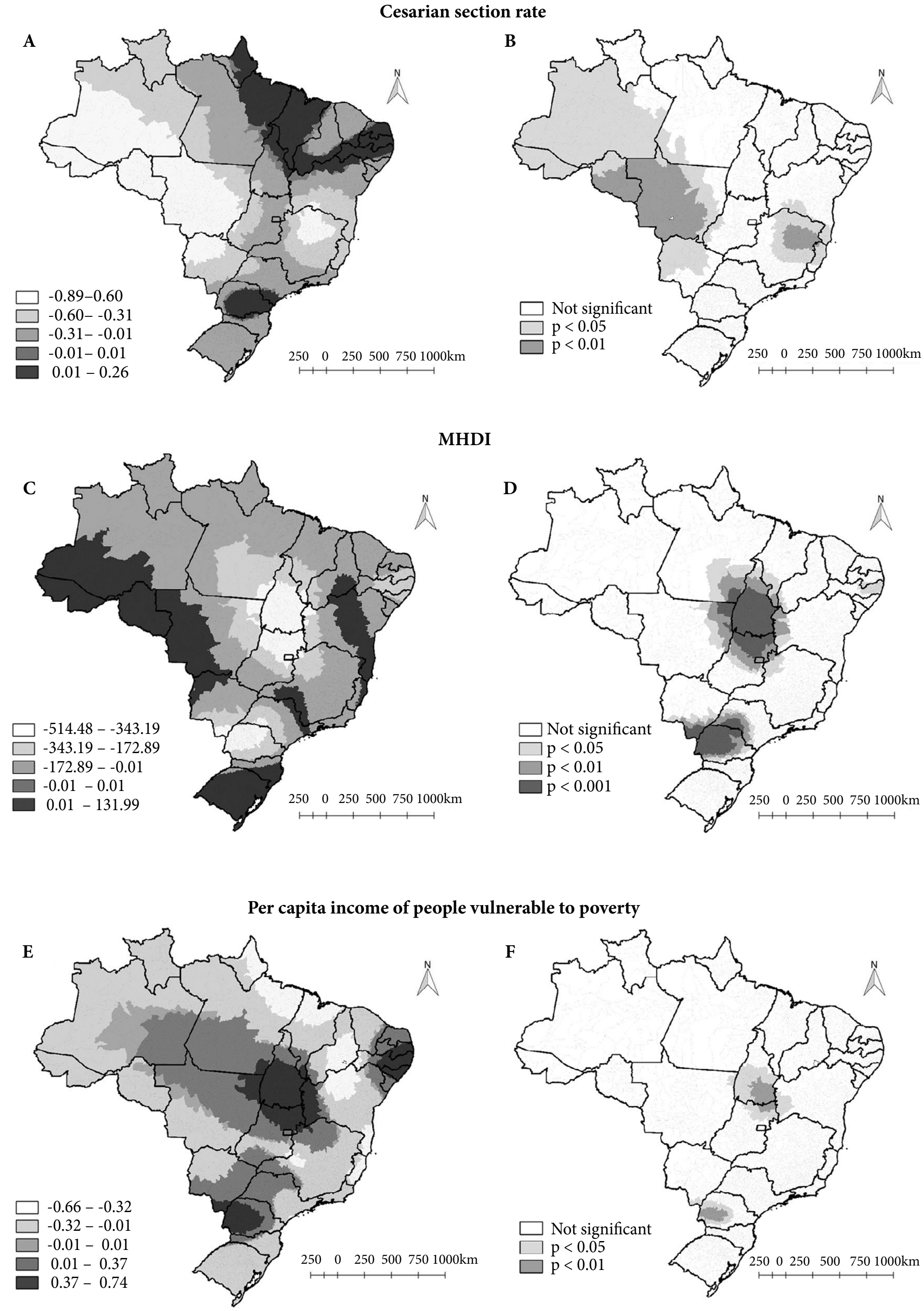

Figure 3. Spatial distribution of estimated coefficients and statistical significance of independent variables associated with maternal mortality in the GWR model. Brazil, 2010-2020[a].

[a] GWR: Geographically Weighted Regression, spatial regression model; MHDI: Municipal Human Development Index.

Source: Authors based on data from the Industry Federation of the State of Rio de Janeiro, Live Birth Information System and 2017 Atlas of Social Vulnerability.

Full results are available at: https://doi.org/10.48331/scielodata.ACINRO.

Discussion

The results of the temporal analysis of the MMR reveal a stationary trend over the last decade across the country, except in 2020, when there was a sharp increase in the ratio, coinciding with the onset of the COVID-19 pandemic[15-17].

In 2020, the mortality rate in pregnant women hospitalized due to COVID-19 was 5.5% and that of postpartum women was 12.9%. In 2021, lethality increased to 11.5% among pregnant women and 22.3% among postpartum women. In May 2021, the Pan American Health Organization (PAHO) published a report showing that there was an increase in cases of COVID-19 among pregnant and postpartum women between January and April of the same year and a significant increase in maternal deaths from the disease across 12 countries in the Americas[18,19].

The region with the highest mean MMR was the North, followed by Northeast. It is important to mention that socioeconomic issues are determining factors when MMRs are compared across states. According to the literature, the North has the highest rate of maternal deaths, reflecting disparities in access to health and education across regions and low socioeconomic status[20,21].

Despite having the largest percentage of high complexity hospitals in the country, the Southeast witnessed a rise in the MMR during the study period. However, this is probably because regions with better health indicators and better quality maternity care become referral centers, receiving more severe cases where the outcome may often be death[22,23].

The only region that showed a decreasing trend in the joinpoint analysis was the South. The results of another study in Brazil suggest that this reduction may be due to the fact that the South has high levels of socioeconomic development, facilitating the allocation of resources to improve the quality of care. In addition, the implementation of the *Rede Cegonha* (Stork Network) within the country's public health system, *o Sistema Único de Saúde* (SUS) or Unified Health System, has led to advances in antenatal, childbirth and postpartum care, resulting in a reduction of adverse maternal and neonatal outcomes, especially in this region[24].

Rates of maternal mortality in Chile are lower than those in Brazil, standing at around 15 maternal deaths per 100,000 live births in 2020. This may be explained by the adoption of new strategies to guarantee quality health care and help minimize maternal mortality, including four or more antenatal care visits, childbirth assisted by a skilled birth attendant, and postnatal care within two days of birth[25].

The present study shows the spatial distribution of maternal mortality in Brazil. The results of the local Bayesian empirical analysis shows that the municipalities with the highest smoothed rates of maternal mortality during the study period were in the states of Amazonas (in the North), Piauí and Maranhão (Northeast) and Mato Grosso do Sul (Midwest). In the spatial autocorrelation test, states in the Northeast and Mato Grosso do Sul showed a high/high pattern of distribution. This was confirmed by the Getis-Ord Gi* statistic, which revealed hotspots in the Northeast, especially in Piauí, and in the north of Mato Grosso do Sul.

Although poverty and income inequality in the northeast has declined in recent decades, the indicators reveal that disparities still exist between this region and other regions, and within the region[26]. It is important to highlight that levels of health professional adherence to the use of antenatal risk stratification guidance are low in municipalities in the Northeast and access to antenatal care is reduced, especially among women with high-risk pregnancies. In addition, it is important to highlight the lack of training of primary care providers to develop the appropriate mix of skills and competencies needed to care for pregnant women[27,28].

Our findings also revealed clusters of maternal mortality in municipalities located in Mato Grosso do Sul, more specifically on the Brazil/Bolivia border. This is a reflection of the fragility of antenatal, childbirth and postpartum care and the social vulnerability of women living in these areas. It is important to highlight that, despite scarce human and financial resources, these municipalities receive a large number of Bolivians seeking free health care. While health is the right of all those living in Brazil, not just Brazilian citizens (Law 13684), the quality of health services may be affected by the pressure on the health system caused by migration, resulting in increased health costs without any contribution from the Bolivian government[29-31].

Cesarean-section rates were negatively associated with the MMR in states in the North (Amazonas, Acre, Rondônia), and in Mato Grosso, Mato Grosso do Sul and Minas Gerais, with

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maternal mortality increasing with decreasing rates. At first glance, this result appears to be a paradox. However, geographical barriers to access to more complex care, including distance to health facilities, especially in the North, can result in maternal and neonatal deaths when there are childbirth complications requiring an emergency cesarean section. In addition, lack of access to and poor quality of antenatal care in primary health care services increases the likelihood of errors when indicating vaginal birth[32].

In remote rural and riverside communities in the state of Amazonas, for example, populations do not receive regular essential public services and the journey to health facilities located in administrative centers can take days or weeks as people depend chiefly on precarious river transport[33,34]. Given the fragility of public health services in these communities, it is essential that municipalities in the Amazon region promote training in the early identification of risk situations that require timely referral to higher level services[35].

With a similar context to the state of Amazonas, Mozambique has low cesarian section rates, especially in poor rural areas, and high risk of maternal morbidity and mortality associated with the fragility of the public health system, in turn, favors the occurrence of clandestine abortions, which in turn increases the risk of problems such as hemorrhage, anemia, eclampsia and postpartum infections, which can lead to death[36].

Our findings show increased maternal mortality with decreasing MHDI in municipalities in Paraná, Tocantins and Goiás. A similar result was found by a study of predictors of maternal mortality in Brazil, in which severe maternal morbidity was negatively associated with the HDI[37].

Our findings reveal a negative association between per capita household income of people who are vulnerable to poverty and the MMR in municipalities located in the south of Tocantins and west of Paraná. Contrasting findings were reported in a study showing that MMRs across the country are influenced mainly by low per capita income in different states[38]. Hence, while the proportion of people living under the poverty line has dropped in recent decades, one of the main challenges facing the country is the reduction of poverty in the face of income inequality, especially between urban and rural areas[39].

A study of the correlation between socioeconomic, health and disease burden indicators and the MMR in 82 developing countries found that maternal mortality is correlated with socioeconomic factors. Wide variations in maternal mortality levels exist among different income groups, which suggests that countries need to design comprehensive interventions that acknowledge the potential effect of purchasing power on the reduction of maternal mortality[40].

This study has some limitations. First the use of secondary data can result in inconsistencies in data quantity and quality due to underreporting and missing information. Second, the results of the multiple analysis should be interpreted with caution as the coefficients for cesarian-section rates and per capita income of people who are vulnerable to poverty are very close to zero. However, these limitations do not invalidate our findings and the present study makes an important contribution to research on this topic.

Conclusion

Our findings show that the MMR was stable up to 2019, followed by an alarming increase in 2020 coinciding with the onset of the COVID-19 pandemic in the country. The regions with the highest mean MMR were the North and Northeast. The results of the joinpoint analysis revealed a statistically significant increasing trend in mortality in the North and Southeast during the study period. The results of the spatial statistical analyses revealed clusters of maternal deaths concentrated in states in the North (Amazonas and Tocantins), Northeast (Piauí, Maranhão and Bahia) and Midwest (Mato Grosso do Sul). Cesarean-section rate, MHDI and per capita household income of people who are vulnerable to poverty were negatively associated with the MMR.

The findings of this study provide an important contribution to existing knowledge on maternal health in Brazil. For strategies aimed at preventing complications during pregnancy and the puerperium to be effective, it is necessary to step up the implementation of current policies to promote improvement in the health conditions of women living in regions with the highest rates of maternal deaths. However, interventions to prevent maternal deaths are not the sole responsibility of the health sector, since the promotion of maternal health extends far beyond the basic aspects of antenatal, childbirth and postpartum care, meaning that it is necessary to focus on the social determinants of this problem.

Collaborations

IVG Oliveira, TA Maranhão: conception and design of the study; analysis and interpretation of data; great contribution to writing; reading and approval of the final version. TKA Araujo, MMC Frota: study implementation; analysis and interpretation of data; great contribution to writing; reading and approval of the final version. Torres, MIF Rocha, MED Xavier: great contribution to the writing; reading and approval of the final version. GJB Sousa: study conception and design; data analysis and interpretation; great contribution to the writing; reading and approval of the final version.

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