

Factors associated with mortality from 5 to 14 years of age according to geographically weighted regression

Fatores associados à mortalidade dos 5 aos 14 anos: uma regressão geograficamente ponderada

Factores asociados a la mortalidad de 5 a 14 años: una regresión ponderada geográficamente

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Abstract Mortality data for the 5 to 14 age group is scarce and often of low quality, despite most of these deaths being preventable. Social determinants of health offer an alternative perspective to understand the context of these deaths. An analytical ecological study using geographically weighted regression was conducted to identify the association between social determinants and deaths among 5 to 14-year-olds in Mato Grosso from 2009 to 2020. The model included variables related to demographic, geopolitical, environmental factors, living conditions, and access to health services. The model effectively explained mortality patterns in both age groups. For 5 to 9-year-olds, deaths were influenced by demographic, environmental, geopolitical, and health services factors, while for 10 to 14-year-olds, demographic, environmental factors, and living conditions played a larger role. The models were similar but showed varying variable compositions and behaviors depending on location and age group. The strongest associations for ages 5 to 9 were concentrated in the northeast and southeast regions, characterized by major grain production and state/international borders. For ages 10 to 14, associations were more heterogeneous.

Key words Mortality, Social determinants of health, Spatial regression

Resumo Os dados de mortalidade dos 5 aos 14 anos são escassos e frequentemente de baixa qualidade. Apesar disso, a maioria dos óbitos são considerados evitáveis. Os determinantes sociais da saúde podem auxiliar a compreender o contexto dessas mortes. Estudo ecológico analítico que usou regressão geograficamente ponderada para identificar associação entre determinantes sociais e óbitos dos 5 aos 14 anos em Mato Grosso de 2009 a 2020. O modelo incluiu variáveis relacionadas a fatores demográficos, geopolíticos, ambientais, condições de vida e acesso aos serviços de saúde. O modelo explicou com eficácia os padrões de mortalidade nos grupos etários. Dos 5 aos 9 anos, os óbitos foram influenciados por fatores demográficos, ambientais, geopolíticos e dos serviços de saúde. Dos 10 aos 14 anos, os fatores demográficos, ambientais e as condições se destacaram. Mesmo semelhantes, os modelos variaram na composição e no comportamento das variáveis, conforme a localização e o grupo etário. As associações mais fortes dos 5 aos 9 anos foram concentradas nas regiões nordeste e sudeste, caracterizadas pela grande produção de grãos e fronteiras estaduais/internacionais. Dos 10 aos 14 anos, as associações foram heterogêneas.

Palavras-chave Mortalidade, Determinantes sociais da saúde, Regressão espacial

Resumen Datos de mortalidad de 5 a 14 años son escasos y, a menudo, de baja calidad. La mayoría de los óbitos se consideran evitables. Determinantes sociales de la salud pueden ayudar a comprender el contexto de estas defunciones. Estudio ecológico analítico utilizó regresión geográficamente ponderada para identificar la asociación entre los determinantes sociales y los óbitos de 5 a 14 años en Mato Grosso, de 2009 a 2020. El modelo incluyó variables relacionadas a factores demográficos, geopolíticos, ambientales, condiciones de vida y acceso a servicios de salud. El modelo explicó los patrones de mortalidad en los grupos etarios. De 5 a 9 años, los óbitos fueron influenciados por factores demográficos, ambientales, geopolíticos y servicios de salud. De 10 a 14 años, los factores demográficos, ambientales y condiciones de vida se destacaron. Aunque similares, los modelos variaron en la composición y el comportamiento de las variables según la ubicación y el grupo etario. Las asociaciones más fuertes de 5 a 9 años se concentraron en las regiones noreste y sureste, caracterizadas por una gran producción de granos y fronteras estatales/internacionales. De 10 a 14 años, las asociaciones fueron heterogéneas.

Palabras clave Mortalidad, Determinantes sociales de la salud, Regresión espacial

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Introduction

One of the main challenges in research on the relations between social determinants and health is to demonstrate hierarchy between social, economic, and political factors and to understand how their dynamics impact the health and life of population groups. Understanding this chain of mediations allows identifying issues that are amenable to interventions, identifying where such interventions can be most relevant¹.

Especially in children and adolescents, the health and disease pattern varies widely between and within populations and correlates with various determinants (economic, educational, social, cultural, climatic, geographical, and nutritional), in addition to industrialization, urbanization, the genetic frequencies of certain disorders, and healthcare infrastructure².

From a public health perspective, the identification of causes of death and the estimation of risk related to socioeconomic factors allows identifying the degree to which each factor contributed to this mortality. It is thus possible to justify and target public efforts to reduce health inequities³.

Evidence shows that social protection programs and those that promote access to primary healthcare services have contributed to reducing infant mortality and health inequities⁴. In Brazil's state capitals, the principal determinants of infant mortality in 2012 were biological, mediated by maternal socioeconomic conditions and insufficient prenatal care⁵. The mortality trend in children from 2001 to 2017 showed a statistically significant correlation with economic, educational, sanitation, and healthcare factors in all regions of Brazil⁶.

Little is known generally about whether socioeconomic differences in mortality persist into adolescence or are attenuated over the years, since the data on social variables and mortality are still scarce and with poor quality⁷.

The interest in studies on under-five mortality is undeniable, given its relevance as an indicator of the population's health situation. However, the analysis of mortality in the subsequent age groups, from 5 to 14 years, has justified the recent emphasis it has received, since it mainly involves avoidable deaths⁸⁻¹¹.

From 2009 to 2020, both in Brazil and in the Brazilian state of Mato Grosso, deaths of children and adolescents 5 to 14 years of age were predominantly in males, avoidable, and related to external causes, especially traffic accidents. Contrary to Brazil's downward national trend

during the period, the mortality trend in these age groups in Mato Grosso was classified as stationary. This and the high number of deaths in the state led to an alert and the need for intervention¹².

The current study aimed to identify the geographical variation in factors associated with mortality in individuals 5 to 14 years of age in the state of Mato Grosso, Brazil.

Materials and methods

This was an analytical ecological study that used geographically weighted regression (GWR) to analyze mortality data in children and adolescents 5 to 14 years of age residing in the state of Mato Grosso from 2009 to 2020.

The state's 141 municipalities were used as the aggregation units, and the total number of deaths in each municipality was identified as the outcome variable, based on the Poisson model. For data analysis, the digital maps were associated with the respective geographical scales.

Mortality data were extracted from the Mortality Information System (SIM in Portuguese), which contains data from death certificates (DC) issued throughout the country and has open access on the website of the Information Technology Department of the Unified Health System (DATASUS).

The population data and those referring to explanatory variables were extracted from the websites of the Brazilian Institute of Geography and Statistics (IBGE), the Mato Grosso State Health Secretariat (SES-MT), Mapbiomas, e-Gestor, and DATASUS itself, through the Health Information Tabulator (TabNet).

The year 2015 was chosen as the reference for extracting data on the outcome variables since it represented approximately the midpoint in the target period. However, some variables were built according to the available information, not always consistent with the reference year.

Excel spreadsheets were produced with the data stratified by age group, from 5 to 9 and from 10 to 14 years of age, and by the victim's municipality of residence. Although this is a population group that has been little explored, for this analysis, the age groups were categorized according to the stratification used by the World Health Organization (WHO), taking into account the different mortality characteristics among them¹².

Considering that the total number of deaths in the municipalities was used as the outcome variable, we excluded deaths that did not occur

in the two age groups in the target period. We thus analyzed mortality data from 117 municipalities for deaths from 5 to 9 years of age and from 125 municipalities for deaths from 10 to 14 years of age.

The potential explanatory variables were identified as relevant in the literature, given the theoretical epidemiological framework for the outcome. The variables were categorized in five domains: demographic, geopolitical, environmental, living conditions, and health services access, coverage, and quality.

1. Demographic characteristics

- Sex ratio: this variable represents the male-to-female mortality ratio. The data source is DATASUS, and the variable is classified as numerical (acronym: sexo).

- Nonwhite/white ratio: this variable indicates the mortality ratio between nonwhite and white populations. It is sourced from DATASUS and is also numerical (acronym: racor).

- Ratio of underlying causes: this variable measures the deaths from external causes relative to deaths from all other causes. The data is obtained from DATASUS, and the classification is numerical (acronym: cbas).

2. Geopolitical characteristics

- Division of regional health office: this categorical variable classifies regions based on their division of Regional Health Offices, sourced from SES-MT (acronym: ers).

- Distance to reference municipality: a numerical variable representing the distance in kilometers to a reference municipality for higher-complexity health services, according to the microregions, sourced from IBGE (acronym: ref).

- Distance to state capital: this numerical variable measures the distance in kilometers to the state capital, also sourced from IBGE (acronym: cap).

- Borders: a categorical variable indicating the presence of state and/or international borders in the municipality, with data from IBGE (acronym: front).

3. Environmental characteristics

- Population density: indicates inhabitants per square kilometer in 2010, a numerical variable sourced from IBGE (acronym: dens).

- Sewage system: represents the percentage of the resident population with sewage disposal in 2010, another numerical variable from IBGE (acronym: sanit).

- Street improvement: this variable measures the presence and quality of roadway infrastructure around households in 2010, classified

as numerical and sourced from IBGE (acronym: urb).

- Area dedicated to agriculture: indicates hectares dedicated to agriculture in 2017, a numerical variable from IBGE (acronym: agri).

- Proximity to mining operations: a categorical variable representing the smaller distance to a municipality with mining activity during the target period, sourced from Mapbiomas (acronym: garimp1).

4. Living conditions

- Human Development Index (HDI): this numerical variable reflects the Human Development Index in 2010, sourced from IBGE (acronym: idh).

- Basic Education Development Index (IDEB): a numerical variable indicating the IDEB in 2015, with data from IBGE (acronym: ideb).

- All-cause mortality rate (ACMR): represents the total deaths in all age groups during the period per population in the mid-period, multiplied by 100,000. The source is DATASUS, and it is numerical (acronym: cgm).

- Homicide rate: this variable indicates the total deaths with underlying causes from ICD X85 to Y09 and Y35 to Y36, per population in the mid-period, multiplied by 100,000, sourced from DATASUS (acronym: homic).

5. Health services access, coverage, and quality

- Primary healthcare (PHC) coverage: reflects the percentage of the resident population with primary healthcare coverage in 2015. This numerical data is sourced from e-Gestor (acronym: aps).

- Vaccination coverage: the percentage of vaccines that reached ideal coverage in 2015, a numerical variable from DATASUS (acronym: vaci).

- Hospital beds: represents the number of general hospital beds in 2015, classified as numerical and sourced from DATASUS (acronym: leitgeral).

- Pediatric beds: indicates the number of pediatric hospital beds in 2015, a numerical variable from DATASUS (acronym: leitped).

- Pediatric urgency beds: the number of pediatric urgency beds in 2015, a numerical variable sourced from DATASUS (acronym: leiturg).

- SAMU: a categorical variable indicating the presence or absence of mobile emergency medical care teams during the period, with data from DATASUS (acronym: samu).

Regression analysis was performed to test the association between the outcome variable

and explanatory variables, using the R software (R Project for Statistical Computing, version 4.2.2. RBase). Initially, all the variables proposed in the theoretical model were submitted to simple Poisson regression. The magnitude of association was estimated with 80% confidence interval and 20% level of significance.

The variables selected in the first stage were included in the final complete model with multivariate regression (*generalized linear model* – GLM), with 5% significance and 95% confidence interval. In addition to statistical significance, we also considered the theoretical framework as a criterion for maintaining variables in the final model, built with the backward stepwise method.

To assess the data's geographical variability and test the models' fit, the variables in the final multivariate regression model were submitted to geographically weighted regression, using the GWR software (Geographically Weighted Modelling, version 4.09).

This type of analysis aims to verify the degree to which the regression model (controlled/adjusted by geographical factors) can explain the outcome, since the phenomena may undergo changes according to the place where they are studied, potentially characterized as protective or risk factors, according to the calculated regression coefficient¹³.

The spatial autocorrelation of the GLM residuals was assessed using the Moran Index to determine whether autocorrelation persisted, justifying the application of GWR. After fitting the GWR model, the Moran Index was recalculated to assess whether autocorrelation remained. A first-order contiguity matrix was employed. Since this is a permutation test, the result was assessed via the pseudo-p-value.

The models' comparison and selection of the model that best explains mortality from 5 to 14 years of age in Mato Grosso state used analysis of the Akaike information criterion (AIC).

The QGIS Desktop software version 3.22.4, with free access on the IBGE website, was used to produce maps linking the results of the GWR regression analyses to the municipalities' cartographic grids. The regression estimates were categorized in levels and displayed with different color intensities on the maps.

Following the regression analyses, explanatory models were built for the variables associated with mortality in each age group.

Since this was an analysis of secondary data in the public domain and with free access, without identification of individuals, the study received

an Exemption from Ethical Review (no. 09/2022) from the Institutional Review Board of the National School of Public Health, Oswaldo Cruz Foundation (Fiocruz), Rio de Janeiro, Brazil.

Results

From 2009 to 2020, there were 2,068 deaths in children and adolescents 5 to 14 years of age in Mato Grosso state. The mortality profile was similar between the 5-9 and 10-14-year age groups, namely: predominantly male, brown race/skin color, and external causes as the underlying cause, mostly traffic accidents.

Deaths from 5 to 9 years of age were distributed across 117 (83%) of the municipalities in Mato Grosso state, according to records on place of residence. The highest male/female mortality ratio was seen in the municipality de Campinápolis (8.0), the highest non-white/white race ratio was identified in Barra do Garças (8.5), both of which are located in northeast Mato Grosso, and the municipality with the highest ratio between external causes and other causes of death was São José do Rio Claro (3.0), in the north of the state.

Deaths were recorded in children and adolescents 10 to 14 years of age residing in 125 (88.7%) municipalities in Mato Grosso. Chapada dos Guimarães, in central-south Mato Grosso, showed the highest sex ratio (8.0), Nobres the highest non-white/white ratio (10.0), and Campo Novo do Parecis the highest ratio of external causes to other causes (6.0), the latter two municipalities located in the north of Mato Grosso.

Of the 141 municipalities in Mato Grosso state, 35 (24.8%) have state or international borders, 22 (15.6%) have mining activity, 121 (85.8%) lack pediatric urgency beds, and 24 (17.0%) are or have been the headquarters for mobile emergency medical services during the target period. The municipality located farthest from its reference is Rondolândia, 600 kilometers from Pontes e Lacerda; and the municipality located farthest from the state capital (Cuiabá) is Santa Cruz do Xingu, 1,380 kilometers away.

The mortality pattern identified in the state can be explained by variables that comprise most of the aspects covered in the proposed theoretical model. Among the 20 variables submitted to simple regression, 18 met the criteria and entered the multivariate model for the age group from 5 to 9 years, while 17 met the criteria for the 10-14-year group.

In the 5 to 9-year group, 6 variables remained in the final model: 2 (33.3%) pertaining to demographic factors, 1(16.7%) to geopolitical factors, 2 (33.3%) related to environmental factors, and 1 (16.7%) to health services access and quality. Of these, distance to the state capital and presence of a mobile emergency medical service were the only factors that showed negative associations, pointing to more deaths in areas closer to the state capital and assisted by mobile emergency medical service (SAMU); all the others showed positive associations (Table 1).

In the 10 to 14-year age group, 6 variables also remained in the final model: 2 (33.4%) pertaining to demographic factors, 2 (33.3%) to environmental factors, and 2 (33.3%) to living conditions. Of these, the presence of a state or international border and human development index (HDI) showed negative associations; all the others showed positive associations (Table 2).

Considering the variables in the final GLM models, calculation of the Moran index of the residuals showed significant spatial autocorrelation in both the younger age group (Moran'I = 0.04; pseudo p-value = 0.04) and the older group (Moran'I = 0.04; pseudo p-value 0.03), justifying the fit by GWR.

In the 5 to 9-year age group, the GLM model showed an AIC of 517.68, while the GWR model showed an AIC of 140.95 (Table 1). In the 10 to 14-year group, the GLM model showed AIC of 617.7, while the GWR model showed AIC of 190.28 (Table 2).

Based on the criteria, the study showed that the GWR model was superior to the GLM model for explaining mortality in children and adolescents in Mato Grosso in both age groups.

The Moran Index test showed that there was no spatial autocorrelation in the GWR models in either the 5 to 9-year group (Moran'I = 0.02;

Table 1. Behavior of variables and comparison of regression models used to analyze association between sociodemographic factors and number of deaths from 5 to 9 years of age in the municipalities in Mato Grosso state, Brazil, 2009 to 2020.

Factor	Variable	GLM – Complete model				GLM – Final model				GWR – Final model		
		β	SE	T	P-value	B	SE	T	P-value	β med	β min	β max
Demographic	Sex ratio	0.10	0.03	3.18	< 0.01*	0.13	0.03	4.50	< 0.01*	0.13	0.12	0.13
Demographic	Ratio of underlying causes	0.13	0.07	1.95	0.05*	0.16	0.06	2.52	0.01*	0.15	0.12	0.18
Geopolitical	Distance to state capital	-0.01	0.01	-2.53	0.01*	0.01	0.01	2.67	0.01*	-0.01	0.01	-0.01
Environmental	Population density	0.01	0.01	1.93	0.05*	0.01	0.01	1.47	0.14	0.01	0.01	0.01
Environmental	Presence of borders	0.18	0.11	1.61	0.11	0.18	0.10	1.92	0.05*	0.20	0.09	0.24
Health	Presence of SAMU HQ	-0.20	0.12	-1.68	0.09	-0.19	0.09	-2.10	0.04*	-0.18	-0.2	-0.15
Demographic	Nonwhite/white ratio	0.02	0.03	0.63	0.53							
Geopolitical	Division of Regional Health Office	0.01	0.01	0.21	0.84							
Geopolitical	Distance to reference municipality	-0.01	0.01	-0.68	0.50							
Environmental	Area dedicated to agriculture	0.01	0.01	0.57	0.57							
Environmental	Sewage disposal	-0.01	0.01	-1.03	0.31							
Environmental	Street improvement	0.01	0.01	-0.06	0.95							
Environmental	Proximity to mining operations	0.01	0.01	0.98	0.32							
Living conditions	Homicide rate	0.05	0.04	1.45	0.15							
Living conditions	All-cause mortality rate	-0.01	0.01	-0.06	0.95							
Living conditions	Human development index	-1.51	1.50	-1.00	0.32							
Health	PHC coverage	0.01	0.01	0.47	0.64							
Health	Pediatric urgency beds	0.01	0.01	0.70	0.49							
AIC		535.79				517.68				140.95		

Notes: GLM – generalized linear model; GWR – geographically weighted regression; β – regression coefficient; SE – standard error; T – t-statistic; AIC – Akaike information criterion.

Table 2. Behavior of variables and comparison of regression models used to analyze association between sociodemographic factors and number of deaths from 10 to 14 years of age in the municipalities in Mato Grosso state, Brazil, 2009 to 2020.

Factor	Variable	GLM – Complete model				GLM – Final model				GWR - Final model		
		β	SE	T	P-value	β	SE	T	P-value	β med	β min	β max
Demographic	Sex ratio	0.07	0.02	2.88	< 0.01*	0.07	0.02	3.36	< 0.01*	0.07	0.07	0.08
Demographic	Nonwhite/white ratio	0.07	0.02	2.88	< 0.01*	0.07	0.02	3.52	< 0.01*	0.07	0.06	0.07
Environmental	Presence of borders	-0.16	0.10	-1.70	0.09	-0.15	0.09	-1.72	0.08	-0.14	-0.25	-0.06
Environmental	Area dedicated to agriculture	0.00	0.01	1.53	0.13	0.01	0.00	1.62	0.11	0.01	-0.01	0.01
Living conditions	Homicide rate	0.06	0.03	1.96	0.05*	0.05	0.03	1.91	0.06	0.06	0.04	0.08
Living conditions	Human development index	-1.96	1.26	-1.55	0.12	-2.10	0.70	-3.00	< 0.01*	-2.40	-3.05	-1.11
Demographic	Ratio of underlying causes	0.02	0.03	0.73	0.46							
Geopolitical	Distance to state capital	-0.01	0.01	-0.61	0.54							
Geopolitical	Distance to reference municipality	-0.01	0.01	-1.07	0.29							
Environmental	Population density	0.01	0.01	0.95	0.34							
Environmental	Sewage disposal	0.01	0.01	-1.53	0.13							
Environmental	Street improvement	0.01	0.01	0.06	0.95							
Environmental	Proximity to mining operations	0.01	0.01	0.08	0.95							
Living conditions	All-cause mortality rate	0.01	0.01	-0.22	0.83							
Health	Mobile emergency medical service	-0.09	0.09	-1.02	0.31							
Health	PHC coverage	0.01	0.01	-0.46	0.65							
Health	Pediatric urgency beds	0.01	0.01	0.29	0.77							
AIC		632.28				616.7				190.28		

Notes: GLM – generalized linear model; GWR – geographically weighted regression; β – regression coefficient; SE – standard error; T – t-statistic; AIC – Akaike information criterion.

Source: Authors, 2023.

pseudo p-value = 0.32; permutation = 99) or the 10 to 14-year group (Moran's I = 0.02; pseudo p-value = 0.29; permutation = 99), thus confirming that there was no spatial dependence in the residuals.

By linking the mortality coefficients to the explanatory variables and geographical coordinates, we identified a heterogeneous mortality pattern in children and adolescents 5 to 14 years of age in Mato Grosso, according to stratification by age group, geographical variability, and characteristics associated with these deaths. The maps represent the geographical variability of factors associated with mortality from 5 to 9 (Figure 1) and 10 to 14 years of age (Figure 2).

The values for local percent deviance explained (pdev), otherwise known as pseudo-R², showed the adequacy of the resulting models in terms of local factors associated with the two age groups. From 5 to 9 years, the strongest associations were found in the northeast and southeast meso-regions of Mato Grosso (Figure 1B), while

in the 10 to 14-year age group, the central-south and southeast meso-regions showed the strongest associations (Figure 2B).

The analysis of the association with demographic factors, represented by the sex ratio and ratio of underlying causes (5 to 9 years) and the sex ratio and non-white/white ratio (10 to 14 years of age) showed that although all the associations were positive, the variables behaved in a geographically heterogeneous way between the two age groups (Figures 1C, 1D, 2C, and 2D).

The association with geopolitical factors was only observed in deaths from 5 to 9 years, where distance to the state capital showed a negative association, concentrated in the southeast and northeast meso-regions of Mato Grosso (Figure 1E).

As for environmental factors, the presence of a state or international border was associated positively with deaths in the 5 to 9-year age group (Figure 1F) and negatively in the 10 to 14-year group (Figure 2E), both in the northe-

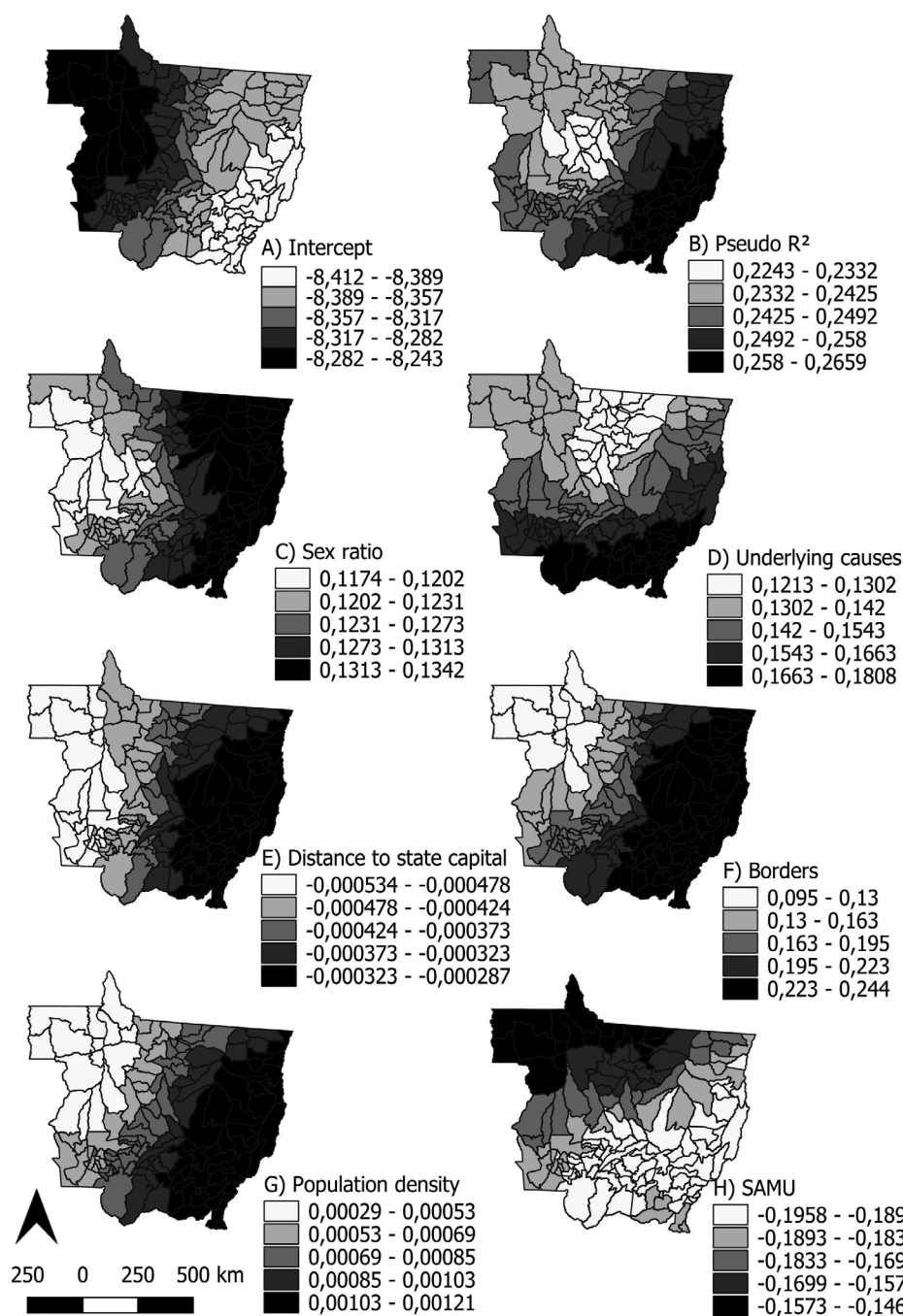


Figure 1. Estimation of geographically weighted regression parameters os factors associated with deaths aged 5 to 9 years in Mato Grosso, Brazil, 2009-2020.

Source: Authors, 2023.

ast and southeast meso-regions of Mato Grosso. In these meso-regions, there was also a positive association between population density and deaths in younger children (Figure 1G). Meanwhi-

le, in the north and southwest meso-regions of the state, there was a stronger association between agricultural areas and deaths in older children (Figure 2F).

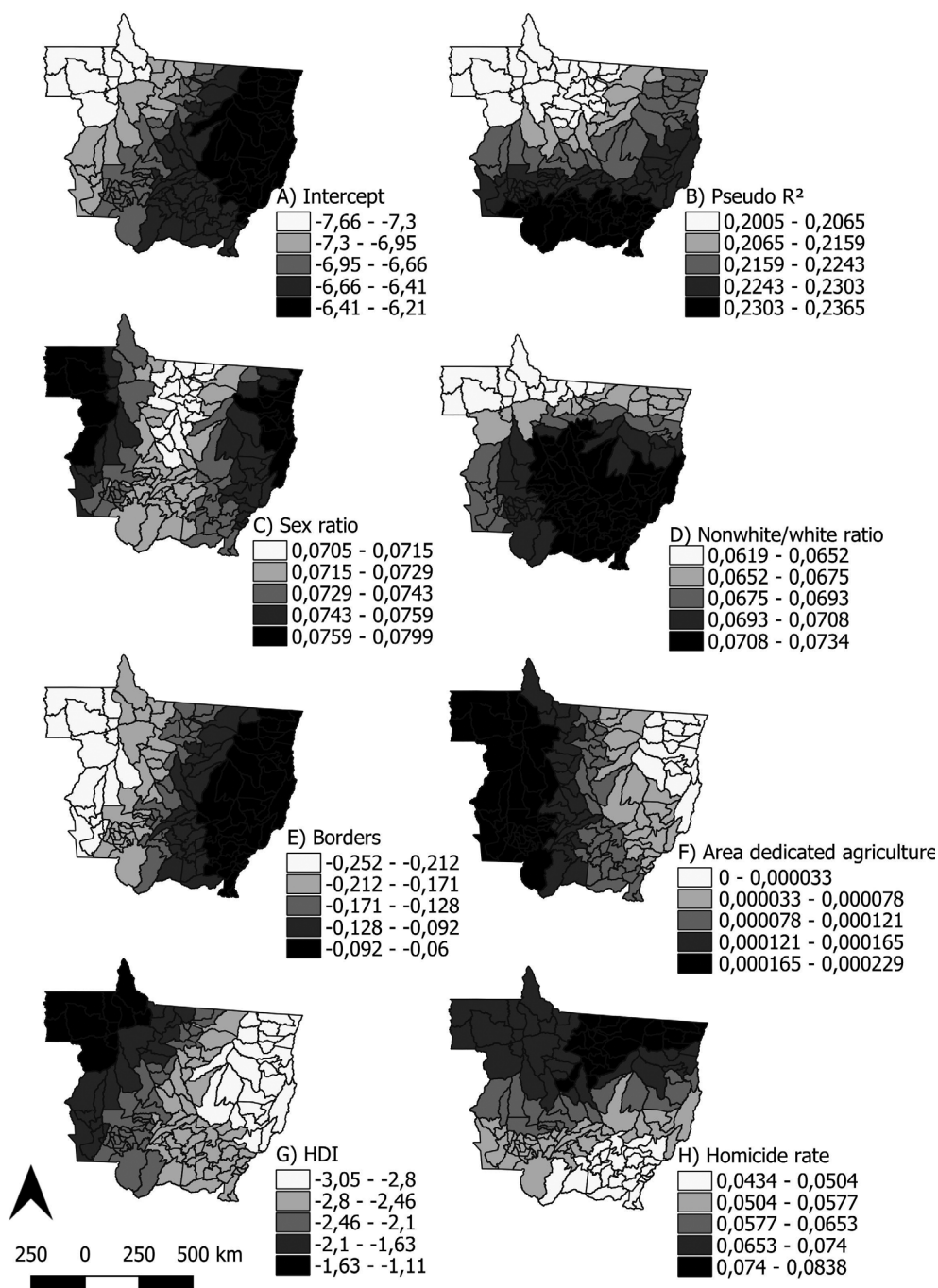


Figure 2. Estimation of geographically weighted regression parameters os factors associated with deaths aged 10 to 14 years in Mato Grosso, Brazil, 2009-2020.

Source: Authors, 2023.

The association with factors related to living conditions was only seen in the 10 to 14-year group; there was a negative association with HDI, prevalent in the north meso-region (Figure 2G), and a positive association with the

homicide rate, prevalent in the north and northeast meso-regions (Figure 2H)

Finally, the analysis of factors involving health services access, coverage, and quality showed a negative association between deaths in the 5

to 9-year group and presence of a mobile emergency medical service headquarters, with the strongest association in the north meso-region of the state (Figure 1H)

The explanatory models based on regression analysis of the variables associated with mortality in both age groups (Figure 3) illustrate the differences identified in this study.

Discussion

From 2009 to 2020, mortality in children and adolescents in Mato Grosso state, Brazil, was associated with social determinants of health. Regression models identified an association between deaths in the 5 to 9-year group and variables in the demographic, geopolitical, environmental, and health services domains, while deaths in the 10 to 14-year group were associated with variables in the demographic, environmental, and living conditions domains (Figure 3). Therefore, the results showed that during the target period, the previously reported socioeconomic differences in infant mortality^{4,6,7} persisted in child and adolescent mortality in Mato Grosso.

The model with the greatest capacity to explain the associations between variables was GWR. Considering the criteria established in this study, GWR outperformed GLM. In the goodness-of-fit analysis of the regression models, AIC can be used to measure performance, since it represents the model's precision, with lower values indicating better fit and quality. Moran index can be used to assist the explanatory model's performance assessment, since it assesses the spatial autocorrelation of the model's residuals, varying from -1 to 1^{14,15}.

Although the models' explanatory characteristics are similar, there were differences in the variables' composition and behavior according to age group and geographical space. Considering that many phenomena can be related to territory, where they are not merely distributed randomly,¹⁴ GWR estimates a set of regression parameters for each location, allowing identification of the parameters' variation across a given territory¹⁵.

The analysis of associations (considering the data's geographical variability) allowed identifying that from 5 to 9 years of age, the strongest associations were concentrated in the northeast

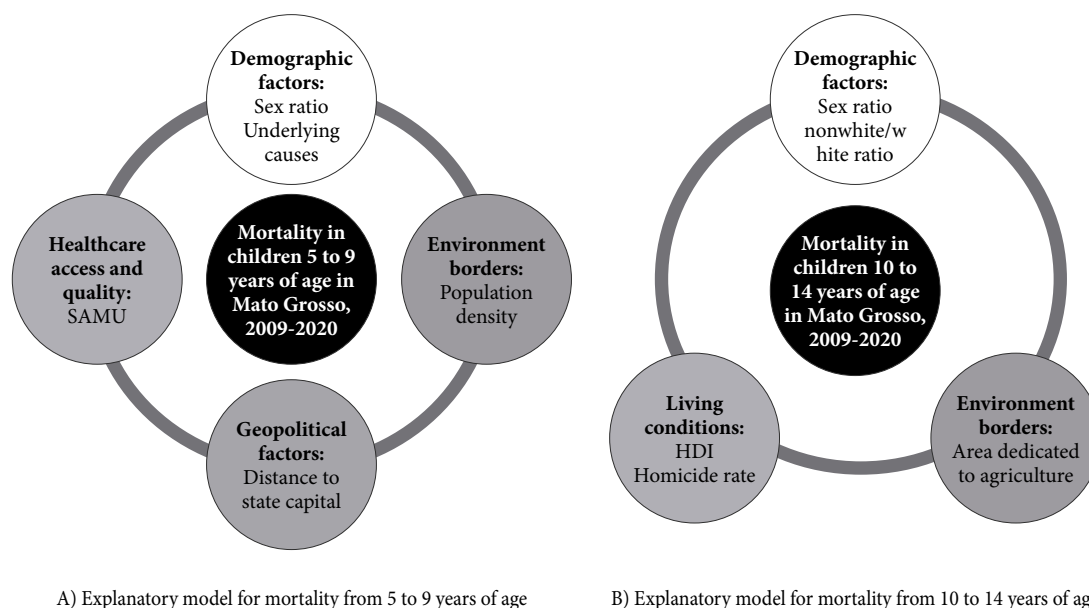


Figure 3. Explanatory models for social determinants associated with mortality from 5 to 14 years of age in Mato Grosso state, Brazil, from 2009 to 2020.

Source: Authors, 2023.

and southeast meso-regions of Mato Grosso, which have a predominantly grain-producing agricultural economy and border on other states of Brazil. In the 10 to 14-year age group, the distribution of associations for each variable proved to be quite heterogeneous, characterizing the relevance and magnitude of the associations between social determinants of health (SDH) and deaths of children and adolescents in each area.

The explanatory model for deaths in the 5 to 9-year age group showed that the outcome was explained mainly by demographic and environmental factors, with some contribution from the geopolitical and healthcare domains. Deaths from 10 to 14 years of age were explained equally by variables from the demographic, environmental, and living conditions domains.

Thus, in both age groups, most of the associations that were identified, both positive and negative, make sense from the theoretical and epidemiological point of view, considering the documented evidence on the relationship between social determinants of health and mortality from 5 to 14 years of age⁹⁻¹¹ and in other population groups^{4,6,7}. However, the doubts that appeared with the identification of unexpected associations merit further investigation and testing with other analytical methods.

In general, the expected positive associations featured the sex ratio, ratio of underlying causes, population density, homicide rate, and area devoted to agriculture, while the expected negative associations highlighted the distance to the state capital, HDI, and presence of headquarters of a mobile emergency medical service. A variable that stood out in the analysis was “presence of state or international borders”, which was positively associated with deaths from 5 to 9 years and negatively associated from 10 to 14 years of age.

The set of explanatory variables associated with deaths in the age group from 5 to 9 years (sex ratio and ratio of underlying causes, distance to the state capital, population density, presence of borders, and mobile emergency medical service) can also be explained by the fact that during the target period, due to the heterogeneity of the state's population distribution, the largest concentration of deaths in this age group was in the micro-region of the state capital, Cuiabá.¹⁶

From 2007 to 2016, the Baixada Cuiabana (14 outlying municipalities in Greater Metropolitan Cuiabá) was the region with the lowest downward trend in infant mortality in Mato Grosso state, leading the authors to warn of a possible reversal in the logic of the Unified Health System (SUS), in which the highest in-

vestments have been targeted to medium and high-complexity services, normally available in regions with better socioeconomic indicators, stimulating the search for a parallel “portal of entry” into the healthcare system.¹⁷ This trend also reproduces the health inequities that should otherwise be mitigated.

This questioning may also be attributed to the context of deaths from 5 to 9 years of age analyzed in this study, since the morbidity and mortality of children in this age group are influenced by interventions targeted to children under 5 years of age^{10,11}.

In the case of deaths from 10 to 14 years of age, the explanatory variables (sex ratio and non-white/white ratio, presence of borders, area dedicated to agriculture, homicide rate, and HDI) may also be explained by the growth of agribusiness and the prevailing socioenvironmental conflicts in Mato Grosso.

Mato Grosso ranks first among the states of Central-West Brazil in terms of agrarian conflicts. Intensive agricultural modernization since the 1970s has been the main component in the state's population growth. The improvement of agricultural production to serve the domestic and international markets requires increasingly complex and modern farm machinery, resulting in a decrease in labor demand and intensification of the rural exodus, resulting in underemployment in the informal market and contributing to the chaotic growth of peripheral urban areas and to the increase in social inequalities¹⁸.

In addition, the deaths' characteristics emphasize the relevance of federal highway BR-163 in this context. Highway BR-163 connects municipalities with heavy urban hierarchy and serves as the main farm produce marketing route for Mato Grosso, Brazil's leading grain-producing state. The development of many municipalities located along the highway resulted from the intense migratory flow toward the state's agricultural frontier and mining areas^{19,20}.

Importantly, ecological studies that analyze the association between social, economic, and/or environmental factors and outcomes with multiple causes can have their results influenced by the definition of geographical scale, data aggregation unit, and target analytical period. It is thus possible to obtain diverse associations between the variables, depending on the respective geographical scale²¹.

This study analyzed secondary data, so it was not possible to rule out errors in the completion of death certificates, information in data sources, or data insertion in the Mortality In-

formation System (SIM). Another limitation was the unavailability of current data for some of the explanatory variables: with the delay in the Population Census originally scheduled for 2020, some data may not be totally trustworthy in relation to the target period.

However, the study's main limitation proved necessary to explore new methodological strategies: the analysis of rare events and/or small units of analysis. The study thus displays the potential of the methodological choices and their applicability, given the tools' availability and the highly similar context found in different regions of Brazil and other countries.

Considering the characteristics of these deaths in the state (from external causes, especially traffic accidents)¹², the combination of the set of explanatory variables makes epidemiologi-

cal sense, since some 60% of the population in Mato Grosso lives more than two hours from the closest reference hospital for trauma, which is more than the maximum time for accessing treatment services in complex cases, thus potentially decreasing the likelihood of victims' recovery from accidents and assaults²².

Given the high proportion of avoidable deaths in the age groups analyzed here¹², the identification of associations between avoidable mortality and social determinants of health corroborates the need for multisector interventions. The analysis of the magnitude of these associations in each location allows the development of more targeted strategies, better resource allocation, and more satisfactory results with the reduction of social inequities that contribute to deaths in children and adolescents.

Collaborations

All the authors contributed to the research project's design, data analysis and interpretation, writing of the article and relevant critical revision of the intellectual content, and approval of the final version for publication.

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Data availability statement

The data sources adopted in the research are indicated in the article's body.

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