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Mortality in 5-19-year-olds due to external causes in Brazil (2014-2024): results from a nationwide spatiotemporal study

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Abstract

External causes are an important source of preventable mortality among children and adolescents in Brazil, with marked regional and age-specific differences. This study described spatial and temporal patterns of mortality from external causes among Brazilians aged 5–19 years from 2014 to 2024. We conducted an ecological study using data from the Brazilian Mortality Information System for 133 intermediate geographic regions. Mortality was analyzed by sex and age group (5–9, 10–14, and 15–19 years) using Bayesian spatiotemporal Poisson models estimated with the Integrated Nested Laplace Approximation (INLA). During the study period, 169,175 deaths from external causes were recorded among individuals aged 5–19 years, and 85.6% occurred in males. Mortality risk declined annually in both sexes and all age groups, stabilizing near the end of the period. Higher risks were concentrated in the North and in parts of the Northeast and Central-West, while lower risks predominated in the South and Southeast. Transport accidents were the leading external cause among children aged 5–9 years, whereas assaults predominated among adolescents aged 15–19 years. Self-inflicted injuries increased among females aged 10–14 and 15–19 years. Overall, mortality from external causes declined but remained spatially heterogeneous, with distinct patterns by age and sex. By integrating spatial and temporal dimensions, this study identifies vulnerable areas and population groups and provides evidence to support targeted prevention, territorial health planning, and policies to reduce avoidable mortality.

Introduction

External causes of death refer to deaths resulting from non-natural events, including homicide, self-inflicted injury, accidents, and other incidents (Souza et al., 2025). These causes generate a substantial socioeconomic burden through premature mortality among young adults, higher emergency medical costs, long-term disability-related care, and financial strain on families and public health systems. In Brazil, deaths from external causes represent a major public health concern, with the highest mortality rates reported among men and young adults aged 20–39 years. The leading causes include assault, transport accidents, falls, and self-harm, and their spatiotemporal distribution varies across regions according to social, economic, and demographic factors (Andrade et al., 2025).

Although deaths among children from infectious diseases and cancer have declined in some developed countries, largely because of early diagnosis, vaccination, antibiotics, and advances in medical and surgical treatment, deaths due to external causes remain among the leading causes of mortality in this age group (Cunningham et al., 2018; Tunesi et al., 2023). The 2030 Agenda for Sustainable Development established the reduction of mortality among children under five years of age, as well as the prevention of injuries, violence, harmful practices, and substance abuse among young people, as key global targets (United Nations, 2026). However, Masquelier et al. (2018) adverted that deaths among older children (5–9 years) and young adolescents (10–14 years) also reserved attention, since the number of cases has been expressive and they are predominantly from avoidable causes. These authors claimed that since 2000, the pace of progress in reducing mortality among older children and young adolescents has been

slower than that for children younger than 5 years, which calls for increased attention towards this age group (Masquelier et al., 2018).

In a systematic review study, Liu et al. (2022) estimated the distribution of causes of death for 5–19-year-olds across age-sex groups, geographies and time, and showed that globally in 2019, the leading specific causes are road traffic injuries, neoplasms, malaria, drowning, and diarrhea. In Brazil, Degli-Esposti et al. (2023) reported that injury-related mortality among children and adolescents is an increasing concern, with firearms currently representing the leading cause of death in this group. Other studies have applied time-series approaches, including joinpoint analysis, to describe and identify mortality trends among children and adolescents in local contexts (Boschi-Pinto et al., 2023; Diniz-Alves et al., 2025; Lima et al., 2022). Boschi-Pinto et al. (2023) found that, among individuals aged 5–14 years in Rio de Janeiro from 2000 to 2019, the main causes of death were external causes and neoplasms. Diniz-Alves et al. (2025) also reported that external causes of morbidity and mortality were the leading causes of death among children aged 5–14 years in Brazil's Northeast region. Similar findings were observed by Lima et al. (2022) in the state of Mato Grosso from 2009 to 2020.

Spatial analysis techniques provide a better understanding of the spatial patterns of violent and accidental incidents, identifying areas with high mortality rates that require priority investment in effective interventions and public policies that address the health needs of each region. In this context, Andrade et al. (2025) and Souza et al. (2025) analyzed spatiotemporal trends in deaths from external causes in Brazil and showed that these mortality indicators follow distinct and regionally heterogeneous trajectories. However, in Brazil, few spatial studies have specifically examined the mortality from external causes among older children and adolescents.

Thus, the present study objectives to describe the mortality from external causes in Brazil, in the period from 2014 to 2024, using a Bayesian spatiotemporal model with estimation based on the INLA method. This research is compatible with the principles of United Nations' Sustainable Development Goal 16.2 of eradicating all forms of violence against children and ensuring their safe development, and with the Global Strategy for Women's, Children's, and Adolescent's Health (2016–30), which has survival as a main objective and adolescent mortality as one of its 16 core indicators (WHO, 2026).

Methods

Setting and study design

We conducted an ecological study using secondary mortality data for Brazilian intermediate geographic regions from 2014 to 2024. The Brazilian Institute of Geography and Statistics (IBGE) introduced the classification of immediate and intermediate geographic regions in 2017 (IBGE, 2024). The 510 immediate regions consist of groups of municipalities and represent regional divisions shaped by social, political, and economic processes across the country. The 133 intermediate regions, in turn, are formed by groups of immediate regions linked by the influence of one or more metropolises, regional capitals, or

representative urban centers. We aggregated the data by intermediate regions to reduce excessive sparsity. The reporting of this study was guided by the GATHER Statement (Guidelines for Accurate and Transparent Health Estimates Reporting) (Stevens et al., 2016).

Measurements

The number of deaths from external causes, recorded according to place of residence, was obtained from the Brazilian Mortality Information System (SIM), which compulsorily records deaths in all municipalities across Brazil (Rebouças et al., 2025). The system uses data from Death Certificates, following the standards established by the Ministry of Health. Deaths from external causes were classified according to Chapter XX of the 10th International Classification of Diseases, including:

- V01-V99: Transport accidents,
- W65-W74: Accidental drowning and submersion,
- X60-X84: Self-inflicted intentional injuries,
- X85-Y09: Assault,
- Y10-Y34: Event of undetermined intent,
- Y35-Y36: Legal intervention and operations of war,
- Y40-Y84: Complications of medical and surgical care,
- Y85-Y89: Sequelae of external causes of morbidity and mortality, and
- Other codes (W00-W64 and W75-W99): Other external causes of accidental injury.

Crude mortality rates were calculated by dividing the annual number of deaths from external causes among children and adolescents by the population in the corresponding age group and multiplying the result by 100,000. Analyses were stratified into three age groups: 5–9 years (older children), 10–14 years (young adolescents), and 15–19 years (older adolescents). Annual population estimates for 2014 to 2024 were derived from the 2010 and 2022 population censuses, obtained from SIDRA (the IBGE Automatic Recovery System). Geometric interpolation for the intercensal years and projections for 2023 and 2024 were estimated with the 'epiDeaths' R package, based on the average annual growth rate (Martinez & Anjos, 2026).

All the data were initially collected at municipal level and then aggregated at intermediate regional levels using the R program.

Statistical analysis

The number of deaths from external causes in intermediate region *i* during year *t*, denoted by y_{it}, was modeled as $y_{it} \sim Poisson(\rho_{it}E_{it})$, assuming a Poisson distribution with mean $\rho_{it}E_{it}$. Here, E_{it} represents the expected number of deaths in intermediate region *i* (*i* = 1,...,133) in year *t*, with *t* = 1 for

2014, *t* = 2 for 2015, and so forth (Carroll et al., 2015). The Bayesian statistical model was specified as follows:

$\eta_{it} = \log \rho_{it} = \alpha + \xi_i + \gamma_t + \phi_t + \delta_{it}$,

where α is the intercept, and $\xi_i = \upsilon_i + \nu_i$ combines two area-specific effects. The term γ_t represents the temporally structured component, modeled dynamically as a second-order random walk (RW2), whereas ϕ_t was assigned a Gaussian exchangeable prior. The interaction term δ_{it} captures residual spatiotemporal variation not explained by the main spatial and temporal effects. In this formulation, $\exp(\alpha)$ represents the average mortality rate across the 133 intermediate regions over the study period.

The temporal effect $\exp(\gamma_t + \phi_t)$ represents the ratio between the mortality rate in year *t* and the average rate for the full study period. In $\xi_i = \upsilon_i + \nu_i$, υ_i denotes the spatially structured residual, modeled with an intrinsic conditional autoregressive (iCAR) structure in which adjacency-based weights are assigned to each region. This specification follows the BYM2 reparameterization of the Besag-York-Mollié model (Riebler et al., 2016). The term ν_i represents the unstructured residual and was modeled with an exchangeable normal prior (Blangiardo et al., 2013). The area-specific relative risk, or spatial trend, was estimated from the posterior means of the random effects as $\exp(\xi_i) = \exp(\upsilon_i + \nu_i)$ for each of the 133 intermediate regions. Higher values of $\exp(\xi_i)$ indicate a higher mortality risk in region *i* over the 2014–2024 period (Richardson et al., 2004). This Bayesian approach was implemented using integrated nested Laplace approximation (INLA), which provides simulation-free approximations for Bayesian inference (Blangiardo et al., 2013). Alternative models based on other probability distributions and other spatial and temporal structures were also fitted, and the deviance information criterion (DIC) and the Watanabe-Akaike information criterion (WAIC) were used to discriminate between models. The BYM2-RW2 model based on Poisson distribution was ultimately chosen for final analysis due to its superior ability to capture both spatial heterogeneity and temporal dependencies in mortality rates.

Global Moran's I and Geary's C statistics were used to assess spatial autocorrelation in the smoothed rates (Moran, 1950; Geary, 1954). Moran's I ranges from − 1 to + 1: values close to + 1 indicate positive spatial autocorrelation, values near 0 suggest a random spatial pattern, and values close to − 1 indicate negative spatial autocorrelation. Whereas Moran's I measures linear similarity relative to the global mean, Geary's C focuses on local differences by summing the squared differences between neighboring values. Geary's C usually ranges from 0 to 2, with values below 1 indicating positive spatial autocorrelation, meaning that neighboring areas have similar values, and values above 1 indicating negative spatial autocorrelation, meaning that neighboring areas have dissimilar values.

All data organization and analyses were performed using R software version 4.4.1. The 'sp', 'spdep', 'sf' and 'mapview' packages were used to handle the spatial data and generate maps based on the shapefile for the intermediate regions available on the IBGE website. Bayesian spatial models were fit using the 'R-INLA' package (Blangiardo et al., 2013).

Results

A total of 169,175 deaths by external cause were recorded in Brazil from 2014 to 2024 among individuals aged 5–19 years, being 85.6% of them occurring in males and 14.4% of females. Table 1 presents the number of external cause deaths stratified by sex and age group, along with their proportion of all deaths in each group. The absolute number of deaths declined substantially over the study period. Among males aged 15–19 years, deaths decreased from 15,069 in 2014 to 7,881 in 2024, corresponding to a reduction of approximately 47.7%. Among females in the same age group, the decline was smaller, from 1,701 to 1,195 deaths, representing a reduction of approximately 29.7%. Among males aged 10–14 years, deaths decreased from 1,697 to 831 (51.0%), while among those aged 5–9 years, deaths fell from 767 to 475 (38.1%). Among females, deaths declined from 407 to 277 (31.9%) in the 5–9-year age group and from 673 to 388 (42.4%) in the 10–14-year age group. External causes were the leading cause of death in both sexes and in all age groups analyzed. They represented 29.4%, 44.4%, and 80.0% of all deaths among males aged 5–9, 10–14, and 15–19 years, respectively, compared with 21.5%, 28.6%, and 40.5% among females in the same age groups.

Table 1
Reported number of deaths from external causes by year, sex, and age group, with percentages relative to all deaths. Brazil, 2014–2024.

	Male			**Female**		
	5–9 yrs	**10–14 yrs**	**15–19 yrs**	**5–9 yrs**	**10–14 yrs**	**15–19 yrs**
Year	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**	***n* (%)**
2014	767 (36.6)	1,697 (50.6)	15,069 (82.8)	407 (26.6)	673 (34.1)	1,701 (43.3)
2015	583 (32.0)	1,552 (51.0)	14,221 (81.4)	387 (26.8)	537 (29.1)	1,631 (42.1)
2016	575 (30.9)	1,419 (47.2)	14,845 (82.5)	319 (22.2)	531 (28.4)	1,512 (39.8)
2017	602 (31.8)	1,375 (48.6)	14,772 (83.2)	286 (21.0)	554 (31.1)	1,661 (44.3)
2018	533 (30.5)	1,238 (47.7)	12,775 (81.9)	261 (19.7)	503 (28.5)	1,471 (42.1)
2019	468 (26.4)	1,067 (42.4)	10,529 (79.1)	268 (19.3)	482 (28.3)	1,305 (38.6)
2020	483 (32.1)	1,001 (43.1)	10,386 (78.8)	269 (25.0)	444 (28.5)	1,362 (39.3)
2021	426 (27.9)	911 (41.2)	9,195 (76.4)	289 (23.3)	462 (29.1)	1,362 (38.4)
2022	453 (25.2)	868 (37.6)	8,457 (75.8)	258 (17.8)	443 (25.5)	1,233 (37.5)
2023	451 (24.3)	889 (37.5)	7,960 (76.0)	282 (18.4)	441 (27.6)	1,227 (40.8)
2024	475 (24.9)	831 (35.1)	7,881 (75.3)	277 (17.9)	388 (23.4)	1,195 (38.2)
Total	**5,816 (29.4)**	**12,848 (44.4)**	**126,090 (80.0)**	**3,303 (21.5)**	**5,458 (28.6)**	**15,660 (40.5)**

Table 2 shows the number of reported deaths from external causes among males and females in 2014, 2019 and 2024, categorized by ICD-10 codes. Plots in Fig. 1 shows time trends of the crude mortality rates by external causes, according to sex, age group, and ICD-10 codes. Among males aged 15–19, the leading category was assault (X85–Y09), accounting for 63.0% of deaths from external causes in 2014 (9,488), 54.8% in 2019 (5,767), and 48.3% in 2024 (3,808). Transport-related causes (V01–V99) were the second largest category, representing 20.2% of deaths in 2014, 17.1% in 2019 and 22.6% in 2024. Among females in the same age group, assault also represented a significant proportion of deaths, 34.5% in 2014, 31.2% in 2019 and 24.6% in 2024. However, deaths among females were less concentrated in a single category than among males. Transport-related causes accounted for 40.6% of external-cause deaths in 2014, 29.3% in 2019 and 33.6% in 2024, making them the largest category in both 2014 and 2024. Intentional self-harm (X60–X84) accounted for 11.1%, 20.9% and 22.5% of deaths among females aged 15–19 in 2014, 2019 and 2024 respectively. Among males, deaths from intentional self-harm accounted for a lower proportion of deaths from external causes, at 3.2%, 7.1%, and 7.3% in 2014, 2019, and 2024 respectively.

Table 2
Reported deaths from external causes among males and females aged 5–9, 10–14, and 15–19 years, classified by ICD-10 codes. Brazil, 2014, 2019 and 2024.

		Male			Female		
		5–9 yrs	**10–14 yrs**	**15–19 yrs**	**5–9 yrs**	**10–14 yrs**	**15–19 yrs**
Year	**ICD-10** [a]	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**
2014	V01-V99	346 (45.1)	467 (27.5)	3,045 (20.2)	169 (41.5)	243 (36.1)	691 (40.6)
	W65-W74	170 (22.2)	281 (16.6)	641 (4.3)	77 (18.9)	90 (13.4)	54 (3.2)
	X60-X84	4 (0.5)	80 (4.7)	481 (3.2)	-	62 (9.2)	191 (11.2)
	X85-Y09	62 (8.1)	571 (33.6)	9,488 (63.0)	55 (13.5)	168 (25.0)	587 (34.5)
	Y10-Y34	41 (5.3)	90 (5.3)	541 (3.6)	20 (4.9)	30 (4.5)	67 (3.9)
	Y35-Y36	-	13 (0.8)	270 (1.8)	-	-	2 (0.1)
	Y40-Y84	2 (0.3)	3 (0.2)	6 (< 0.1)	4 (1.0)	5 (0.7)	3 (0.2)
	Y85-Y89	1 (0.1)	2 (0.1)	9 (0.1)	-	-	1 (0.1)
	Other codes	141 (18.4)	190 (11.2)	588 (3.9)	82 (20.1)	75 (11.1)	105 (6.2)
	Total	**767**	**1,697**	**15,069**	**407**	**673**	**1,701**
2019	V01-V99	162 (34.6)	262 (24.6)	1,805 (17.1)	98 (36.6)	138 (28.6)	383 (29.3)
	W65-W74	118 (25.2)	184 (17.2)	466 (4.4)	46 (17.2)	58 (12.0)	51 (3.9)
	X60-X84	2 (0.4)	85 (8.0)	749 (7.1)	-	104 (21.6)	273 (20.9)
	X85-Y09	43 (9.2)	295 (27.6)	5,767 (54.8)	26 (9.7)	91 (18.9)	407 (31.2)
	Y10-Y34	33 (7.1)	86 (8.1)	984 (9.3)	33 (12.3)	27 (5.6)	98 (7.5)
	Y35-Y36	-	6 (0.6)	360 (3.4)	-	-	3 (0.2)

ICD-10 codes: V01-V99: Transport accidents, W65-W74: Accidental drowning and submersion, X60-X84: Self-inflicted intentional injuries, X85-Y09: Assault, Y10-Y34: Event of undetermined intent, Y35-Y36: Legal intervention and operations of war, Y40-Y84: Complications of medical and surgical care, and Y85-Y89: Sequelae of external causes of morbidity and mortality.

		Male			Female		
		5–9 yrs	**10–14 yrs**	**15–19 yrs**	**5–9 yrs**	**10–14 yrs**	**15–19 yrs**
Year	**ICD-10** [a]	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**	***n*** **(%)**
	Y40-Y84	5 (1.1)	6 (0.6)	6 (0.1)	3 (1.1)	9 (1.9)	3 (0.2)
	Y85-Y89	-	1 (0.1)	8 (0.1)	2 (0.7)	1 (0.2)	1 (0.1)
	Other codes	105 (22.4)	142 (13.3)	384 (3.6)	60 (22.4)	54 (11.2)	86 (6.6)
	Total	**468**	**1,067**	**10,529**	**268**	**482**	**1,305**
2024	V01-V99	168 (35.4)	247 (29.7)	1,780 (22.6)	92 (33.2)	116 (29.9)	402 (33.6)
	W65-W74	118 (24.8)	138 (16.6)	436 (5.5)	53 (19.1)	40 (10.3)	29 (2.4)
	X60-X84	1 (0.2)	74 (8.9)	576 (7.3)	3 (1.1)	83 (21.4)	269 (22.5)
	X85-Y09	40 (8.4)	179 (21.5)	3,808 (48.3)	27 (9.7)	66 (17.0)	294 (24.6)
	Y10-Y34	33 (6.9)	63 (7.6)	496 (6.3)	24 (8.7)	32 (8.2)	105 (8.8)
	Y35-Y36	-	8 (1.0)	462 (5.9)	-	-	5 (0.4)
	Y40-Y84	7 (1.5)	5 (0.6)	11 (0.1)	2 (0.7)	8 (2.1)	8 (0.7)
	Y85-Y89	2 (0.4)	2 (0.2)	8 (0.1)	-	2 (0.5)	-
	Other codes	106 (22.3)	115 (13.8)	304 (3.9)	76 (27.4)	41 (10.6)	83 (6.9)
	Total	**475**	**831**	**7,881**	**277**	**388**	**1,195**

ICD-10 codes: V01-V99: Transport accidents, W65-W74: Accidental drowning and submersion, X60-X84: Self-inflicted intentional injuries, X85-Y09: Assault, Y10-Y34: Event of undetermined intent, Y35-Y36: Legal intervention and operations of war, Y40-Y84: Complications of medical and surgical care, and Y85-Y89: Sequelae of external causes of morbidity and mortality.

Transport accidents were the most frequent cause of death among children aged 5–9, across both sexes and all age groups. The second most frequent external cause of mortality in this age group was accidental drowning and submersion (W65–W74), as specified in Table 2. For adolescents aged 10–14, transport accidents were the most frequent cause of death for females in 2014 and 2019 (33.6% and 27.6%, respectively), while for males it was assaults in 2014 and 2019 (33.6% and 27.6%, respectively), followed by transport accidents in 2024. Among females aged 10–14, a significant proportion of deaths

from external causes were due to self-inflicted intentional injuries in 2019 and 2024, accounting for 21.6% and 21.4% of such deaths, respectively.

In the spatiotemporal analysis, 413 records for which the municipality of residence was unknown were excluded. Figure 2 shows the temporal trends in the risk of death from external causes, as estimated by the Bayesian analysis, along with the corresponding spatial pattern maps. For this analysis, an independent model was fitted for each combination of sex and age group. The trends estimated by the term $\exp(\gamma_t + \phi_t)$ included in the models show an annual decline in the risk of death from external causes relative to the period 2014–2024 average, for both sexes and all age groups, with stability at the end of the period. For both sexes, the maps of the spatial patterns for older children (5–9 years) and young adolescents (10–14 years) shows higher relative risks of mortality in relation to national average in the North region and in part of the Northeast and Center-West regions, and lower relative risks in part of the South and Southeast regions. For the 15–19 age group, the maps in Fig. 2 show lower Moran coefficients than for the other age groups. This indicates a more spatially heterogeneous distribution of mortality risks, with areas of high and low values located close to each other.

Figure 3 shows maps of the smooth mortality rates by external causes (deaths per 100,000 population) in 2014, 2019, and 2024, estimated by the Bayesian spatiotemporal model and stratified by decile categories. Maps of smoothed mortality rates for the 5–9 and 10–14 age groups suggest stronger positive spatial autocorrelation, with higher Moran's indices and neighboring areas showing similar patterns. In contrast, maps for the 15–19 age group show a more patchwork-like distribution and lower Moran's indices, indicating greater geographic variability. These findings reinforce that mortality patterns differ by age group, where traffic-related deaths are more prominent among children aged 5–9 years, whereas deaths due to violence are more prominent among adolescents aged 15–19 years. Regional characteristics contribute to marked spatial differences across age groups. Overall, however, the maps show the lowest mortality rates in the Southeast region and a declining trend over the study period.

Discussion

This study describes different mortality patterns due to external causes when comparing between sexes and age groups. Among males, the most common cause of death from external causes in the 5–9 age group is transport accidents, whereas assaults are the leading cause among adolescents aged 15–19. The 10–14 age group appears to represent a transition between these trends, with mortality rates from transport accidents approaching those from assaults.

The decreasing annual trend in children and adolescents due to external causes, observed in this study, is consistent with that of previous studies conducted in other populations (Tunesi et al., 2023; Urfı et al., 2025). Wei et al. (2025) analyzed Global Burden of Disease (GBD) 2021 data, which provides estimates for 204 countries and territories through 2021, to examine trends in incidence, mortality, and disability-adjusted life years (DALYs) associated with unintentional injuries among children and adolescents. Their findings showed substantial global declines in these outcomes. The authors attributed the reduction in

the global age-standardized mortality rate for injuries among people under 20 years of age to advances in injury prevention and health system responses. They noted that many countries expanded emergency medical services, trauma centers, and surgical care, improving outcomes for injured children. They also highlighted the adoption and enforcement of safety regulations in several nations, including requirements for child car-seat use, motorcycle helmet use, seat-belt use, safe storage of toxic substances, and fencing around pools or wells (Wei et al., 2025). These measures may also, albeit partially, explain the reductions in mortality rates from external causes among children and adolescents in Brazil.

However, mortality rates from self-inflicted intentional injuries have increased among females aged 10–14 and 15–19 years, unlike the pattern observed for other causes of death. In a systematic review, Augustin et al. (2025) identified suicide as the second leading cause of death among young people aged 15–29 years in Brazil, linking it to socioeconomic instability, rising mental health problems, and social pressure. Suicide has also been reported as the third leading cause of death among individuals aged 10–24 years, with increasing rates associated with bullying, academic pressure, social isolation, and limited access to mental health services.

This study identified transport accidents as a major cause of mortality among children and adolescents. Although Brazil has strict laws against drinking and driving, many drivers continue this behavior, possibly reflecting broader cultural patterns (Bazílio et al., 2022). The Dry Law, introduced in 2008 and revised in 2012 and 2016, established zero tolerance for alcohol consumption among drivers, strengthened enforcement, and increased penalties. Previous studies have reported significant reductions in traffic injuries and fatalities after these measures were adopted (Andreuccetti et al., 2011; Malta et al., 2014; Nunes et al., 2021). Although these studies did not specify victims' ages or whether people under 20 years were involved in the crashes, stronger enforcement of this legislation may have contributed to lower mortality from external causes in this age group. Other factors may also have played a role, including improvements in vehicle safety, road infrastructure, and post-crash care. Since 2003, the Brazilian National Policy for Urgent Care has sought to coordinate health-sector responses to epidemiological risks, including traffic accidents (Costa et al., 2018). Its mobile prehospital component, the Mobile Emergency Care Service (Serviço de Atendimento Médico de Urgência, SAMU), has incorporated technological advances and physician-led medical regulation, including coordination of out-of-hospital emergency care in public and private settings, telemedicine, patient-flow management between outpatient services and hospitals, and support for mass-casualty events in collaboration with military emergency services (Costa et al., 2018). Together, these measures may help prevent a substantial number of deaths from traffic accidents.

In the present study, accidental drowning and submersion was the second most frequent external cause of mortality among older children, with no evident reduction in rates over the study period. Senisse-Pajares et al. (2025) assessed the current state of drowning prevention efforts in the Americas, including Brazil, by examining governance structures, policies, legislation, and the implementation of key interventions to reduce drowning risk. The study identified three main areas relevant to drowning

prevention: management and coordination, policies and legislation, and community-based interventions. The Brazilian Lifesaving Society (SOBRASA) was founded in 1995 by firefighters specializing in lifesaving, with the mission of reducing drowning-related mortality and morbidity through the implementation of prevention-oriented water safety programs (Szpilman et al., 2020). Additional interventions undertaken by governmental and non-governmental sectors in Brazil are described in the World Health Organization's Global Status Report on Drowning Prevention 2024 (WHO, 2024). The report lists several strategies for drowning prevention, including daycare services for preschool children, inclusion of swimming and water safety in school curricula, installation of barriers to restrict access to water, presence of lifeguards at public swimming venues, rescue and resuscitation training programs, operational search-and-rescue services, free weather alerts, operational disaster warning systems, community resilience initiatives for flood-risk management, and community disaster resilience programs. The adoption and strengthening of these strategies may be important for reducing drowning-related deaths among children and adolescents in Brazil.

Among males aged 15–19 years, the present study found that assault was the leading category of mortality due to external causes. Consistent with this finding, a report by the United Nations Children's Fund (UNICEF) showed that the homicide rate among children and adolescents in Latin America and the Caribbean is four times higher than the global average (UNICEF, 2022). The report identifies homicide as the leading cause of death among adolescents aged 10–19 years in the region and attributes the high levels of violence against children to a dominant patriarchal culture, limited caregiver knowledge of effective non-violent disciplinary practices, authoritarian social norms, weak government systems, corruption, organized crime, narco-economies, urban marginalization, the proliferation of small arms and light weapons, and punitive security policies. These factors, together with persistent threats to gender equality and insufficient recognition of the rights of the LGBTQI2 + community, have contributed to a regional context marked by pronounced inequalities. In Brazil, the decline in homicide rates in recent decades has been associated with investments in public safety, socioeconomic improvements, reductions in unemployment, legislation restricting firearm access, and state investment in education and culture, among several other factors described in the literature (Lucas, 2008; Peres et al., 2011; Peres et al., 2012).

The present study also highlights marked regional differences in mortality rates from external causes across Brazil, suggesting that these patterns may be associated with different combinations of social vulnerability and territorial context. During the study period, the spatial component of the Bayesian model showed higher relative mortality risks, compared with the national average, in the North region and in parts of the Northeast and Center-West regions, whereas lower relative risks were observed in parts of the South and Southeast regions. This finding is consistent with studies by Andrade et al. (2025), Baptista et al. (2021), Soares Filho et al. (2024a), and Wanzinack et al. (2022). To explain these regional differences, these authors point to the interiorization of homicide-risk areas in Brazil, the greater burden of homicides and traffic accidents, and heightened Indigenous vulnerability in the North and Northeast regions, as well as urban segregation, firearm availability, alcohol use, and localized areas of high lethality in parts of the South and Southeast regions. Overall, territorial space is a central dimension

for understanding and preventing deaths from external causes. Wanzinack et al. (2022) argue that addressing urbanization challenges in Brazil's most populous cities, reducing inequalities, and investing in municipal policies related to social development, education, health, and income may contribute to reducing homicide rates.

In addition to the absence of causal inference and the potential for ecological fallacy, which are inherent limitations of studies of this nature, several other limitations should be considered. Alternative statistical models incorporating different covariates from additional data sources, as well as alternative specifications of spatial and temporal components, might have improved predictive performance. Underreporting of mortality events may have affected the analysis, and methods for redistributing garbage codes were not applied in this study (Soares Filho et al., 2024b). Furthermore, Cerqueira and Lins have highlighted the possibility of "hidden homicides" in mortality information systems, referring to homicides that are not officially classified as such (Cerqueira and Lins, 2024). The estimated mortality rates may also be biased because they were based on annual population interpolations derived from IBGE census data, which may differ from actual population counts. In addition, the aggregation of data at the intermediate regional level may have masked intra-regional disparities. Estimates produced by the INLA-based model may also have been affected by instability arising from small numbers of deaths in some regions. Finally, deaths were aggregated by year of occurrence, while the assessment of seasonal patterns could provide valuable insights into the timing of mortality peaks and better help inform targeted prevention strategies (Urfı et al., 2025).

Despite these limitations, this study contributes to community health by identifying particularly vulnerable areas and supporting the development of more targeted public policies. It also provides evidence that can help administrators and society monitor changes over time, assess whether prevention strategies are reaching the most affected areas, and reduce potentially avoidable deaths. The findings further suggest that incorporating territorial contexts may help health and public security authorities better target interventions against avoidable causes of mortality and address socioeconomic inequalities.

Declarations

Author Contribution

CBS conceived the study. CBS, EZM, and JKSO contributed to the study design. Material preparation and data collection were performed by MPF, BSL, JBA, VCCAL, and JKSO. Analysis was performed by EZM. JF and MLZ contributed to data interpretation and manuscript revision. The first draft of the manuscript was written by EZM and MPF and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability

The data used during the current study are freely available from the Brazilian Mortality Information System (Sistema de Informação sobre Mortalidade - SIM) and Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE).

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Figures

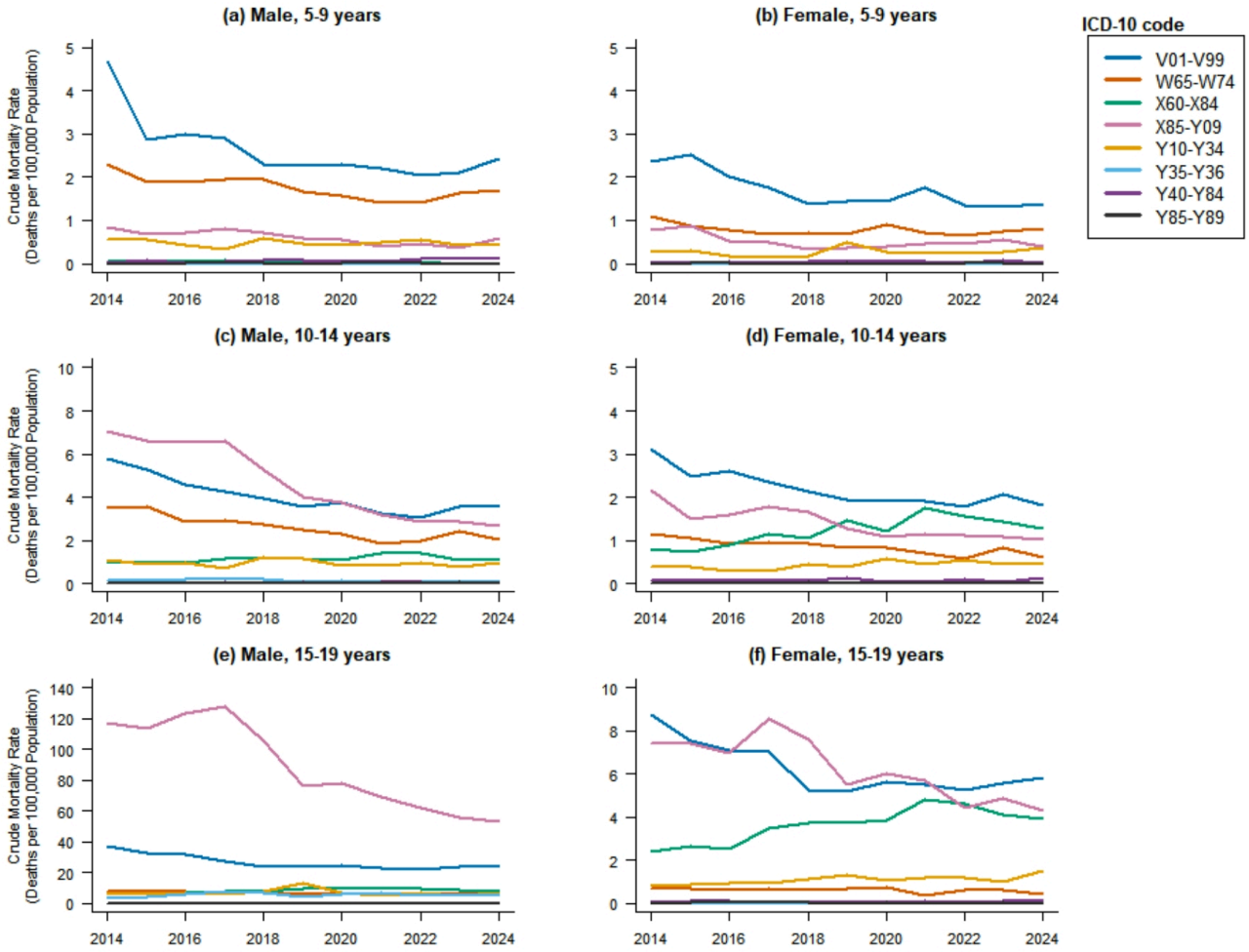


Figure 1

Crude mortality rates by external causes, according to sex, age group, and ICD-10 codes (deaths per 100,000 population). ICD-10 codes: V01-V99: Transport accidents, W65-W74: Accidental drowning and submersion, X60-X84: Self-inflicted intentional injuries, X85-Y09: Assault, Y10-Y34: Event of undetermined intent, Y35-Y36: Legal intervention and operations of war, Y40-Y84: Complications of medical and surgical care, and Y85-Y89: Sequelae of external causes of morbidity and mortality.

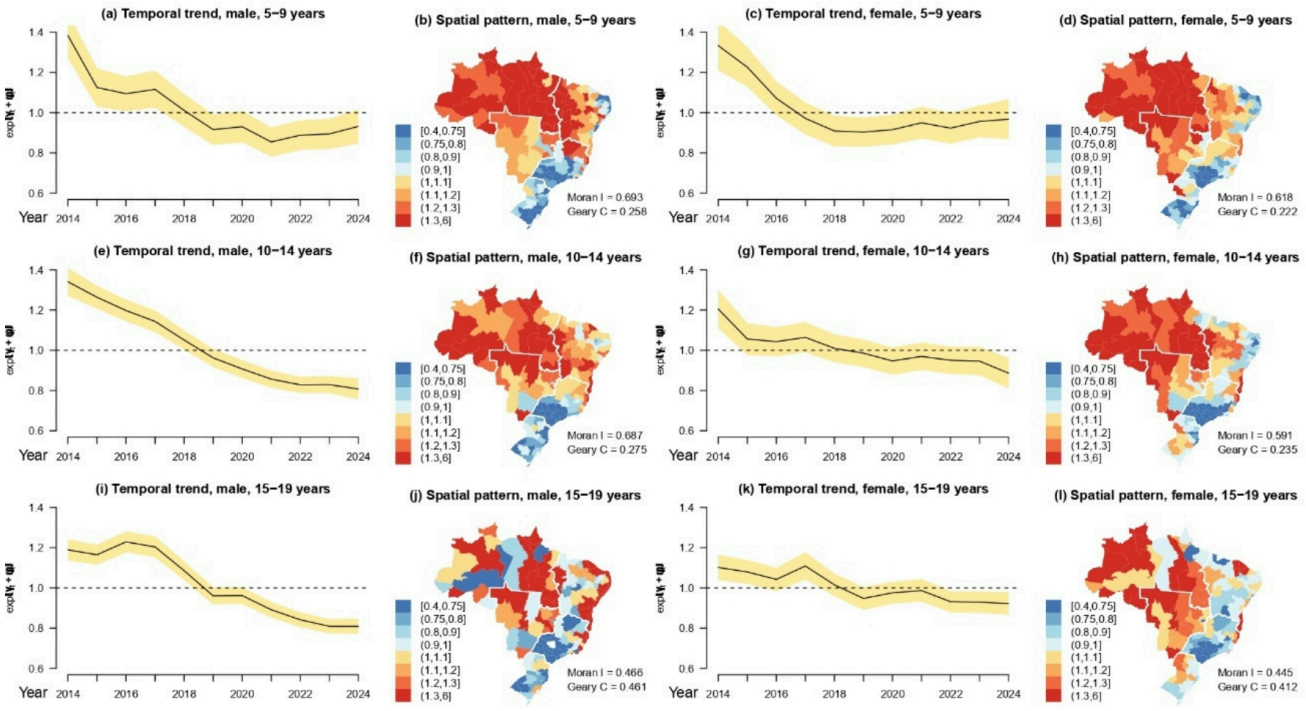


Figure 2

Spatial and temporal effects estimated by the Bayesian model, according to sex, age group. The yellow region in the graphs of the temporal trends are 95% credible intervals. The maps highlight the five major regions of Brazil (North, Northeast, Central-West, Southeast, and South).

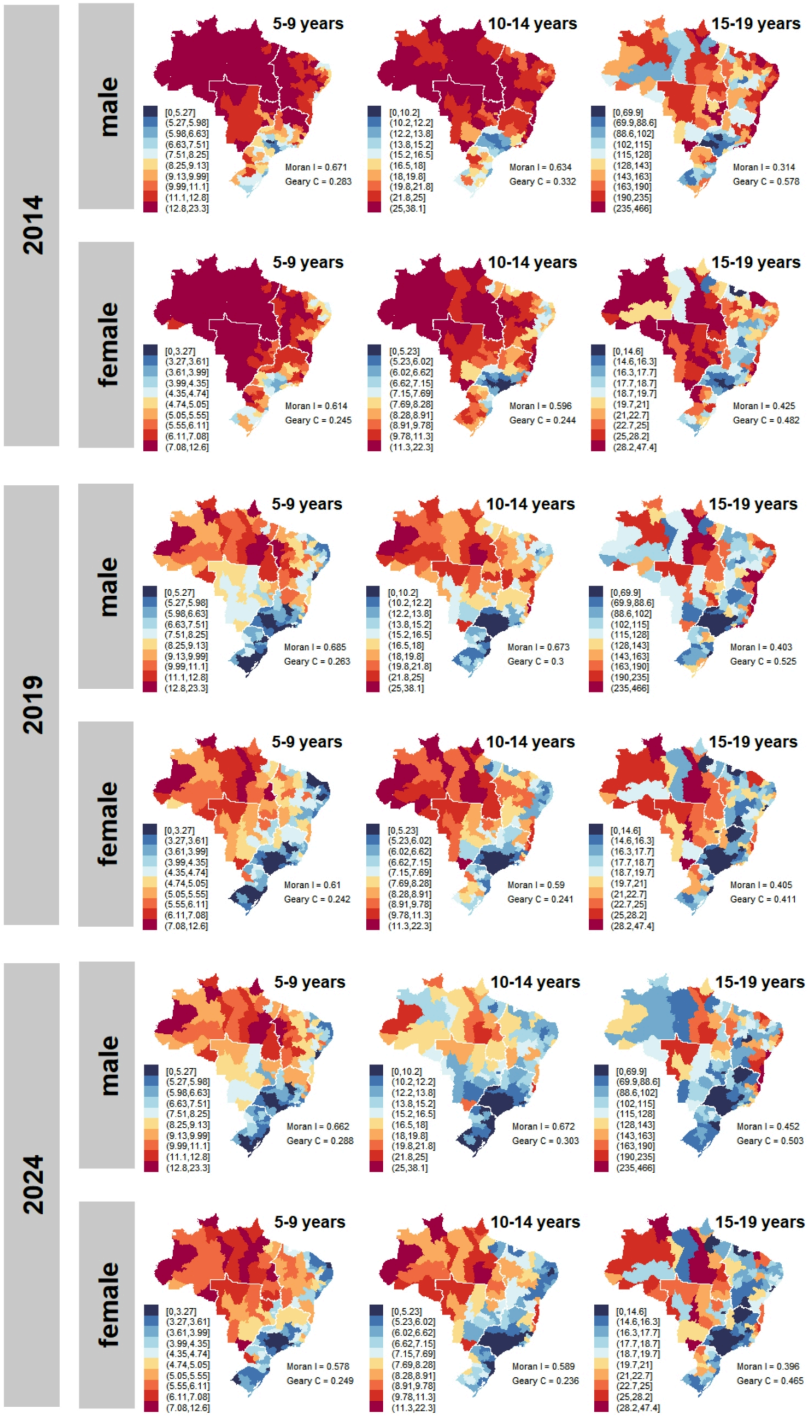


Figure 3

Smoothed mortality rates by external causes (deaths per 100,000 population) in 2014, 2019, and 2024, according to sex and age groups, estimated by the Bayesian spatiotemporal model and stratified by decile categories.