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High-risk space-time clusters of mortality in children 5 to 14 years of age in Mato Grosso state, Brazil

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Abstract *The study aimed to detect high-risk areas for deaths of children and adolescents 5 to 14 years of age in the state of Mato Grosso, Brazil, from 2009 to 2020. This was an exploratory ecological study with municipalities as the units of analysis. Considering mortality data from the Mortality Information System (SIM) and demographic data from the Brazilian Institute of Geography and Statistics (IBGE), the study used multivariate statistics to identify space-time clusters of excess mortality risk in this age group. From 5 to 9 years of age, two clusters with high mortality risk were detected; the most likely located in the state's southern mesoregion (RR: 1.6; LRT: 8,53). Among the 5 clusters detected in the 10-14-year age group, the main cluster was in the state's northern mesoregion (RR: 2,26; LRT: 7,84). A reduction in mortality rates was observed in the younger age group and an increase in these rates in the older group. The identification of these clusters, whose analysis merits replication in other parts of Brazil, is the initial stage in the investigation of possible factors associated with morbidity and mortality in this group, still insufficiently explored, and for planning adequate interventions.*

Key words *Mortality, Cluster analysis, Risk areas, Vulnerable populations, Social Determinants of Health*

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Introduction

Mortality patterns in the population can be considered one of the main strategies for understanding health conditions and aspects related to life in society. Their analysis can back the necessary interventions in public health and collective wellbeing[1].

In addition to the consolidated policies for reducing deaths in children under 5 years, mortality from 5 to 14 years of age has drawn growing attention, especially due to the causes, which are mostly avoidable. Studies from 2010 to 2016 in countries with diverse socioeconomic backgrounds showed a downward trend in mortality from 5 to 14 years of age (the decrease was greater in the 5 to 9-year group compared to 10 to 14 years)[2-4].

Traffic accidents are the leading external cause of death in this age group in both wealthier and middle- and low-income countries[5]. The other causes of death vary according to age group, sex, and region of occurrence[2].

The analysis of mortality in children and adolescents from the perspective of regional characteristics allows identifying similarities and differences, where the implementation of more effective interventions should result in multisector efforts at different administrative levels. The promotion of policies that modify the social reproduction of inequalities can benefit children and adolescents, who represent society's future[6].

In this context, a statistically significant correlation was demonstrated between infant mortality and economic, educational, and health characteristics and health services access between 2001 and 2017 in different regions of Brazil[7].

In Mato Grosso state, from 2007 to 2016, infant mortality was classified as mostly avoidable (65.1%), with variation in trends between health regions, which present differences in socioeconomic conditions and access to public healthcare services[8], suggesting that such variations may also be found in mortality in other age groups.

From 2009 to 2020, Brazil showed a downward mortality trend in the age groups from 5 to 9 and 10 to 14 years of age. During the same period, the state of Mato Grosso showed a stationary pattern in the mortality trend in these same age groups. The identification of this pattern and the high number of deaths in the state compared to other states of Brazil raise a serious warning signal[9].

Spatial analysis is one of the analytical techniques used in ecological studies, allowing to compare populations and discuss the characteristics of different regions and the relations with the spatial structure to which they belong. Visualization of the events' spatial distribution supports the in-depth investigation of areas with excess risk concerning the need to identify potential explanatory factors and more effective interventions[10-12].

The current study thus aimed to detect areas with increased risk of death in children and adolescents 5 to 14 years of age in Mato Grosso state from 2009 to 2020.

Material and methods

This was an ecological study of area-aggregated data, using as the analytical units the 141 municipalities in the state of Mato Grosso (MT). Located in Central-West Brazil, the state had an estimated population of 3,523,288 in 2022 and a territory of 903,207 km², ranking next to last in Brazil in terms of population density, with 3.36 inhabitants/km² [13,14].

Since these age groups have received relatively little attention in the analysis of mortality indicators, we analyzed the deaths of children and adolescents 5 to 14 years of age residing in Mato Grosso state, from 2009 to 2020, the latest 12-year period with available data when the study was performed, stratified by the two age groups (5 to 9 and 10 to 14 years), according to the stratification used by the World Health Organization (WHO), available in the Health Information Tabulator (Tabnet)[13].

Although 2020 was the first year of the COVID-19 pandemic, it was maintained in the historical series since the case-fatality rate in these two age groups is the lowest[15].

We used demographic data based on the estimate from the Brazilian Institute of Geography and Statistics (IBGE) and mortality data from the Mortality Information System (SIM) according to the victim's municipality of residence, extracted from the platform of the Unified Health System's Information Technology Department (DATASUS) in March 2022.

One of the Ministry of Health's priorities since 1996 has been to improve Brazil's health information systems. Various initiatives have been launched to upgrade the data in the SIM base[16]. In Mato Grosso, although there are still inconsistent data, downward or stable trends in data incompleteness have been seen for most sociodemographic variables, thus demonstrating an improvement in the system's data[17].

Crude annual mortality rates were calculated per 100,000 for each municipality. Data were displayed in Excel® tables and categorized by age group and period.

Considering the turning points in the analysis of the mortality trend from 5 to 14 years of age in Mato Grosso[9], deaths were grouped in two 6-year intervals, from 2009 to 2014 and from 2015 to 2020. Since death is a "rare event", with few occurrences per year, for calculating the mortality rates, we grouped all the deaths in the periods in each municipality according to age group and based on the population sum in each time interval.

The study excluded deaths for which there was no record of municipality of residence (1 death from 5 to 9 years and 2 deaths from 10 to 14 years of age, all in the period from 2009 to 2014, totaling 3 exclusions in the entire target period).

Small values were obtained in some municipalities, and other municipalities were identified with no deaths at all during the period. That rates were thus adjusted by local Bayesian estimate (LBE) using the GeoDA™ software, smoothing the measures and allowing analysis among neighboring municipalities.

The analysis of rare events and/or in small regions using the crude rate as the indicator may generate false conclusions, since it is the estimator most sensitive to instability of the analysis and interpretation of such outcomes[8]. The occurrence of events in certain areas can influence (and be influenced by) the occurrence in neighboring areas, and in this sense the LBE serves as an alternative for smoothing these rates, to jointly analyze the information on the area and its neighboring areas[18].

Thematic maps were built with the crude and adjusted rates for each municipality, according to age group and period, using the QGIS Desktop software version 3.22.4, which linked the epidemiological data to the municipalities' map grids (the software features open access on the website of the Brazilian Institute of Geography and Statistics -IBGE). The rates were categorized in levels and displayed with different color intensities on the maps.

Poisson distribution was used, submitted to a scan statistic, with 5% significance, considering the occurrence of deaths as a count of independent events with the same probability of occurrence. The analysis considered geographically non-superimposed circular clusters with time precision according to the previously defined periods. SaTScan version 10.0 was used, and space-time clusters were detected, having applied the maximum percentage as 5% of the population and a 200 km radius.

Using multivariate scan statistics, the software automatically simulates different analyses to jointly explore data from areas with the greatest geographic proximity, distributed across time. The process detects space-time clusters, calculating and comparing relative risks (RR) inside the clusters in relation to areas outside these clusters, and identifies the most likely ones. The most likely cluster is that with the highest value in the likelihood ratio test (LRT)[19].

The results of analyses performed in SaTScan were also exported to QGIS, where the cluster maps were made.

Since this was an analysis of secondary and grouped public-domain, open-access data, without identification of individuals, the article received approval of exemption from ethical review, No. 09/2022, from the Institutional Review Board of the Brazilian National School of Public Health.

Results

In Mato Grosso state, from 2009 to 2020, 2,068 children and adolescents 5 to 14 years of age died, 876 in the age group from 5 to 9 years and 1,192 from 10 to 14 years.

From 2009 to 2014, the municipality of Torixoréu in the southern mesoregion of Mato Grosso showed the state's highest crude mortality rate in the 5 to 9-year group (123.84/100 thousand). From 2015 to 2020, this position was occupied by Porto dos Gaúchos, in the northern mesoregion, with a crude mortality rate of 125.63/100 thousand (Figure 1)

From 2009 to 2014, the crude rates identified 24 municipalities in Mato Grosso with more than 50 deaths in children from 5 to 9 years per 100 thousand. After adjusting for LBE, this number dropped to 3 municipalities. A similar reduction was seen in the period from 2015 to 2020: 16 municipalities showed crude rates higher than 50/100 thousand from 5 to 9 years, while only one municipality showed such values after the adjustment (Figure 1).

In this age group, considering both crude and adjusted rates, the mortality rates were lower in the second period compared to the first. The number of municipalities with adjusted rates greater than 30/100 thousand decreased from 47 from 2009 to 2014 to 27 from 2015 to 2020 (Figure 1).

The mortality rates from 10 to 14 years of age were higher than from 5 to 9 years. And unlike the younger children, the number of municipalities with adjusted rates greater than 30/100 thousand increased from 98 from 2009 to 2014 to 116 from 2015 to 2020, with a clear increase in values in the second period compared to the first (Figure 2).

Adjustment by LBE reduced the number of municipalities in Mato Grosso with more than 50 deaths per 100 thousand in children and adolescents 10 to 14 years of age, both in 2009-2014 (from 31 to 6 municipalities) and in 2015-2020 (from 41 to 15 municipalities) (Figure 2).

This age group featured the municipalities of Ribeirãozinho (155.88/100 thousand), located in the southern mesoregion, in the first period, and Estrela (238.1/100 thousand) in the central-southern mesoregion, in the second period, with the highest adjusted mortality rates in Mato Grosso (Figure 2).

Spatial scan analysis of mortality in children 5 to 9 years of age in Mato Grosso detected two high-risk clusters, both from 2009-2014, the most likely of which consisted of 19 municipalities in the central-southern mesoregion. The analysis of mortality from 10 to 14 years of age detected five clusters: three in the first period and two in the second, which included the most likely cluster, consisting of 6 municipalities in the northern mesoregion (Figure 3).

Although close, the age group clusters were not geographically equivalent, without juxtaposition among them. The main cluster in the 5 to 9-year group was in the area close to the state capital, Cuiabá, while the main cluster from 10 to 14 years of age was close to the border with the state of Pará (Figure 3).

Among the seven clusters detected as areas with excess mortality risk in the age groups from 5 to 9 and from 10 to 14 years of age in Mato Grosso, only two were statistically significant.

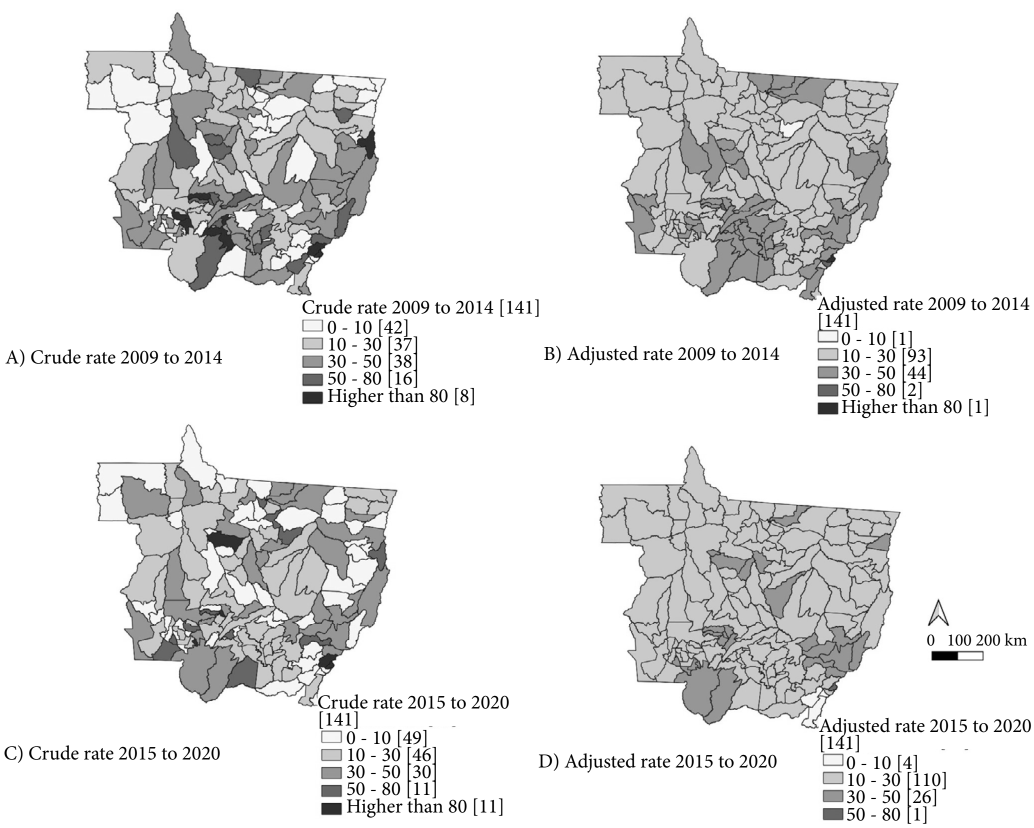

Figure 1. Crude mortality from 5 to 9 years of age and adjusted by Bayesian estimate, Mato Grosso state, Brazil, 2009 to 2020.

Source: Authors (2023).

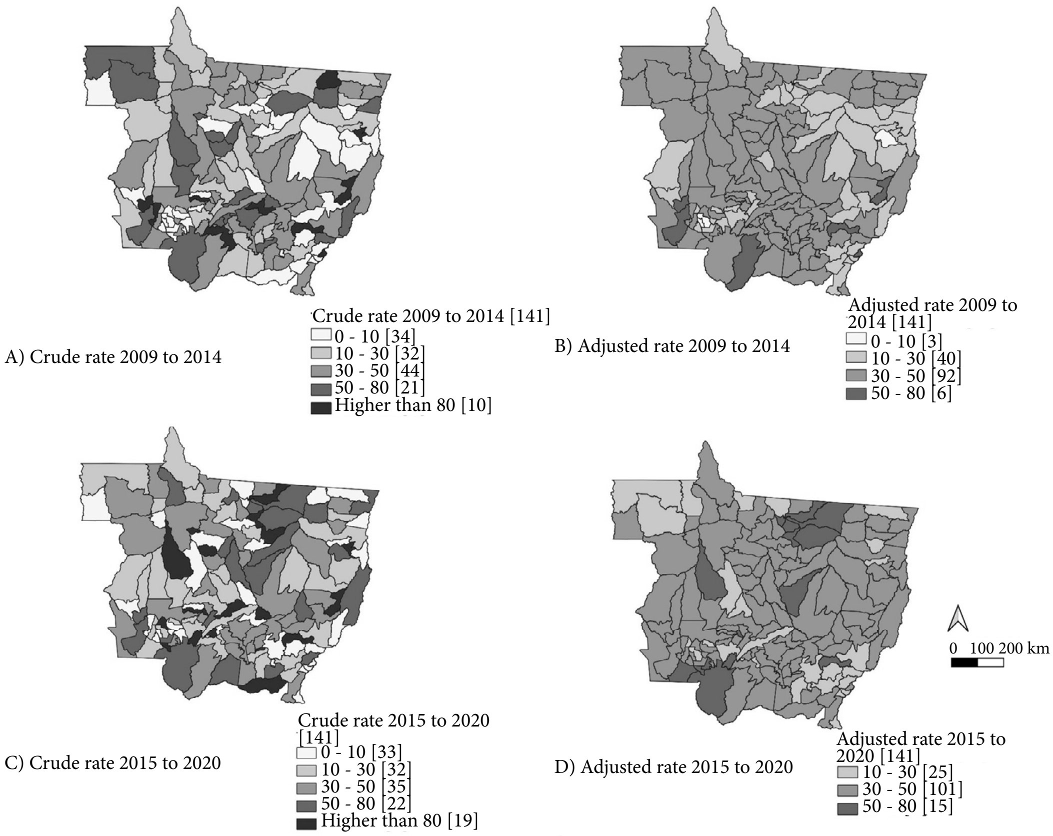

Figure 2. Crude mortality from 10 to 14 years of age and adjusted by Bayesian estimate, Mato Grosso state, Brazil, 2009 to 2020.

Source: Authors (2023).

However, the high relative risks identified in the other clusters are evidence of the severity in relation to death (Table 1).

Among the clusters identified in the stratum from 5 to 9 years, the cluster in the southern mesoregion showed a higher relative risk (3.59) than the central-southern cluster (1.6). Still, since the central-southern mesoregion showed the highest likelihood ratio test, LRT (8.53), it was considered this age group's main cluster (Table 1). Among the five clusters in the 10 to 14-year age group, the highest RR was in the southeastern mesoregion (3.89), but the northern mesoregion showed a higher LRT (7.84) and was classified as this age group's main cluster (Table 1).

Discussion

From 2009 to 2020, the spatial distribution of deaths in children and adolescents 5 to 14 years of age in Mato Grosso proved to be heterogeneous, evidencing large clusters of municipalities representing areas with excess risk for the target outcome, located in regions with urban connections and close to mining areas and state borders.

The age group from 5 to 9 years showed a reduction in the number of municipalities with high mortality from 2015 to 2020 compared to the period from 2009 to 2014. The age group from 10 to 14 years showed the opposite scenario, where the number of municipalities with high mortality rates increased in the latter period. These changes may be associated with living conditions in these municipalities and merit further investigation.

Figure 3. Space-time clusters of deaths from 5 to 14 years of age in Mato Grosso state, Brazil, 2009 to 2020.

Source: Authors (2023).

Public policies related to the reduction in infant and under-5 deaths may influence the mortality pattern in the immediately older age groups, modifying the order of the leading underlying causes of death and even postponing them[2-4]. With an important reduction in infant mortality from 2007 to 2016[8], Mato Grosso (as well as Brazil as a whole) experienced a larger reduction in the mortality rate in the 5 to 9-year group than in the 10 to 14-year age group from 2009 to 2020[9].

Complex growth and development processes in children and adolescents during the transition to adulthood are amenable to interventions that can alter their morbidity and mortality outcomes. Local contexts, culture, beliefs, sex, race, sexuali-

Table 1. Space-time clusters of deaths from 5 to 14 years of age according to Kulldorff's space-time scan, Mato Grosso state, Brazil, 2009 to 2020.

Indicators	Municipalities	Radius	Period	Pop.	Observed Deaths (N)	Expected Deaths (N)	Obs./ Exp.	RR	LRT	p-value
Deaths 5-9 yrs./ pop. **Cluster 1**	**Central-southern mesoregion:** Denise, Arenápolis, Alto Paraguai, Nortelândia, Nova Olímpia, Santo Afonso, Nova Marilândia, Diamantino, Barra do Bugres, Jangada, Acorizal, Porto estrela, Rosário Oeste, Lambari D'Oeste, Várzea Grande, Salto do Céu, Nobres, São José do Rio Claro, N. S. do Livramento.	133.4 km	01/01/2009 to 31/12/2014	38,791	99	64.73	1.53	1.6	8.53	0.022
Deaths 5-9 yrs./ pop. **Cluster 2**	**Southern mesoregion:** Pontal do Araguaia, Torixoreu, Ribeirãozinho	62.6 km	01/01/2009 to 31/12/2014	821	5	1.39	3.58	3.59	2.78	0.995
Deaths 10-14 yrs./pop. **Cluster 1**	**Northern mesoregion:** Marcelândia, União do Sul, Nova Santa Helena, Peixoto de Azevedo, Matupá, Terra Nova do Norte	109.8 km	01/01/2015 to 31/12/2020	6,484	30	13.28	2.26	2.29	7.84	0.04
Deaths 10-14 yrs./pop. **Cluster 2**	**Central-southern mesoregion:** Poconé, Barão de Melgaço, Cáceres, N. S. do Livramento, Porto Estrela, Várzea Grande	154.9 km	01/01/2009 to 31/12/2014	34,980	102	77.39	1.32	1.35	3.83	0.833
Deaths 10-14 yrs./pop. **Cluster 3**	**Southeastern mesoregion:** Conquista D'Oeste, Vale de São Domingos	54.1 km	01/01/2009 to 31/12/2014	578	5	1.29	3.88	3.89	3.07	0.969
Deaths 10-14 yrs./pop. **Cluster 4**	**Northern mesoregion:** Brasnorte	0 km	01/01/2015 to 31/12/2020	1,624	9	3.6	2.5	2.52	2.87	0.983
Deaths 10-14 yrs./pop. **Cluster 5**	**Southeastern mesoregion:** Nova Brasilândia, Itaúba, Itiquira, Campo Verde, Nobres	92.9 km	01/01/2009 to 31/12/2014	6,576	24	14.55	1.65	1.66	2.6	0.995

Source: Authors (2023).

ty, health services access, geographic conditions, and economic status are examples of determinant factors in these processes[20].

Factors linked to lack of food and education and weakened family relations characterize situations of social vulnerability that significantly affect the conditions for survival of children and adolescents[21].

The seven clusters that were identified represent areas with excess mortality risk from 5 to 14 years of age in Mato Grosso. Such excess risk may be associated with social, economic, and environmental factors like traffic conditions and the supply of services, among others[7,22].

A recent space-time analysis of cases of severe acute respiratory syndrome (SARS) and COVID-19 in 2020 and 2021 in Mato Grosso showed that the clusters were connected by the state's federal highways, urban connections, and hierarchical urban network[23].

The current study presented a similar scenario, in which most of the clusters consisted of municipalities located along federal highway BR-163 or connected to it indirectly. The highway is the main marketing route for Mato Grosso, Brazil's leading grain-producing state[24]. It interconnects municipalities that are highly relevant in the urban hierarchy[23]; many resulting from the intense migratory flow towards the agricultural frontier and the mining areas[25].

The hierarchical classification of Brazilian cities was proposed to contribute to the localization of investments and the implementation of public and private services, directly and/or indirectly affecting the living conditions of each region's residents, especially as regards access to public goods and services[26]. Such access can be crucial in the health-disease process.

The main cluster (cluster 1) in the 5 to 9-year age group, located in central-southern Mato Grosso, represents an area circumscribed by municipalities with strong urban hierarchical influences such as Tangará da Serra, Cáceres, Nova Mutum, and the state capital, Cuiabá. Taken together, these municipalities accounted for some 20% of the absolute number of deaths from external causes from 5 to 9 years of age in Mato Grosso[13].

The area identified as the main cluster (cluster 1) from 10 to 14 years of age is a mining region. Mining began in the Peixoto de Azevedo area in the late 1970s. Social problems identified in mining areas in Mato Grosso follow the same pattern as in the rest of Brazil and mainly involve labor and affective relations: poverty, low schooling, poor sanitation, poor health conditions, limited access to health services, prostitution, and the "gold syndrome"[27].

In addition to the environmental consequences, the population shifts caused by mining have expanded the land areas with disorganized occupation, enriching a privileged few and impoverishing many. From the aesthetic and social point of view, vestiges of this context of vulnerability are visible to this day in former mining areas, especially in the first prospecting sites such as Paranaíta, Alta Floresta, Peixoto de Azevedo, Apiacás, and others[28].

The interstate border areas also deserve attention due to the administrative capacity needed to solve problems shared by neighboring municipalities. The administration of the Unified Health System (SUS) in these regions is a tripartite challenge requiring high capacity for integration between state government projects, limiting the effectiveness of results from the planning phase through their execution[29].

Of the 2,068 deaths of children and adolescents 5 to 14 years of age in Mato Grosso from 2009 to 2020, 1,302 were classified as avoidable through interventions by the SUS according to the List of Avoidable Causes of Deaths (from 5 to 74 years of age)[30]. External causes led this ranking and accounted for 35.5% and 47.1% of the deaths from 5 to 9 years and from 10 to 14 years of age, respectively. Violence and accidents, especially traffic accidents, led the deaths from external causes, particularly in areas with more interurban connections[8,13]. Beyond the health sector, the reduction of mortality from violence requires multiple, inter-sector, linked interventions, especially with the area of education[31].

In deaths from traffic accidents, children and adolescents can be victims (pedestrians, cyclists, automobile passengers, motorcycle passengers, school bus passengers) or causes (as under-age drivers of automobiles or motorcycles)[32]. Such accidents can generally be related to logistic and environmental factors, including poor enforcement of traffic legislation and precarious maintenance of public byways, highways, and signage, among others[33].

The comparison and analysis of crude and adjusted mortality rates, especially in rare events or small populations[12], produce important observations on the recording, processing, and magnitude of events analyzed in certain locations.

An example of the variability revealed by adjustment with the LBE is the analysis of rates in Itiquira, a municipality with an estimated population of 13,727 located on the state border and next to Rondonópolis, a city with high urban hierarchy, with an estimated population of 239,613[14]. From 2015 to 2020, the crude mortality rate from 5 to 9 years was zero in Itiquira; after adjustment, the rate reached 139.35/100 thousand. This suggests possible recording errors in the victims' place of residence and the need for shared administration of the supply of goods and services to reduce mortality risk in the region.

Importantly, the study was limited to the analysis of secondary data from death certificates, without ruling out the possibility of errors in both the completion of the original documents and the keying-in of data in the database. However, the study was able to reveal specificities (which had previously received little attention) in the distribution of deaths, mostly avoidable, in the age groups.

Considering the high proportion of avoidable deaths, particularly related to traffic accidents, the unexpected result that few municipalities in the clusters were among those with higher proportions of deaths from external causes in all the age groups highlights the result's relevance and emphasizes the need to better understand factors associated with this outcome.

Considering open access to software programs like those used in this study, the space-time analysis technique provides high precision and ease of routine use in health services, especially in Health Surveillance. Besides detecting adverse conditions, its use can assist in the development, execution, and monitoring of strategies, targeting efforts and optimizing resources to solve numerous collective health problems.

The identification of areas with excess mortality from 5 to 14 years of age in Mato Grosso state, the analysis of which deserves replication elsewhere in Brazil's territory, is an important stage in the initial investigation of factors associated with such mortality and for planning multifactor interventions to reduce morbidity and mortality in this age group. Beyond the identification of these areas, it is necessary to analyze the degree to which they may be similar and the principal critical points to be solved in each region for these interventions to be potentially case-resolving and effective, thereby guaranteeing better conditions of survival for children and adolescents in Mato Grosso.

Collaborations

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

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