Spatial analysis of the AIDS mortality rate among young people in a province of the Brazilian Amazon: An ecological study

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Abstract

Worldwide, policies to combat human immunodeficiency virus (HIV) have led to a small decrease in the acquired immunodeficiency syndrome (AIDS) mortality rate among young people. For greater policy efficacy, it is necessary to determine the influence of social determinants of health (SDHs) in each territory. The objective of this study was to spatially analyse the AIDS mortality rate among young people in a province of the Brazilian Amazon and the spatial variability of the rate promoted by SDHs. All reports of AIDS deaths between 2007 and 2018 among young people living in the state of Pará were included in the study. The mortality rate was analysed using spatial distribution and autocorrelation, spatial scanning, and geographically weighted regression (GWR). During the study period, there were 1,372 deaths from AIDS among young people with a territorial expansion. The spatial autocorrelation showed two high-high clusters in the period from 2007 to 2010, one formed by municipalities in south-eastern Pará and one in the metropolitan region of Belém, with only the latter remaining between 2011 and 2018. This region showed a higher spatial risk for AIDS mortality and was the only cluster with spatiotemporal risk in the 2013-2018 period. Spatial variability was promoted by the i) the youth homicide rate, ii) the elementary school dropout rate and iii) the number of families registered in the Unified Registry for Social Programs (CadÚnico). This study provides support for the implementation of effective focal policies to combat HIV and reduce the mortality rate among young people in Pará.

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Introduction

Worldwide, although the use of antiretroviral therapy (ART) has led to a 47% reduction in the mortality rate from acquired immunodeficiency syndrome (AIDS) in the last decade, this decline was lower among young people, i.e. 24%. Among all females, the mortality rate decreased by 34%, and among all males, it decreased by 6% (UNAIDS, 2021a). Globally, in 2019, approximately 46,000 young people died from AIDS, with a higher number of deaths observed among females than among males, *i.e.* 26,000 and 21,000, respectively (UNAIDS, 2021b). These facts pose health challenges.

The trends in Brazil have followed the worldwide ones, with a 19.4% decrease in AIDS mortality among young people aged 15 to 29 years old (2011: 1,612 deaths; 2020: 1,300 deaths). Among young women, the decrease was 40.2%, and among young men 7.2% (men: 1,019 deaths in 2011 and 946 deaths in 2020; women: 592 deaths in 2011 and 354 deaths in 2020). In the Brazilian scenario, the North has had the highest mortality rate, with the rate increasing in four of its seven states in the last decade: Amapá (240.2%), Rondônia (30.4%), Tocantins (11.9%) and Pará (6.5%). Pará, and its capital Belém, now rank second among the Brazilian states and capitals with the highest AIDS mortality rate, with 7.0 and 14.1 per 100 thousand inhabitants, respectively (Ministry of Health, 2021a).

Pará has, according to the Brazilian Institute of Geography and Statistics (IBGE), the third lowest human development index (HDI) among the Brazilian states, *i.e.* 0.646 (IBGE, 2021). Policy and resource support for people living with HIV/AIDS is insufficient considering the large territorial area, rainy climate, densely forested areas and large proportion of the population who only have access to health services by boat. In the entire state, there are 48 testing and counselling centres (TCCs), seven specialized HIV/AIDS assistance services (SASs) and 33 antiretroviral dispensing units (DDUs). Regarding preexposure prophylaxis (PrEP)], only two health units, both located in Belém, dispense such drugs. However, 1,650 medications were dispensed from 2018 to 2020, ranking Pará in the top among states in the North with regard to the amount of PrEP drugs dispensed (Ministry of Health, 2021b; SICLOM, 2021).

The fight against AIDS mortality among young people involves barriers such as social inequalities, gender-based violence, stigma and social prejudice against people living with human immunodeficiency virus (HIV), as well as insufficient public policies (UNAIDS, 2021b). Public policies have been implemented to combat AIDS mortality, for example, decentralization of HIV test and the release of ART free of charge for all those diagnosed with HIV (Ministry of Health, 2018; Agostini *et al*., 2019). However, to achieve mortality-related goals, it is necessary to consider the social determinants of health (SDHs) in each territory, which are defined as the social, economic, cultural, ethnic/racial, psychological and behavioural factors that influence the occurrence of health problems in the population (Viana *et al*., 2019).

Spatial analysis techniques are useful tools in this context because they allow identifying the areas with the greatest epidemiological pressure and correlating the problem studied with SDHs (Rouquayrol and Gurgel, 2018). Thus, health interventions can be more focused and effective. A literature review with the search terms: "Acquired Immunodeficiency Syndrome" or "AIDS" or "HIV"; "Spatial Analysis" and/or "Temporal Analysis" and "Mortality" resulted in only nine studies, four of which conducted in Brazil (Maranhão *et al*., 2020; Mota *et al*., 2018; Ross *et al*., 2018; Teixeira *et al*., 2014) and five on the African continent (Mee, 2014; Nasmosha *et al*., 2013; Sartorius, 2013; Sartorius and Sartotius, 2013; Sifuna *et al*., 2018). However, none of these studies had young populations as the main focus. Additionally, only one single spatial study used geographically weighted regression (GWR) (Maranhão *et al*., 2020) to measure the influence of SDHs on AIDS mortality.

This was an ecological study using secondary data from the Brazilian Mortality Information System (MIS). The main goal of this study was to analysis spatially the AIDS mortality among young people in Pará over the period 2007-2018 using spatial autocorrelation, spatial and spatio-temporal risk and GWR techniques.

Materials and Methods

Study design and population

Pará is situated in the northern region of Brazil and has the second largest territorial area in Brazil (1,247,955.238 km^2). The state is divided into 144 municipalities and 6 mesoregions: Lower Amazon, Southwest Pará, Marajó, Northeast Pará, Metropolitan of Belém and Southeast Pará (Figure 1). The projected population for the year 2020 was 8,724,642 people, with approximately 27.43% of this population consisting of young people.

The study population consisted of young people in Pará who had died in the period from 2007 to 2018 and whose primary cause of death was AIDS. All reports of young people living in other states were excluded from the study.

Study variables

Notifications of death due to AIDS were obtained from MIS, made available by the State Department of Public Health. The variables selected were date of death, date of birth, sex, age, race/colour, education, marital status and municipality of residence. The data were grouped by year of notification, double-checked and redundancies corrected. The mortality rate was calculated by dividing the number of deaths by the number of young people projected for each municipality. The result was then multiplied by 100,000. Annual population projections were obtained from the website of the Interagency Network of Information for Health. The SDHs were obtained from the statistical yearbook of the Amazon Foundation for Studies and Research and the website of IBGE, grouping them into the following dimensions: i) Housing: Electricity consumers; ii) Education: Total elementary school dropout rate and total high school drop-out rate; iii) Income: Total number of families enrolled in the unified registry for social programs (CadÚnic) with a per capita household income of up to ½ the minimum wage, average formal employee compensation, employment bonds for formal employees with a complete high school education and total employment bonds for formal employees; iv) Health: number of hospitals, number of health stations and centres per 10,000 inhabitants, physicians per 10,000 inhabitants and Hospital beds per 1,000 inhabitants; v) Security:

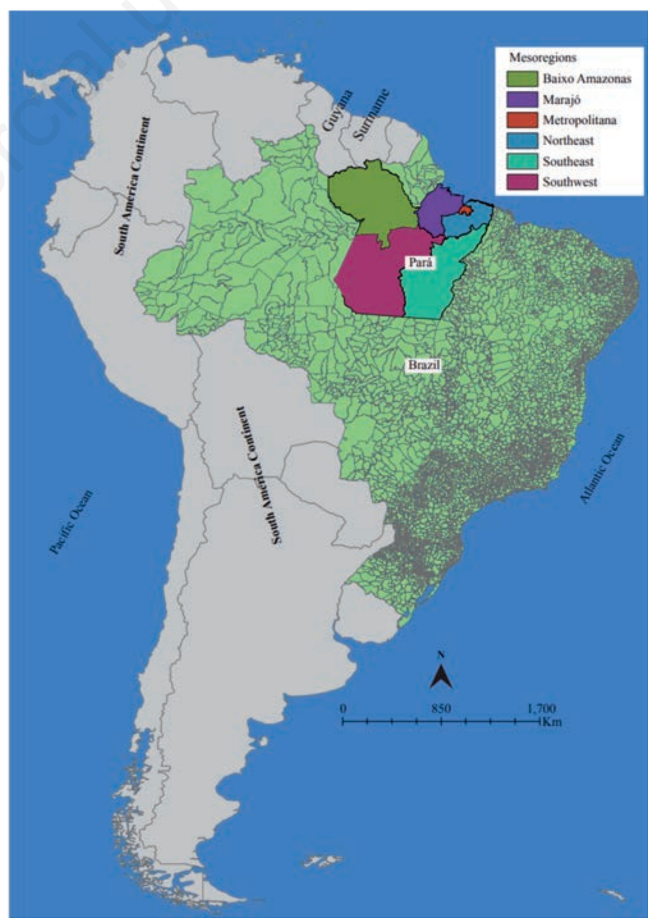

Figure 1. Spatial location of the Brazilian state of Pará. The political mesoregions of Pará (Baixo Amazonas, Marajó, Metropolitana de Belém, Northeast, Southeast and Southwest) are shown in different colours (see IBGE, 2022).

youth homicide rate per 100,000 inhabitants, robbery rate per 100,000 inhabitants and family health strategy and primary health care coverage.

Data analysis

To characterize the sociodemographic profile of the studied population, descriptive analysis was performed using the SPSS Statistics, version 23.0. The results are expressed as absolute (n) and relative (%) frequencies. In the spatial analysis, spatial distribution and autocorrelation of the mortality rate, spatial scanning and GWR were used, with the mortality rate calculated per quadrennium (2007-2010, 2011-2014 and 2015-2018) to avoid annual variations. The number of deaths in the quadrennium divided by the population mean for the same period multiplied by 100,000 was used for the calculation. The results were smoothed by Box–Cox transformation (Box and Cox, 1964) to eliminate outliers.

Considering that neighbouring geographic spaces share similar values (spatial autocorrelation) Global Moran's index (*I*) was used, with 999 permutations, allowing determination of the relationship between observations and spatial proximity, (Okoli *et al*., 2019). The values of *I* can vary from -1 to 1, where values from -1 to 0 indicate an inverse correlation, 0 no correlation at all and values from 0 to 1 a direct correlation (Câmara *et al*., 2004). To show the location of clusters, Local Moran analysis, i.e. local indicators of spatial association (LISA) as described by Anselin (1995) was used to identify the four types of clusters: high-high (HH) and low-low (LL) mortality rates indicating a direct correlation; and low-high (LH) and high-low (HL) mortality rates representing an inverse correlation. Both were performed using ArcGIS, version 10.5.1 (ESRI, Redlands, CA, USA).

In the spatial scan analysis, the spatial and spatiotemporal risks were analysed by the Poisson discrete model using SatScan, version 9.7 (Kulldorff, Cambridge, MA, USA). For spatial risk, the criteria for non-overlapping circular clusters were used applying a window size not exceeding 50% of the exposed population and 999 permutations. For spatial-temporal cluster detection, the temporal precision in years and the window size at a maximum of 50% for the study period were considered. Areas with a relative or greater relative risk (RR) ≥ at 1, $p \leq 0.05$) were considered to be risk factors. GWR was used for the analysis of the influence of SDHs on the spatial distribution of the AIDs mortality rate. The dependent variable was the mortality rate for the 12 years of the study, and the SDHs served as independent variables.

Initially, the collinearity of the independent variables was analysed by Pearson correlation. Subsequently, all correlations with $p < 0.05$ were analysed using ordinary least squares (OLS) using a stepwise approach to obtain the best model. Only models with a variance inflation factor (VIF) less than 10 were considered. The best model was the one with the lowest Akaike information criterion (AIC), the highest R^2, adjusted R^2 and lowest VIF, at $p<0.05$. For model validation, the spatial dependence of the residuals was discarded by applying Global Moran analysis. After validating the OLS model, GWR was employed using multi-scale GWR (MGWE) software (ASU, MD, USA). This technique involves the selection of a kernel function for geographic weighting, which can be fixed or adaptive, where the latter was used because it had the lowest corrected AIC (AICc) value (kernel fixed band: AICc = 389.207; kernel adaptive band: AICc = 388.762). Then, Global Moran analysis was again applied to the residuals of the GWR model. Once the model was validated, the OLS and GWR models were compared, and the model with the highest R^2, adjusted R^2 and lowest AIC was supposed to be the best model. Choropleth maps of the spatial analysis and GWR results were created in ArcGIS (Naiaka, 2016).

Results

A total of 1,372 deaths from AIDS in Pará were reported

Table 1. Sociodemographic profile of young people from Pará killed by AIDS in the period 2007-2018.

Variable	Deaths by AIDS				Total of death	
	Men (n=911)		Women (n=461)		(n=1,372)	
	n	%	n	%	n	%
Schooling degree						
Illiterarate	14	1.53	3	0.65	17	1.23
Elementary school	177	19.42	125	27.11	302	22.01
High school	274	30.07	178	38.61	452	32.94
College	386	42.36	112	24.29	498	36.29
No response	60	6.5	43	9.32	103	7.5
Race/skin colour						
Yellow	2	0.21	2	0.43	4	0.29
White	167	18.33	61	13.23	228	16.61
Native Indian	1	0.10	1	0.21	2	0.14
Brown	683	74.97	348	75.48	1031	75.14
Black	58	6.36	49	10.62	107	7.79
Marital status						
Married	47	5.15	42	9.11	89	6.48
Divorced	1	0.10	1	0.21	2	0.14
Single	745	81.77	344	74.62	1089	79.37
Common-law marriage	59	6.47	39	8.45	98	7.14
Widower	4	0.43	9	1.95	13	0.94
No response	55	6.03	26	5.63	81	5.90

among people aged 15 to 29 years in the period from 2007 to 2018, with 961 deaths among men (66.39%) and 461 among women (33.6%). Table 1 provides the sociodemographic information for the study population. Most men had higher education (42.4%), and most women had secondary education (38.61%). For both sexes, brown skin colour was predominant (men: 75.0%, women: 75.5%), as was a single civil status (men: 81.8%, women: 74.6%).

Figure 2 shows the spatial distribution of the AIDS mortality rate smoothed by quadrennium 2007-2010 (Figure 2A), 2011-2014 (Figure 2B) and 2015-2018 (Figure 2C). Throughout the period, there was an expansion of AIDS mortality in Pará, with municipalities in the metropolitan area of Belém, Lower Amazon, the Northeast, the Southwest and the Southeast being the most impacted.

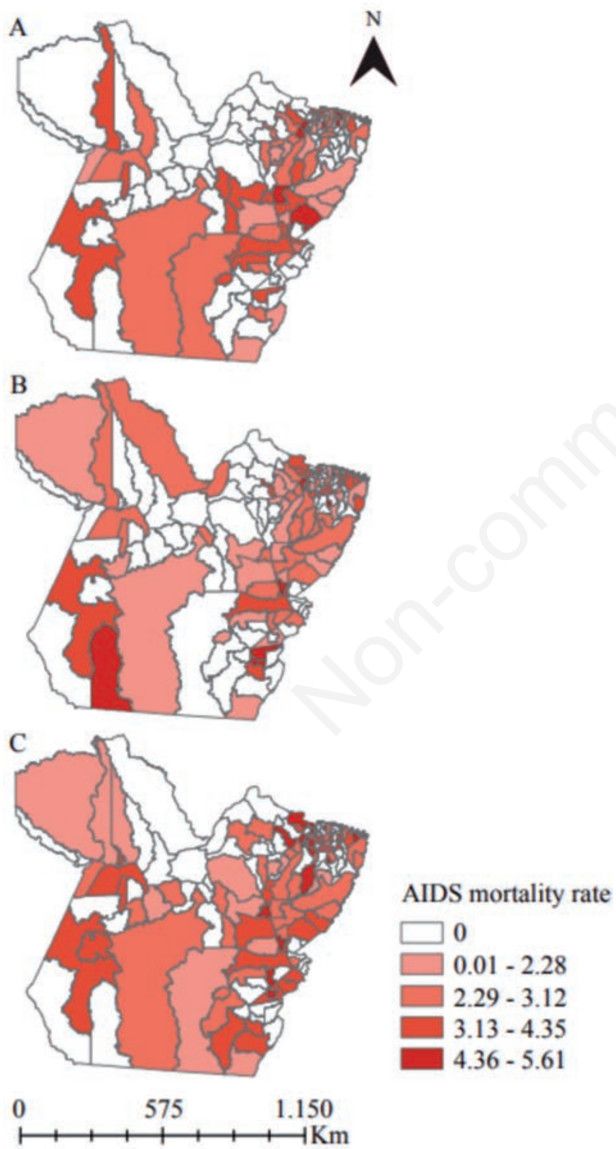

Figure 2. Spatial distribution of AIDS mortality rate among young people in Pará by four-years periods. A: 2007-2010; B: 2011-2014; C: 2015-2018.

Global Moran's *I* revealed spatial autocorrelation with respect to AIDS mortality rates in the three quadrenniums (2007-2010: I = 0.15, p = 0.001; 2011-2014: I = 0.11, p = 0.012; 2015-2018: I = 0.11 p = 0.01). In the quadrennium 2007-2010 (Figure 3A), the LISA map revealed two HH mortality rate clusters, one of which formed by municipalities in the metropolitan region of Belém (RMB) and the other by municipalities in the Southeast region. In the following 4-year periods, 2011-2014 (Figure 3B) and 2015-2018 (Figure 3C), there was only one HH cluster formed by municipalities in the metropolitan region of Belém. In all quadrenniums, there was a LL mortality rate cluster formed by municipalities in the Lower Amazon and Marajó.

The spatial analysis showed 2 spatial risk zones for AIDS mortality among young people in Pará. The first was formed by Belém (RR = 2.94, Figure 4A), and the second was formed by Ananindeua, Marituba, Benevides and Santa Bárbara (RR = 1.65, Figure 4A). Spatiotemporal risk was restricted to the municipalities of Belém, Ananindeua, Marituba, Benevides, Santa Bárbara, Bujarú and Santa Izabel do Pará (RR = 2.59, Figure 4B) in the period from 2013 to 2018.

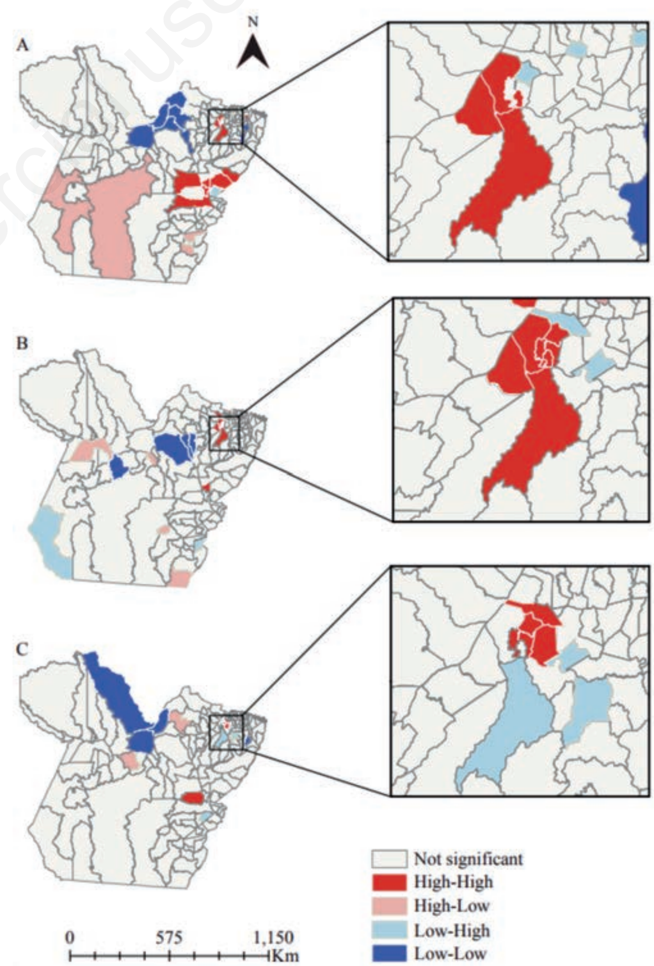

Figure 3. LISA map of the AIDS mortality rate among young people from Pará per four-years periods. A: 2007-2010; B: 2011-2014; C: 2015-2018.

Regarding the influence of SHDs on the spatial heterogeneity of AIDS mortality among young people in Pará, the OLS method indicated that the best explanatory model included the youth homicide rate, the elementary school drop-out rate and the total number of families enrolled in the (CadÚnico) (AIC = 244.27, R^2 = 0.160, adjusted R^2 = 0.142, VIF = 1.082). Moran's analysis Global showed no correlation of residuals (I = 0.07; p = 0.10). The GWR model was a better explanatory model than was the OLS model (AICc = 388.76; R^2 = 0.244, adjusted R^2 = 0.196), with no spatial autocorrelation of the residuals (I = 0.03; p = 0.37).

Figure 5A shows the local R^2 for the GWR model and Figures 5B, 5C and 5D show the spatial distribution of the same three SHDs followed by their β coefficients (Figures 5E, 5F, and 5G). The homicide rate conferred a higher risk of AIDS mortality among young people in the municipalities of the Lower Amazon and the Southwest Pará region. Regarding the elementary school dropout rate, the risk of AIDS mortality was lower in the Northeast region and in the metropolitan regions of Belém. The total number of families enrolled in the Unified Registry for Social Programs conferred a higher risk for AIDS mortality in the municipalities of the Southeast and Southwest regions.

In summary, the results of this study showed an expansion of the AIDS mortality rate among young people in Pará. The spatial autocorrelation showed persistence of the HH cluster formed by municipalities in the metropolitan area of Belém, and for the mortality rate due to AIDS throughout the study period. The area with the highest spatial risk for AIDS mortality among young people was composed of the municipalities of Belém, Ananindeua, Marituba, Benevides and Santa Bárbara, which are part of the metropolitan region of the state. The area with the highest spatiotemporal risk was formed by the municipalities of Belém, Ananindeua, Marituba, Benevides, Santa Bárbara, Santa Izabel do Pará and Bujarú, and the greatest spatiotemporal risk occurred between 2013 and 2018. The spatial variability of the mortality rate was promoted by the youth homicide rate, the elementary school dropout rate and the number of families registered in CadÚnico.

Discussion

Although there was a territorial expansion of AIDS mortality in Pará, there was a decrease in the HH mortality rate, in which the cluster observed in south-eastern Pará was not observed between 2011 and 2018, with the only cluster remaining in the metropolitan region was that in Belém. This may have been due to the increased coverage of primary health care (PHC) services in these municipalities and the decentralization policies related to testing and treatment for all individuals diagnosed with HIV. With the expansion of testing, early diagnosis and treatment increased and in consequence the likelihood of death from AIDS decreased. In turn, the metropolitan region of Belém has the lowest PHC coverage rate in spite of having the highest coverage of specialized health care services for People Living with HIV/AIDS (PLWHA), which leads to late disease diagnosis and increases the likelihood of death from AIDS. In Africa, the expansion of the coverage of HIV tests and the implementation of ART for all individuals diagnosed with HIV, regardless of the number of CD4 T cells, reduced the rate of AIDS mortality in countries such as Botswana by 59% in a period of 8 years (Barak *et al*., 2019; Mirkuzie *et al*., 2021).

The RMB presented the highest spatial and spatiotemporal risk (2013-2018) for the AIDS mortality rate. The RMB, in addition to having the highest population density in Pará (6.07 inhabitants/km^2), has the lowest PHC coverage rate, which further increases the chance of a late diagnosis. The spatiotemporal risk in the period from 2013 to 2018 coincides with the period of expansion of HIV tests. Although Belém has less PHC network coverage, the accessibility to services is greater than in inland municipalities since the PHC units are located in urban centres and a large part of the population lives in rural areas with access hampered by geographic barriers (Garnelo *et al*., 2018). However, a temporal study in Pará showed that even with the expansion of testing and ART policies, the diagnosis of AIDS corresponded to 50% of total diagnoses (HIV + AIDS) in 2018 (De Sá *et al*., 2021). These facts suggest the possibility of underreporting of AIDS mortality in municipalities in the interior of Pará because many individuals die without having been tested for HIV.

The spatial regression showed the highest risk of AIDS mortality in the municipalities in the Southeast and Southwest regions and Lower Amazon was associated with the youth homicide rate, elementary school dropout rate and number of families enrolled in CadÚnic. The municipalities in these regions of Pará are undergoing strong economic growth due to the construction of highways and hydroelectric dams and the implementation of mining, livestock and agriculture industries. This development has attracted a large number of immigrants, promoting an urban demographic explosion and generating serious social inequities, such as urban

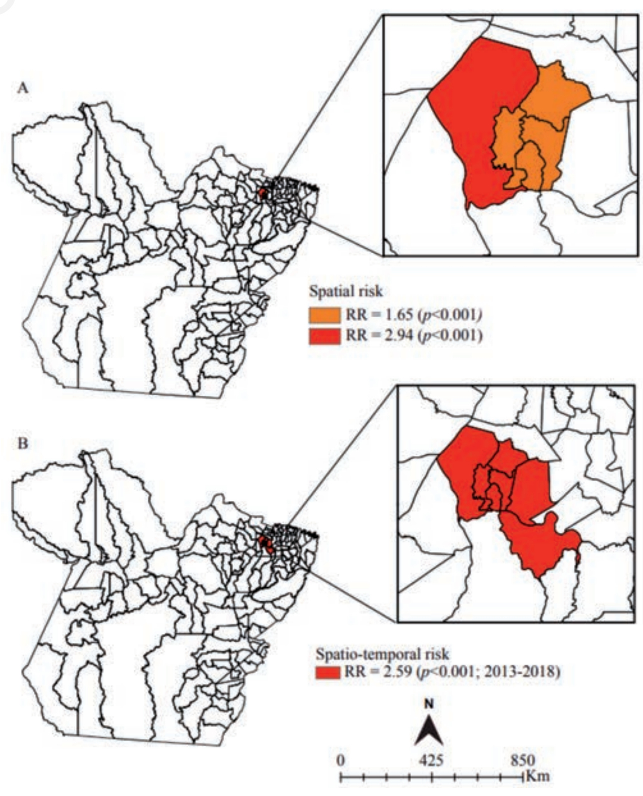

Figure 4. Risk areas mapping for AIDS mortality among young people in Pará 2007-2018. A: the spatial risk are areas; B: the spatio-temporal risk area.

violence (Richards and Vanwey, 2015). Since 2010, there has been an increase in urban violence and mortality from AIDS and malaria in the municipalities in these regions of Pará promoted by the construction of highways (Barcellos *et al*., 2010). HIV is directly linked to violence. In the United States, a study showed that people living with HIV and exposed to a violent environment had low adherence to ART, did not use condoms frequently and had multiple sexual partners (Ojikutu *et al*., 2018). The same low propensity for adherence to ART occurs among people with a low education, as observed among young people in South Africa (Cluver *et al*., 2018).

Considering that in municipalities in the Southwest region and Lower Amazon there is only one SAS and the low socioeconomic status hinders the access of PLWHA to these services, a higher AIDS mortality rate is expected in this region. In the United States, it was observed that poor Latin Americans living far from health centres had difficulties accessing specialized HIV prevention, diagnosis and treatment centres (Kanamori *et al*., 2021).

Aiming to reduce the HIV epidemic among young people, in 2007, the Ministry of Health launched the Health in Schools Program, in which sexual and reproductive health is a topic. However, a study among public school students in Belém, the capital of Pará, showed a low level of knowledge about the forms of HIV transmission/prevention (Lima *et al*., 2020). Much still needs to be done to increase the access of young people to HIV prevention, diagnosis and treatment services. In Brazil, as well as in Africa, the obligation of legal guardians to accompany young people under 18 to these services is a barrier to accessibility (Robert *et al*., 2020) That contributes to a late diagnosis. In China, educational campaigns aimed at combating HIV among young people have increased the HIV testing and the quicker HIV diagnosis decreased the AIDS mortality rate (Zhang *et al*., 2017). Stigma and social prejudice are also other barriers to testing. A literature review revealed that strategies aimed at reducing stigma and prejudice promoted greater demand for testing services (Thapa *et al*., 2018).

This study was limited by the quality of the information, which is dependent exclusively on the professionals responsible for it. One must also consider the underreporting of deaths from AIDS, which according to a previous study was approximately 4.2% in the North region of Brazil (Do Carmo *et al*., 2021). Because this

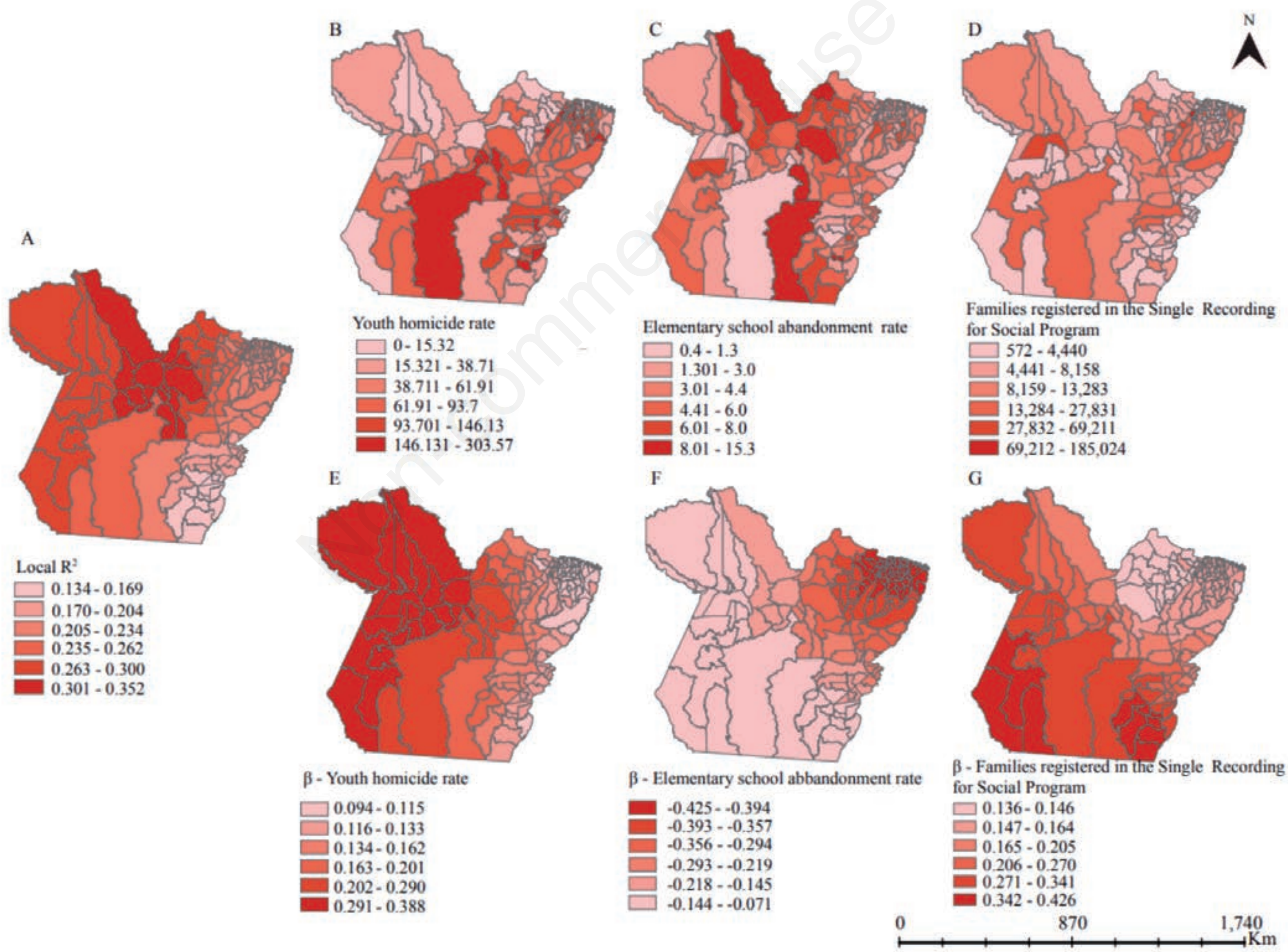

Figure 5. Spatial regression of AIDS mortality rates among young people from Pará 2007-2018. A: the Local R^2 of the GWR model; B: the youth homicide rate; C: the elementary school dropout rate; D: the total number of families enrolled in the Unified Registry for Social Programs; E: show the spatial distribution of the β-coefficients of the youth homicide rate, F: the elementary school drop-out rate; G: the total number of families enrolled in the Unified Registry for Social Programs.

was an ecological study, we cannot correlate the phenomenon studied with causalities (immigration and sociodemographic factors, among others). In addition, this study was conducted before the COVID-19 pandemic, which may have further aggravated the scenario; thus, additional studies are needed.

Conclusions

The results of this study indicate AIDS mortality is expanding among young people in Pará, a finding that suggests that public policies aimed at combating HIV among young people is inefficient, possibly with the exception of the RMB, which presented a spatiotemporal risk in the period from 2013 to 2018 only. The spatial variability of the AIDS mortality rate with higher association, with youth homicide rate, elementary school drop-out and families enrolled in CadÚnico, underlines the need for investments promoting the quality of life of rhese populations, especially in the municipalities of the Southeast and Southwest regions and Lower Amazon.

It is a worry that public policies against HIV play minimal roles in reducing the AIDS mortality rate among young people. It is evident that educational media campaigns and sexual and reproductive education in schools and communities are inefficient if social equity cannot be guaranteed. It is necessary to ensure accessibility to HIV counselling, prevention, diagnosis and treatment services for young people as well as access to work, leisure and education for the elimination of HIV.

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