Cardiovascular diseases mortality in Brazilian municipalities: estimates from the Global Burden of Disease study, 2000–2018

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Summary

Background Age-standardized mortality rates (ASMR) for cardiovascular diseases (CVD) have decreased in Brazil in the last decades due to better control of risk factors and access to healthcare. However, how this reduction is distributed across the country's municipalities is unknown. We aimed to evaluate changes in CVD mortality rates across Brazilian municipalities from 2000 to 2018 using estimates from the Global Burden of Disease (GBD) study.

Methods In this ecological study, ASMR for CVD were estimated using GBD methodology for 5564 Brazilian municipalities from 5 regions in the triennials: 2000–2002, 2009–2011, 2016–2018. A visuospatial analysis was applied to create clusters in ASMR with Moran Local analysis. Municipalities were stratified by population size in <30,000, 30,000–300,000, and >300,000 inhabitants per region. The % changes in ASMR from 2000–2002 to 2016–2018 were calculated.

Findings In 2000–2002, ASMR for CVD were higher in more developed regions and in larger municipalities of all regions, except for the South. In 2016–2018, CVD ASMR increased in the least developed Northern regions. The % reduction in CVD ASMR was lower in small vs large municipalities within all 5 regions, varying from −3% in small Northern municipalities to −43% in large Southern municipalities.

Interpretation The reduction in CVD mortality in Brazil was lower in municipalities from the most vulnerable regions and smaller populations. Public policies tailored to these smaller municipalities, particularly on the least developed regions, must be considered a priority.

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Keywords: Brazil; Cardiovascular diseases; Mortality; Disparities

Introduction

Cardiovascular diseases (CVD) account for nearly 45% of non-communicable diseases (NCD) mortality globally, promoting negative economic and social impacts, particularly in low- and middle-income countries (LMIC).[1] In Brazil, a middle-income country, CVD account for 30% of deaths, being the first cause of death in recent decades, only behind COVID-19 in 2020 and 2021.[2,3]

The epidemiological transition in Brazil started in the 1960s when NCD became the main cause of death.[4,5] Improved sanitation and nutritional conditions, along with broad vaccination coverage, have led to a decrease in infectious and nutritional diseases and an increase in life expectancy.[4–6] In parallel, urbanisation and economic growth contributed to lifestyle changes, including an increase in of unhealthy behaviours such as high-caloric diets, low physical activity levels, and smoking and alcohol consumption, contributing to CVD becoming the leading cause of death in the country.[4–6] From the 1990s, age-standardized mortality rates (ASMR) for CVD started to decrease in Brazil, mainly driven by health promotion campaigns, better control of risk factors, and improved access to healthcare.[6] However, these

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Disclaimer: This summary is available in Portuguese in the Supplementary Material.

Research in context

Evidence before this study

The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) has provided regular estimates for the complex patterns and trends in population health around the world at the national level. In more recent years, subnational estimates have also been presented for some countries. Since GBD's 2016 edition, subnational estimates have been presented for Brazil, allowing comparisons across Brazilian states. The GBD national estimates show that age-standardized mortality rates (ASMR) for CVD started to decrease in Brazil from the 1990s, mainly driven by health promotion, better control of risk factors, and improved access to healthcare. However, the paces of these epidemiological changes occurred heterogeneously across Brazilian states, including in the burden of cardiovascular risk factors, due to the significant differences in sociodemographic, socioeconomic and healthcare aspects. However, GBD data on the municipal level was not available for Brazil. Municipal level data would be relevant to inform local public health decisions in a country with a decentralised health system such as Brazil.

Added value of this study

Using an innovative data modelled with GBD methodology for 5564 Brazilian municipalities by a collaboration of IHME researchers and GBD Brazil Network, we provide novel and relevant estimates for CVD mortality at the municipal level. In summary, we observed that CVD mortality was reduced in Brazil but heterogeneously across municipalities. This reduction was lower in the municipalities from the most socioeconomically vulnerable regions, the North and Northeast, and in those municipalities with smaller populations. Considering the two most common causes of deaths in Brazil, ischemic heart disease and stroke, the pattern described is similar, but more pronounced for stroke.

Implications of all the available evidence

These findings suggest that investments to address CVD burden in Brazil should focus and be tailored to these smaller municipalities, particularly of the least developed regions. Moreover, this innovative analysis reveals the opportunity to use GBD methodology to estimate mortality in smaller areas in Brazil.

epidemiological changes occurred heterogeneously across Brazilian states, including the burden of cardiovascular risk factors.[7,8]

This heterogeneity partly results from significant socioeconomic and healthcare disparities among the 5 Brazilian regions: South, Southeast, Mid-West (or Center-West), Northeast, and North.[9] The South and Southeast are the more urbanised and socioeconomically developed areas, with wider access to healthcare, whereas the North and Northeast are more economically deprived, the North being more sparsely populated. Demographic and socioeconomic indicators of all Brazilian regions are described in Supplementary Figure S1. Moreover, within these regions, there are still disparities across municipalities regarding urbanisation, socioeconomic development, and access to healthcare, and the smaller municipalities are usually less developed and present impaired access to the entire healthcare network.[10]

Given that equity and decentralisation are among the principles of Brazil's universal public health system, the Sistema Único de Saúde (SUS), understanding trends in CVD mortality rates across municipalities is necessary for tailoring public policies and advance towards equity.[11] Regarding decentralization, Brazilian municipalities are responsible for ensuring access to primary health care (PHC), health surveillance, and specialized care, including hospitals and emergency services. This makes the municipal level of governance crucial for addressing the burden of CVD in Brazil.[12] The aim of this study was to evaluate the changes in CVD mortality rates across Brazilian municipalities from 2000 to 2018, using the estimates for municipalities from the "Global Burden of Disease" (GBD) Study.

Methods

Study design, location, and period

This is an ecological study in which the ASMR for CVD was estimated using the Global Burden of Disease (GBD) methodology for all 5564 Brazilian municipalities from the 5 regions in the triennials: 2000–2002, 2009–2011, and 2016–2018. We analyzed CVD mortality data in three-year periods to smooth fluctuations in rates over the years due to low numbers in small municipalities. Municipalities were then stratified by population size into <30,000; 30,000–300,000; and >300,000 inhabitants per region.

Indicators and data sources

Mortality rates were calculated as the average of deaths for each three year period in the numerator. The estimated number of deaths for each municipality derived from the Institute for Health Metrics and Evaluation (IHME) database, from the University of Washington, in the context of the Global Burden of Disease (GBD) study, produced in partnership with the GBD Brazil network. The GBD Brazil Network was created in 2015 in a partnership between UFMG and the Brazilian Ministry of Health with the IHME. With more than 200 collaborators from diverse research centers across Brazil, the network aims to contribute, evaluate, and improve the GBD estimates for Brazil.[13] More details can be found at https://gbdbr.com.br/a-rede-gbd-brasil/.

The main current data source regarding mortality in Brazil is the Mortality Information System (*Sistema de Informação de Mortalidade*, SIM), the official source of mortality data in the country, qualified for causes of death. SIM's quality is rated four stars by the GBD study's star rating system (0–5 stars) to assess the quality of cause of death data.[14]

The estimation of mortality data by municipality in Brazil followed the same methods used to estimate mortality rates at the state level in GBD.[14] A summary of data processing steps is included below. First, data were assigned a GBD cause using the listed ICD code, and data with aggregated sex or age were split onto detailed groups.[15] Next, a correction for misclassification of Dementia, Parkinson's Disease, and Atrial fibrillation and flutter was applied.[15] Then, data underwent the process by which garbage codes (ICD codes that cannot reliably be assigned to a specific GBD cause, i.e. senility or heart failure) are redistributed to real GBD causes.[16] Finally, data were smoothed to account for stochastic variation across years in a process called noise reduction.[15]

For the denominator in rate calculations, we used the average population based on estimates from the Ministry of Health and the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*, in Portuguese, (IBGE)) at the municipal level for each triennial.[17] For age standardization, we used the standard population from the GBD study, based on 100,000 inhabitants.[16] Details about the methodology and the results of the GBD study are available in other publications.[15,16,18]

To examine the relationship between socioeconomic vulnerability and CVD mortality, we analyzed the correlation between CVD ASMR with the Brazilian Deprivation Index (BDI or *Índice Brasileiro de Privação*, in Portuguese) at the municipality level. The BDI, launched in 2020, considers a combination of z-scores of three deprivation indicators on the scale of census tracts: percentage of households with income less than half a minimum wage, percentage of illiterate individuals aged 7 years or older, percentage of individuals with inadequate access to water, sanitation, waste collection and bathroom. BDI generates a final score in which the lowest value represents an area with less deprivation, and the highest value represents an area with greatest deprivation.[19,20]

Definitions of CVD deaths

The underlying cause of death was defined as due to CVD according to the International Classification of Diseases (ICD) codes, based on death certificates (DC) the document that informs the causes of deaths in countries with vital statistics systems, such as Brazil (*Sistema de Informação de Mortalidade*, SIM, in Portuguese).[21] The following causes of death and their corresponding ICD-10 codes were classified as a CVD death, according to the GBD Study's classification list of causes, namely: 1- rheumatic valve disease (codes I01-I01.9, I02.0, I05-I09.9); 2-ischemic heart disease (codes I20-I25.9); 3- stroke (G45-G46.8, I60-I69.9); 4- hypertensive heart disease (I11); 5- cardiomyopathy and myocarditis (A39.52, B33.2-B33.24, D86.85, I40-I43.9, I51.4-I51.5); 6-atrial fibrillation and flutter (I48); 7- aortic aneurysm (I71); 8- peripheral artery disease (I70.2-I70.7, I73-I73.9); 9-endocarditis (A39.51, I33-I33.9, I38-I39.9).[22] Garbage codes, such as heart failure (I50) and pulmonary embolism (I26), which do not define the pathology that caused the death, were redistributed to the aforementioned specific causes based on the GBD methodology, according to algorithms defined in that study.[15]

In a secondary analysis, we presented data for ischemic heart disease (IHD) and stroke in separately due to their higher frequency as causes of death, making it possible to report the changes in these cause-specific deaths at the municipal level, without increasing uncertainty about the estimates. Deaths were classified as due to ischemic heart disease or stroke according to the ICD codes described above.

Statistical analysis

The ASMR for CVD were presented in choropleth maps and tables. Aggregate data analyses were also conducted according to Brazilian regions and stratified by population size (≤30,000 inhabitants; 30,000–300,000; >300,000) within each region. The population size strata were defined after conducting an exploratory analysis; 95% confidence intervals (95% CI) were calculated according to the Center for Disease Control and Prevention method.[23] Finally, percentages of changes in ASMR from 2000–2002 to 2016–2018 were calculated.

The ASMR spatial analysis was based on the calculation of the Moran Global index, which was used to assess the relationship of spatial interdependence among all the polygons around Brazil, expressed as a single value for the entire country.[24] Next, the Local Moran Index (LISA) was used to detect clusters between Brazilian municipalities.[24] For the purpose of better understanding the results, only the high–high and low–low rate clusters were used, which imply a positive association, i.e. groups of municipalities with similar mortality rates. A correlation between socioeconomic vulnerability, evaluated by the Brazilian Deprivation Index, and ASMR in the most recent period was calculated by Pearson's correlation coefficient for the municipalities in significant clusters detected by the Univariate Local Moran index (LISA).[25] Data presentation and analysis was conducted using the R software with the aid of the *Rgeoda* package.[26]

For the primary analysis of CVD deaths, we also performed sex-disaggregated analyses, considering the known differences in CVD mortality rates by sex.

Ethical aspects

This study was conducted according to the Resolution 466/12, from the Brazilian National Health Council and integrates the project "Inequalities in indicators of noncommunicable diseases, violence, and their risk factors in small geographic areas", approved by the Institutional Review Board from Universidade Federal de Minas Gerais, number 3258076.

Role of the funding source

Funders had no role in study design, data collection, data analysis, interpretation, and writing of the report.

Results

In the primary analysis, Table 1 shows that there was a 31% reduction in ASMR for CVD in Brazil from 2000–2002 to 2016–2018, however, this reduction was heterogeneously distributed across regions and across the municipalities within these regions, varying from −3% in the small municipalities in the North to −43% in the large municipalities in the South. In 2000–2002 ASMR for CVD were higher in the more developed regions and in the larger municipalities of all regions, except in the South. From 2000–2002 to 2016–2018, there was a decrease in CVD mortality rates across all regions and municipalities. However, because the reduction was smaller in the Northern and Northeastern regions, particularly for smaller municipalities, the ASMR for CVD became more homogeneous across regions and municipalities in Brazil in 2016–2018. The described changes are also depicted in Fig. 1, in which a visuospatial analysis reveals that the higher CVD mortality rates are further concentrated in part of the Northeast and North regions in the most recent period. Fig. 2 summarizes the main findings by depicting the percent change in ASMR per for CVD in Brazilian municipalities from triennials 2000–2002 to 2016–2018.

Regarding the correlation between ASMR for CVD in 2016–2018 and socioeconomic vulnerability, measured by the Brazilian Deprivation Index (BDI), a significant positive correlation between ASMR and higher BDI (ie. higher social vulnerability) was observed. Fig. 3 graphically plots CVD ASMR (Y axis) vs BDI (X axis), at the municipal level in Brazil, Spearman R = 0.44, $p < 0.001$.

Sex-disaggregated analysis (Table 2, Supplementary Figures S2 and S3) revealed higher mean ASMR for men in all regions, independent of the municipality's size and triennial. For men mean ASMR was 303, 244 and 218 per 100,000 in the three triennials, in chronological order, while for women mean ASMR was 223, 168, 147 per 100,000. In general, absolute reductions in ASMR along the triennials were higher for men (85 vs 76/100,000, in Brazil, for men and women, respectively), while relative reductions were higher for women (28 and 34%, in Brazil, for men and women, respectively). The exceptions are the small municipalities in the Centre-West, Northeast and North regions, which had greater absolute and relative reductions in women. Regarding the correlation between ASMR for CVD in 2016–2018 and socioeconomic vulnerability disaggregated by sex, similar, statistically significant associations were observed for women and men (Supplementary Figures S4 and S5).

For the secondary analysis, Supplementary Tables S1 and S2 reveal similar trends in ASMR reductions for Brazil and across regions and municipalities for ischemic heart disease and stroke, respectively. However, the reductions were more pronounced for stroke than ischemic heart disease across the country, particularly for smaller municipalities.

Region	Population size	2000–2002	CI 95% 2000–2002	2009–2011	CI 95% 2009–2011	2016–2018	CI 95% 2016–2018	Absolute change	Percent change
Center-West	<30,000	225	218–232	185	180–190	166	162–170	−59	−26
	30,000–300,000	261	253–269	205	199–210	182	178–186	−79	−30
	>300,000	253	246–260	190	185–194	158	154–161	−95	−38
Northeast	<30,000	213	211–216	202	199–204	194	192–196	−19	−9
	30,000–300,000	244	242–247	224	222–226	212	210–214	−33	−13
	>300,000	279	275–283	210	207–212	186	184–188	−93	−33
North	<30,000	180	174–186	170	165–176	175	170–180	−5	−3
	30,000–300,000	210	204–216	188	183–192	191	187–195	−19	−9
	>300,000	254	246–262	192	187–197	181	177–185	−73	−29
Southeast	<30,000	242	239–245	187	184–189	163	161–165	−79	−33
	30,000–300,000	280	277–283	205	203–207	176	174–177	−104	−37
	>300,000	280	278–282	201	200–203	174	173–176	−105	−38
South	<30,000	277	272–281	197	194–200	168	166–170	−109	−39
	30,000–300,000	290	285–294	210	207–213	174	172–177	−115	−40
	>300,000	261	255–266	179	175–182	148	146–150	−112	−43
Brazil		257	256–258	202	201–202	178	178–179	−79	−31

CI, confidence interval.

Table 1: **Age-standardized mortality rate per 100,000 inhabitants for cardiovascular diseases for each Brazilian region, stratified by the municipalities' population size, in three triennials (2000–2002, 2009–2011, and 2016–2018) and the absolute and relative variation among the triennials for both sexes.**

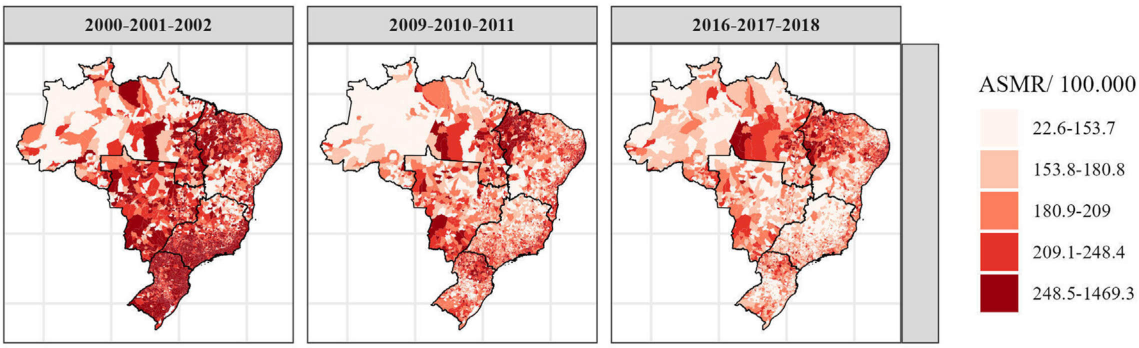

Fig. 1: Age-standardized mortality rates (ASMR) per 100,000 for cardiovascular diseases in Brazilian municipalities in three triennials, 2000–2002, 2009–2011, and 2016–2018.

Discussion

Our data, derived from the innovative estimates of the GBD study for Brazilian municipalities, show that in the first temporal series of the analysis (2000–2002), the CVD ASMR was higher in the municipalities from the most developed regions and larger municipalities in Brazil. In contrast, the estimates from 2016 to 2018 showed a different pattern, with higher ASMR in the least-developed Northern and Northeastern regions. In addition, there was a clear trend towards a lower percent reduction of ASMR in smaller municipalities, and a marked correlation between a smaller reduction in ASMR attributable to CVD and higher socioeconomic vulnerability, at the municipal level. This novel analysis provides deep insights into the temporal trends of CVD mortality in Brazil at the municipal level, revealing the inequities in health and social gains across municipalities. Understanding these disparities is important for public policy planning to address the burden of CVD in Brazil.

In this context, published data from specific regions in Brazil have shown patterns that resemble our findings. In Rio de Janeiro, administrative data from the Brazilian Ministry of Health depicted a regional decline in mortality from circulatory diseases preceded by an increase in the gross domestic product per capita, with a strong inverse correlation between these variables,[27] suggesting an impact of economic growth on CVD prevention and control. Also at the municipal level, a study in Brazilian capital cities depicted an inverse significant correlation between stroke mortality—a CVD event highly dependent on the efficiency of hypertension care cascades and access to healthcare[28]—and municipal human development indexes, evaluated by the United Nations Development Program, overall and within its individual components (income, longevity, and age).[29] A regional analysis of Brazilian federative units between 2000 and 2010, revealed an increase in municipal human development index (being >0.7 in over 50% of them), as well as in the country's supplementary health coverage. These variables—as surrogates for socioeconomic status—were inversely associated with mortality due to circulatory and cerebrovascular diseases between 2004 and 2013. Highlighting the time lapse between economic improvement and outcomes, mortality due to cerebrovascular diseases and hypertensive diseases in 2013 showed an inverse linear association with the municipal HDI in 2000, more than 10 years apart.[30] Similarly, at the national level, improvements in sociodemographic and social vulnerability indexes were associated with a reduction in ASMR from ischemic and cerebrovascular diseases (data from the national SIM).[31] However, these reductions occurred unevenly across states, with more pronounced declines in those with better social indicators.[31]

Previous discussions suggest that CVD exhibits a 'social cross-over', from greater risk in higher socioeconomic groups to lower socioeconomic groups, early during economic development. This is aligned with our data, in which CVD mortality was higher in the most developed regions and larger municipalities at the beginning of the temporal series. However, standardized state-level data from 62.5 million Brazilian adults comparing educational status with CVD mortality in 2010 showed that CVD ASMR ratio for women with less school-years (<8 years) compared to those more educated was higher in the least developed fifth of the states (3.75, 95% CI 3.29–4.28) in comparison with the better developed federative units (2.84, 95% CI 2.75–2.92, p-value for linear trend = 0.002), with similar associations across subtypes of CVD (ischemic heart disease and stroke) and robust to the extent of geographical unit.[32] Thus, existing evidence suggests that, during late economic transition (2010), low socioeconomic groups bore a higher risk of CVD mortality in all states, which was even more pronounced in the least developed ones, failing to support the "social crossover" hypothesis.

Our municipal level data provides more specific insights into the distribution of CVD mortality rates in

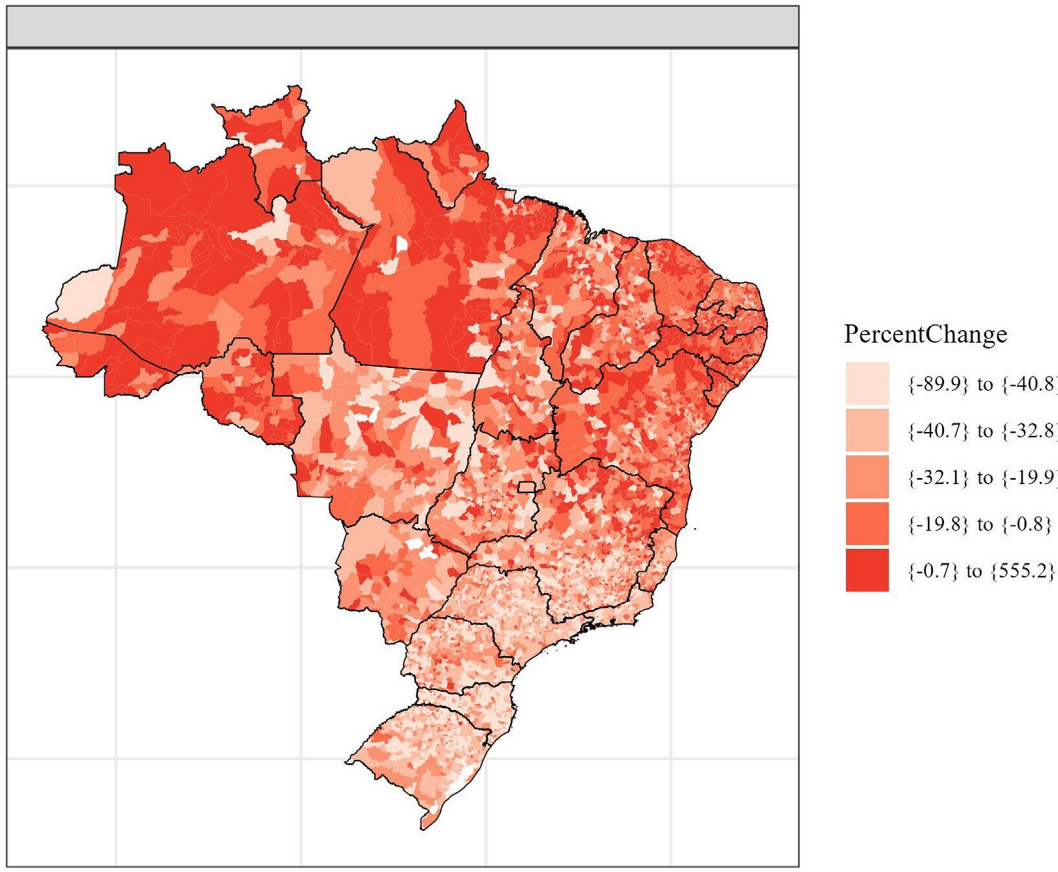

Fig. 2: Percent change in age-standardized mortality rates (ASMR) per 100,000 inhabitants for cardiovascular diseases in Brazilian municipalities from triennials 2016–2018 to 2000–2002.

Brazil, as previous studies showed a substantial variability of CVD mortality metrics at county and municipal levels.[33] Previous analyses, in specific populations, depicted higher CVD mortality following urbanization in Brazil through associated lifestyle and environmental changes.[34] Furthermore, it has been demonstrated that, during the development of urban areas, the time lapse between urbanization and the structuring of primary care services may result in higher CVD mortality, while wider access may later result in better outcomes.[35] Thus, as early stages of epidemiological transition usually coincides with rising rates of urbanization and consequently, better sanitation, nutrition and immunization the ongoing challenge of infectious diseases overlap with the increasing prevalence of NCD in developing municipalities.[6] Such regional observations and our more granular municipality-level data also resemble the findings of the pivotal PURE study, which investigated variations in CVD rates in 21 countries across 5 continents, and reported that CVD occurs more often in low-income (7.1 cases/1000 person-years) and middle-income (6.8/1000 person-years) compared to high-income countries (4.3/1000 person-years), and is the most common cause of deaths overall (40%) although accounting for only 23% of deaths in high-income (vs 41% in middle-income and 43% in low-income countries), despite the higher prevalence of risk factors.[36] Because this was a contemporary study, the social “crossover” has probably impacted the results.

As previously demonstrated from Brazilian data, and following global trends, socioeconomic improvements usually precede the decline in CVD mortality globally and at regional and municipal levels.[37,38] This multifactorial association is evident for various outcomes, such as stroke, myocardial infarction and heart failure,[39] at different income levels. Following this initial steep decline, with a strict correlation with sociodemographic indexes, there is a deceleration in this trend over time, when economic conditions stabilize, and following the implementation of strategies to improve access to health education, prevention, promotion and treatment. Municipalities with delayed and slower socioeconomic development, on the other hand, benefit from the socioeconomic improvements that previously occurred in

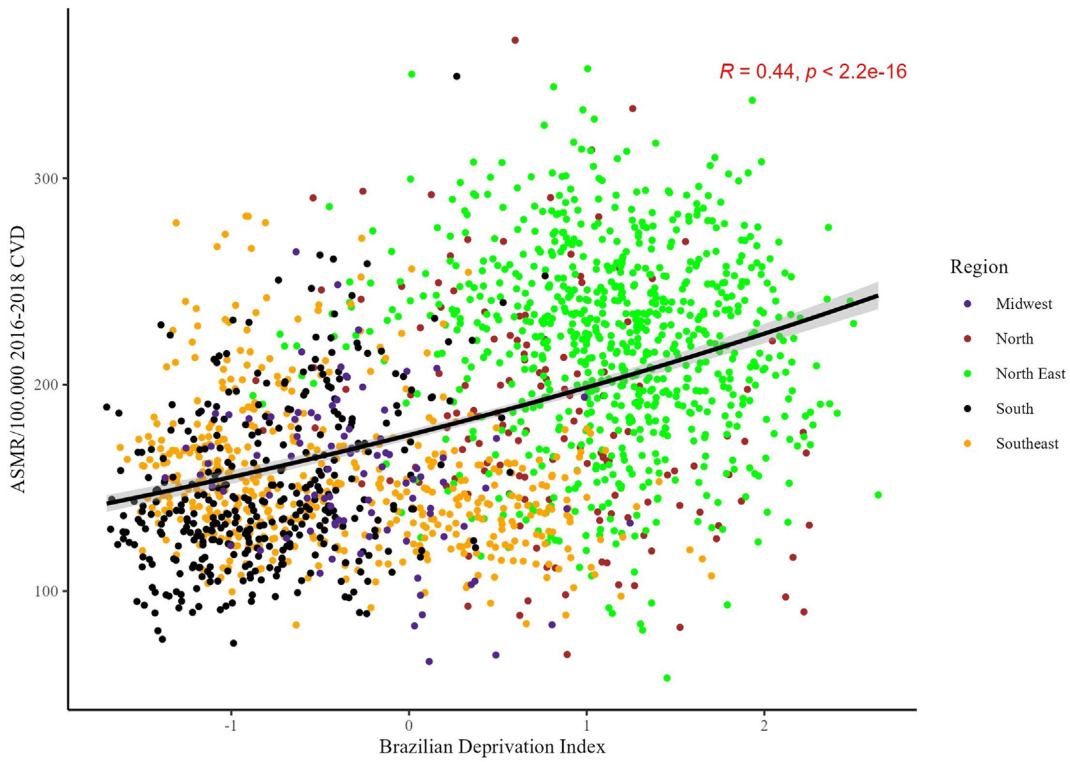

Fig. 3: Correlation between cardiovascular diseases age-standardized mortality rates (ASMR) per 100,000 inhabitants in 2016–2018 and the Brazilian Deprivation Index (BDI).

surrounding regions where the reversal in the CVD mortality trend evolved early.

In Brazil and other Latin American countries, the size of the cities is directly associated with the robustness of health infrastructure (measured by the number of hospital beds and intensive care units, and the density of health professionals) and with the availability of basic services, including primary care and immunization programs.[40] Previous data revealed that lower access to healthcare plays a role in adverse CVD outcomes for individuals in LMIC. Additionally, those with lower education levels in these countries showed higher risk of CVD events, even when they present with better risk factor profiles.[41] Conditions such as cerebrovascular disease and acute coronary syndromes are especially impacted by economic development and infrastructure, as urgent and time-sensitive approaches deeply impact outcomes.[42] Thus, more than numerically highlighting the aforementioned associations, out data underscores the need for reinforcing cardiovascular care, at different levels, in vulnerable Brazilian municipalities. This is especially crucial in municipalities where urbanization is still incipient, and in areas with worse socioeconomic indicators. An individualized approach, taking into consideration regional and municipal characteristics, and prioritizing health promotion, education and prevention, may have a significant impact on CVD mortality. This becomes particularly important as Brazil's age pyramid experiences a dramatic shift, with a rapidly ageing population.

Limitations

Our study has several limitations, especially related to data sources and the GBD methodology. At first, the modelling of GBD estimates is dependent on data completeness and quality. Although Brazil provides overall good quality data for the IHME, the level of detail and completeness—including for qualified mortality data—may vary according to federal unit and particularly for smaller municipalities. This analysis, however, considered primary data from the Mortality Information System applied to the GBD methodology, partially overcoming this limitation. Second, the Brazilian Deprivation Index, used as a surrogate for socioeconomic status, is a local measure and not an individual metric, and may not reflect the circumstances of all citizens within an area, as poor-rated areas are not just home to poor individuals and not all poor individuals live in deprived areas.[43] However, this issue tends to be less important in smaller geographic units, at the municipality-level, as areas become more homogenous in terms of deprivation. Third, other metrics related to infrastructure and access to healthcare, such as the

	Region	Population size	2000–2002	CI 95% 2000–2002	2009–2011	CI 95% 2009–2011	2016–2018	CI 95% 2016–2018	Absolute change	Percent change
Men	Center-West	<30,000	253	248–258	212	208–216	196	192–199	−58	−23
		30,000–300,000	306	298–314	242	237–247	217	213–222	−89	−29
		>300,000	297	290–304	233	228–237	196	192–200	−101	−34
	Northeast	<30,000	249	247–251	242	240–243	232	230–233	−17	−7
		30,000–300,000	295	292–298	277	274–280	259	257–261	−36	−12
		>300,000	354	350–359	276	272–279	241	239–244	−113	−32
	North	<30,000	214	210–219	197	193–200	207	203–210	−8	−4
		30,000–300,000	259	253–265	230	225–234	241	237–245	−18	−7
		>300,000	323	314–331	249	243–255	245	240–250	−78	−24
	Southeast	<30,000	288	296–291	220	218–222	194	192–196	−94	−33
		30,000–300,000	334	332–337	250	248–252	216	215–218	−118	−35
		>300,000	345	342–348	252	250–254	219	218–221	−126	−36
	South	<30,000	324	320–327	231	229–234	198	196–201	−125	−39
		30,000–300,000	334	329–338	245	242–248	206	204–208	−128	−38
		>300,000	322	315–329	223	219–227	185	182–188	−138	−43
	Brazil		303	303–304	244	244–245	218	217–218	−85	−28
Women	Center-West	<30,000	214	209–219	167	163–170	143	141–146	−71	−33
		30,000–300,000	231	224–237	176	172–180	151	148–154	−80	−35
		>300,000	210	205–216	152	148–155	125	123–127	−85	−41
	Northeast	<30,000	203	201–205	176	174–177	170	169–171	−33	−16
		30,000–300,000	218	215–220	186	184–188	179	177–180	−39	−18
		>300,000	235	232–238	167	165–168	147	145–148	−88	−38
	North	<30,000	196	191–200	150	147–154	148	144–151	−48	−25
		30,000–300,000	188	183–193	161	157–164	151	148–154	−37	−20
		>300,000	208	202–214	150	147–154	133	129–136	−76	−36
	Southeast	<30,000	214	211–216	162	161–164	141	140–142	−73	−34
		30,000–300,000	236	235–238	171	170–172	146	145–147	−91	−38
		>300,000	234	232–236	163	162–164	140	139–141	−94	−40
	South	<30,000	265	262–268	167	165–168	150	148–151	−115	−44
		30,000–300,000	244	241–247	182	180–184	140	139–142	−104	−43
		>300,000	218	214–223	172	170–174	121	119–123	−98	−45
	Brazil		223	223–224	168	168–169	147	147–148	−76	−34

CI, confidence interval.

Table 2: **Age-standardized mortality rate per 100,000 inhabitants for cardiovascular diseases for each Brazilian region, stratified by the municipalities' population size, in three triennials (2000–2002, 2009–2011, and 2016–2018) and the absolute and relative variation among the triennials, for men and women.**

number of hospital beds or intensive care units and the number of physicians and nurses per inhabitant, were not considered for our analysis. Despite that, the population size and sociodemographic profile of the municipalities—the key variable of interest—can be considered surrogates for healthcare access in the Brazilian context. Finally, the sociocultural, demographic, economic and ethnic heterogeneity of the cities—influencing lifestyle habits, health behaviours, awareness and control of risk factors– may not be adequately captured by the analytical models applied. Lastly, our study uses GBD estimates from the last GBD 2019 version, which includes SIM mortality data until 2018, because municipal level data has not been updated in the most recent GBD 2021 version.

Despite these limitations, our study presents an innovative approach to assess the variation of CVD mortality according to the size of Brazilian municipalities, and a more detailed and granular way to explore the impact of urbanization and its effects on cardiovascular health over time. Furthermore, a more detailed and definite association between socioeconomic indexes and CVD mortality was shown at the municipal level, reinforcing previous observations. These analyses applied the robust, comprehensive and validated GBD methodology for producing comparable metrics between municipalities, taking advantage of robust primary data from the Brazilian SIM database.

Conclusions

The reduction in CVD mortality in Brazil was lower in the municipalities within the most vulnerable regions and those with smaller populations. Public policies to promote cardiovascular health and address CVD tailored to these smaller municipalities, particularly those in the least developed regions of Brazil, must be considered a priority.

Contributors

L.C.C.B, A.L.P.R, D.C.M and M.N were responsible for conceptualization and methodology. L.C.C.B, A.L.C, B.P.A.G, J.B.S, B.R.N and R.T wrote the original draft of the manuscript. J.B.S, B.R.N and R.T were responsible for the statistical analysis. L.C.C.B, A.L.P.R, D.C.M and M.N revised and edited the manuscript.

Data sharing statement

The data that support the study's findings can be made available to researchers upon reasonable request to the corresponding author.

Editor note

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Declaration of interests

The authors declared no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2025.101106.

References

1 Weintraub WS. The economic burden of illness. *JAMA Netw Open*. 2023;6:e232663.
2 Oliveira GMM, Brant LCC, Polanczyk CA, et al. Estatística cardiovascular – brasil 2023. *Arq Bras Cardiol*. 2024;121:e20240079.
3 Oliveira GMM, Brant LCC, Polanczyk CA, et al. Estatística cardiovascular – brasil 2021. *Arq Bras Cardiol*. 2022;118:115–373.
4 Schmidt MI, Duncan BB, e Silva GA, et al. Chronic non-communicable diseases in Brazil: burden and current challenges. *Lancet*. 2011;377:1949–1961.
5 Yusuf S, Reddy S, Ôunpuu S, Anand S. Global burden of cardiovascular diseases: Part I: general considerations, the epidemiologic transition, risk factors, and impact of urbanization. *Circulation*. 2001;104:2746–2753.
6 Ribeiro ALP, Duncan BB, Brant LCC, Lotufo PA, Mill JG, Barreto SM. Cardiovascular health in Brazil: trends and perspectives: trends and perspectives. *Circulation*. 2016;133:422–433.
7 Brant LCC, Nascimento BR, Passos VMA, et al. Variações e diferenciais da mortalidade por doença cardiovascular no Brasil e em seus estados, em 1990 e 2015: estimativas do Estudo Carga Global de Doença. *Rev Bras Epidemiol*. 2017;20Suppl 01:116–128.
8 Brant LCC, Nascimento BR, Veloso GA, et al. Burden of cardiovascular diseases attributable to risk factors in Brazil: data from the "Global Burden of Disease 2019" study. *Rev Soc Bras Med Trop*. 2022;55:e0263.
9 Regional divisions of Brazil n.d. https://www.ibge.gov.br/en/geosciences/territorial-organization/regional-division/21536-regional-divisions-of-brazil.html?edicao=25384. Accessed September 18, 2024.
10 de Sousa Filho JF, Dos Santos GF, Andrade RFS, et al. Inequality and income segregation in Brazilian cities: a nationwide analysis. *SN Soc Sci*. 2022;2:191.
11 Paim J, Travassos C, Almeida C, Bahia L, Macinko J. The Brazilian health system: history, advances, and challenges. *Lancet*. 2011;377:1778–1797.
12 Castro MC, Massuda A, Almeida G, et al. Brazil's unified health system: the first 30 years and prospects for the future. *Lancet*. 2019;394:345–356.
13 Malta DC, de Azeredo Passos VM, Machado ÍE, Marinho Souza MF, Ribeiro ALP. The GBD Brazil network: better information for health policy decision-making in Brazil. *Popul Health Metr*. 2020;18:23.
14 GBD 2016 Brazil Collaborators. Burden of disease in Brazil, 1990-2016: a systematic subnational analysis for the Global Burden of Disease Study 2016. *Lancet*. 2018;392:760–775.
15 GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*. 2020;396:1204–1222.
16 Johnson SC, Cunningham M, Dippenaar IN, et al. Public health utility of cause of death data: applying empirical algorithms to improve data quality. *BMC Med Inform Decis Mak*. 2021;21:175.
17 DATASUS n.d. https://datasus.saude.gov.br/populacao-residente/. Accessed September 18, 2024.
18 Teixeira RA, Ishitani LH, França E, Pinheiro PC, Lobato MM, Malta DC. Mortality due to garbage codes in Brazilian municipalities: differences in rate estimates by the direct and Bayesian methods from 2015 to 2017. *Rev Bras Epidemiol*. 2021;24:e210003.
19 Allik M, Ramos D, Agranonik M, et al. Small-area deprivation measure for Brazil: data documentation. https://doi.org/10.5525/GLA.RESEARCHDATA.980; 2020.
20 PUBLICAÇÕES n.d. https://cidacs.bahia.fiocruz.br/ibp/publicacao/. Accessed September 18, 2024.
21 Cristiano Lehrer-ybadoo.com, Sistema de Informação sobre Mortalidade (SIM) - Dados Abertos - Centrais de Conteúdos - DAENT - SVSA/MS n.d. https://svs.aids.gov.br/daent/centrais-de-conteudos/dados-abertos/sim/. Accessed September 18, 2024.
22 ICD-10 Version:2019 n.d. https://icd.who.int/browse10/2019/en. Accessed September 18, 2024.
23 Part II. Applying comparability ratios. A guide to state implementation of icd-10 for mortality n.d. https://www.cdc.gov/nchs/data/statab/Document-for-the-States.pdf. Accessed September 18, 2024.
24 Anselin L, Syabri I, Kho Y. *GeoDa: an introduction to spatial data analysis. Handbook of applied spatial analysis*. Berlin, Heidelberg: Springer Berlin Heidelberg; 2010:73–89.
25 Johnston WM. *Causal models in the social sciences*. 2nd ed. Somerset, NJ: AldineTransaction; 1985.
26 Verzani J. *Getting started with RStudio*. Sebastopol, CA: O'Reilly Media; 2011.
27 Soares GP, Klein CH, Silva NA, Oliveira GMM. Evolution of mortality from diseases of the circulatory system and of gross domestic product per Capita in the Rio de Janeiro state municipalities. *Int J Cardiovasc Sci*. 2018. https://doi.org/10.5935/2359-4802.20180003.
28 Martinez R, Soliz P, Campbell NRC, Lackland DT, Whelton PK, Ordunez P. Association between population hypertension control and ischemic heart disease and stroke mortality in 36 countries of the Americas, 1990-2019: an ecological study. *Rev Panam Salud Publica*. 2022;46:e143.
29 de Melo Lucena DM, Dos Santos Figueiredo FW, de Alcantara Sousa LV, et al. Correlation between municipal human development index and stroke mortality: a study of Brazilian capitals. *BMC Res Notes*. 2018;11:540.
30 Villela PB, Klein CH, de Oliveira GMM. Socioeconomic factors and mortality due to cerebrovascular and hypertensive disease in Brazil. *Rev Port Cardiol*. 2019;38:205–212.
31 Bichara JL, Bastos LA, Villela PB, Oliveira GMM. Socioeconomic indicators and mortality from ischemic heart disease and cerebrovascular disease in Brazil from 2000 to 2019. *Arq Bras Cardiol*. 2023;120:e20220832.
32 Mallinson PAC, Luhar S, Williamson E, Barreto ML, Kinra S. Socioeconomic position and cardiovascular mortality in 63 million adults from Brazil. *Heart*. 2021;107:822–827.

33 Spoer BR, Feldman JM, Gofine ML, et al. Health and health determinant metrics for cities: a comparison of county and city-level data. *Prev Chronic Dis*. 2020;17:E137.
34 Armstrong ADC, Ladeia AMT, Marques J, et al. Urbanization is associated with increased trends in cardiovascular mortality among indigenous populations: the PAI study. *Arq Bras Cardiol*. 2018;110:240–245.
35 Hone T, Saraceni V, Medina Coeli C, et al. Primary healthcare expansion and mortality in Brazil's urban poor: a cohort analysis of 1.2 million adults. *PLoS Med*. 2020;17:e1003357.
36 Dagenais GR, Leong DP, Rangarajan S, et al. Variations in common diseases, hospital admissions, and deaths in middle-aged adults in 21 countries from five continents (PURE): a prospective cohort study. *Lancet*. 2020;395:785–794.
37 Soares GP, Klein CH, Silva NA, Oliveira GMM. Progression of mortality due to diseases of the circulatory system and Human Development Index in Rio de Janeiro municipalities. *Arq Bras Cardiol*. 2016;107:314–322.
38 Soares GP, Brum JD, Oliveira GM, Klein CH, Silva NA. Mortalidade por todas as causas e por doenças cardiovasculares em três estados do Brasil, 1980 a 2006. *Rev Panam Salud Publica*. 2010;28:258–266.
39 Schultz WM, Kelli HM, Lisko JC, et al. Socioeconomic status and cardiovascular outcomes: challenges and interventions: challenges and interventions. *Circulation*. 2018;137:2166–2178.
40 Sousa Júnior WC, Gonçalves DA, Cruz DB. COVID-19: local/regional inequalities and impacts over critical healthcare infrastructure in Brazil. *Ambiente Soc*. 2020;23. https://doi.org/10.1590/1809-4422asoc20200114vu2020l3id.
41 Rosengren A, Smyth A, Rangarajan S, et al. Socioeconomic status and risk of cardiovascular disease in 20 low-income, middle-income, and high-income countries: the Prospective Urban Rural Epidemiologic (PURE) study. *Lancet Glob Health*. 2019;7:e748–e760.
42 Moledina A, Tang KL. Socioeconomic status, mortality, and access to cardiac services after acute myocardial infarction in Canada: a systematic review and meta-analysis. *CJC Open*. 2021;3:950–964.
43 Ichihara MYT, Ramos D, Rebouças P, et al. Area deprivation measures used in Brazil: a scoping review: a scoping review. *Rev Saude Publica*. 2018;52:83.