ORIGINAL RESEARCH

10.63923/smhs.2026.155

Summa Medical and Health Sciences
2026; v. 2: e155

Cardiovascular Mortality and Health Service Structure in Municipalities of Espírito Santo with Different Degrees of Urbanization

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Abstract

Territorial inequalities in the distribution of healthcare services may influence cardiovascular mortality by affecting the timeliness, quality, infrastructure, and availability of healthcare personnel for care following a cardiovascular event. This study aimed to evaluate the association between healthcare service infrastructure, degree of urbanization, and cardiovascular mortality across municipalities in Espírito Santo, Brazil. A longitudinal ecological study was conducted using data from the state's 78 municipalities between 2008 and 2025, obtained from the Mortality Information System, the National Registry of Healthcare Facilities, and the Brazilian Institute of Geography and Statistics. A Healthcare Infrastructure Index was developed based on the availability of specialized care beds, inpatient beds, and healthcare professionals per 100,000 inhabitants. Descriptive analyses, analysis of variance, and generalized linear models adjusted for population size and the proportion of older adults were employed. The main model covered the period from 2008 to 2024, with a complementary analysis from 2021 to 2024 to confirm the patterns identified in the longer time-series model. The annual number of cardiovascular deaths increased from 1,200 in 2008 to 1,862 in 2025. Compared with urban municipalities, adjacent rural municipalities had an adjusted rate ratio of 2.17 (95% CI: 2.08–2.26), while adjacent intermediate municipalities had an adjusted rate ratio of 1.79 (95% CI: 1.72–1.87). The proportion of older adults was positively associated with mortality (RR = 1.029; 95% CI: 1.024–1.034), whereas the Healthcare Infrastructure Index showed an inverse association (RR = 0.977; 95% CI: 0.972–0.982). These associations persisted in the complementary

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analysis restricted to more recent years, for which public data records potentially had greater completeness. In conclusion, lower availability of healthcare resources and location in rural and intermediate municipalities were associated with higher cardiovascular mortality rates, reinforcing the need to reduce territorial inequalities in the organization of healthcare delivery networks and access to healthcare.

KEYWORDS: Cardiovascular Diseases; Mortality; Health Services; Residence Characteristics; Ecological Studies.

Introduction

The World Health Organization (WHO) identifies cardiovascular disease (CVD) as the leading cause of mortality worldwide (World Health Organization, 2025). CVD also represents a substantial healthcare cost, primarily due to the complex management of acute cardiovascular events (Stevens et al., 2018). The pathophysiological process underlying CVD involves the rupture or erosion of an atherosclerotic plaque, leading to the formation of a local thrombus that occludes the vessel, obstructs blood flow, and may result in potentially fatal acute events, such as acute myocardial infarction (AMI) and stroke. The main risk factors include hypertension, dyslipidemia, smoking, and diabetes (Lloyd-Jones et al., 2022). The promotion of cardiovascular health involves adopting healthy dietary habits, including the consumption of fruits, vegetables, whole grains, plant-based proteins, and fish, while reducing the intake of sodium, added sugars, and saturated fats; engaging in regular physical activity; smoking cessation; and maintaining adequate sleep (Lichtenstein et al., 2021). When these behavioral measures are insufficient to achieve therapeutic targets, pharmacological interventions are required to control risk factors (Arnett et al., 2019).

In Brazil, CVD accounts for nearly one-third of all deaths (Oliveira et al., 2024), highlighting the importance of implementing prevention and

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health promotion strategies by expanding population access to Primary Health Care (PHC). Strengthening primary care for the Brazilian population plays an important role in the management and follow-up of patients with CVD and has been associated with reduced mortality in municipalities with greater PHC coverage (Rasella et al., 2014).

A considerable proportion of the cardiovascular disease burden is potentially preventable. The PURE study, which followed 155,722 participants from 21 countries across different income levels, attributed more than 70% of cardiovascular disease cases to a small set of modifiable risk factors, with hypertension alone accounting for slightly more than one-fifth of this proportion (Yusuf et al., 2020). Similarly, an individual-participant data analysis involving 1,518,028 participants from 112 cohorts across 34 countries estimated that five factors: body mass index, systolic blood pressure, non-HDL cholesterol, smoking, and diabetes accounted for 57.2% and 52.6% of incident cardiovascular disease cases among women and men, respectively, and for 22.2% and 19.1% of all-cause deaths (Magnussen et al., 2023). In Brazil, declining smoking rates have been accompanied by increases in excess body weight, unhealthy dietary habits, and insufficient adherence to physical activity, alongside a high prevalence of hypertension and an increasingly prevalent burden of diabetes (Ribeiro et al., 2016). In this context, the Cardiovascular Prevention Guideline of the Brazilian Society of Cardiology emphasizes that reducing morbidity and mortality depends on the identification and sustained control of these factors through coordinated actions involving primary and secondary prevention, promotion of healthy lifestyles, and access to appropriate treatment for cardiovascular events (Précoma et al., 2019). Continuity of care plays a central role in this process: a systematic review found that 18 of the 22 included studies associated greater continuity of medical care with significant reductions in mortality (Pereira Gray et al., 2018). Prevention

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and treatment are therefore complementary. In the United States, approximately 44% of the decline in coronary heart disease mortality between 1980 and 2000 was attributed to reductions in risk factors, while 47% was attributed to evidence-based therapies (Ford et al., 2007). Furthermore, among patients with ST-segment elevation myocardial infarction treated with primary percutaneous coronary intervention, each 30-minute delay was associated with a relative risk of death at one year of 1.075 (De Luca et al., 2004). Similarly, the Grampian Region Early Anistreplase Trial (Rawles et al., 1997) reinforces the importance of treatment response time in acute myocardial infarction, reporting that each minute without reperfusion therapy reduces a patient's life expectancy by 11 days. Thus, beyond individual exposure to risk factors, cardiovascular mortality also reflects the capacity of healthcare systems to ensure early diagnosis, longitudinal follow-up, and timely responses to acute complications. Nevertheless, investigations examining how multiple dimensions of healthcare access, including primary care coverage, availability of healthcare professionals, hospital capacity, and access to specialized cardiovascular care, operate simultaneously at the municipal level remain scarce, particularly in the state of Espírito Santo.

This study aims to evaluate the association between municipal indicators of healthcare access and cardiovascular mortality across municipalities in Espírito Santo between 2008 and 2025, based on the hypothesis that greater coverage of these municipal indicators is associated with lower cardiovascular mortality by facilitating improved prevention, diagnosis, and management of hypertension and diabetes, treatment adherence, and timely patient referral.

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Methods

To assess healthcare access and cardiovascular mortality, this study analyzed data from January 2008 to December 2025, covering all 78 municipalities in the state of Espírito Santo, Brazil. The unit of analysis was the municipality-month, totaling 16,848 observations over the 17-year period. The variables included epidemiological indicators of cardiovascular mortality, demographic variables related to population size and age composition, and indicators of primary healthcare capacity, including healthcare infrastructure and human resources.

Cardiovascular mortality data were obtained from the Mortality Information System (SIM), made available by the Department of Informatics of the Brazilian Unified Health System (DATASUS) (Brasil, 2026). Data on population size and the proportion of individuals aged 60 years and older were obtained from the Brazilian Institute of Geography and Statistics (IBGE, 2023) and DATASUS, whereas hospital infrastructure indicators, represented by specialized care beds and inpatient beds, as well as healthcare workforce data, were obtained from the National Registry of Healthcare Facilities (CNES) (Brasil, 2026). The "human resources" variable was defined as the number of professionals in the following categories: general surgeons, general practitioners, nurses, Family Health Strategy nurses, Family Health Strategy physicians, family and community physicians, interventional cardiologists, cardiologists, cardiovascular surgeons, and vascular surgeons. Municipalities were classified according to the IBGE rural-urban typology into urban, adjacent intermediate, and adjacent rural categories, allowing comparisons across different areas and their potential associations with cardiovascular mortality. Statistical analyses were performed using Jamovi software, adopting a significance level of $p < 0.05$.

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The interpretation of results considered the magnitude and direction of associations, as well as their practical implications for public health.

The cardiovascular mortality rate per 100,000 inhabitants was calculated by dividing the number of deaths by the corresponding municipal population and multiplying by 100,000. The proportion of individuals aged 60 years and older was calculated by dividing the population in this age group by the total municipal population and multiplying by 100. This proportion was used as a continuous quantitative variable to partially control for differences in age composition across municipalities. To assess the availability of healthcare infrastructure while avoiding data collinearity, a Healthcare Infrastructure Index (HII) was developed, comprising indicators of specialized care beds, inpatient beds, and healthcare human resources, expressed per 100,000 inhabitants. The three indicators underwent natural logarithmic transformation [$\ln(x + 1)$] to reduce distributional skewness and allow the inclusion of raw values equal to zero. The index was defined as the arithmetic mean of the three transformed indicators, assigning equal weight to each component. The HII was treated as a continuous quantitative variable, with higher values indicating greater availability of healthcare resources for primary healthcare.

To characterize the distribution of healthcare resources across municipalities and determine whether infrastructure availability differed significantly according to rural-urban typology, a one-way analysis of variance (ANOVA) was performed. Healthcare indicators (specialized care beds, inpatient beds, and human resources) were compared across urban, adjacent intermediate, and adjacent rural municipalities. When the overall ANOVA indicated statistical significance ($p < 0.05$), Tukey's post hoc test was applied for pairwise comparisons.

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To evaluate the association between cardiovascular mortality and the effects of the proportion of older adults and healthcare infrastructure, negative binomial regression was performed using generalized linear models (GLMs) with a logarithmic link function. The year 2025 was excluded from the GLM analysis because of incomplete municipal population data for individuals aged 60 years and older. Model adequacy was assessed using the Akaike information criterion (AIC), Bayesian information criterion (BIC), and residual dispersion measures, considering the discrete nature of the dependent variable, represented by monthly death counts, and data overdispersion, characterized by variance exceeding the mean. In the multivariable model, the monthly number of cardiovascular deaths was considered the dependent variable, while the municipal percentage of individuals aged 60 years and older and the Healthcare Infrastructure Index (HII) were included as continuous quantitative independent variables. Rural-urban typology was included as a categorical independent variable, with urban municipalities serving as the reference category for territorial comparisons. The natural logarithm of the municipal population was incorporated as an offset term, allowing effect estimates for cardiovascular deaths to be adjusted for differences in population size across municipalities. The estimated coefficients were exponentiated and presented as adjusted mortality rate ratios, together with their respective 95% confidence intervals and p-values, allowing the direction and magnitude of the observed associations to be identified while controlling for the effects of the other variables. Additionally, a complementary GLM analysis was performed, restricted to the period from January 2021 to December 2024, during which the annual number of deaths exhibited a more stable temporal pattern at the higher levels of the historical series, using the same model specification as the main analysis. This additional analysis aimed to assess the consistency of the associations identified in the main study period, considering that access to healthcare services and the quantification of cardiovascular

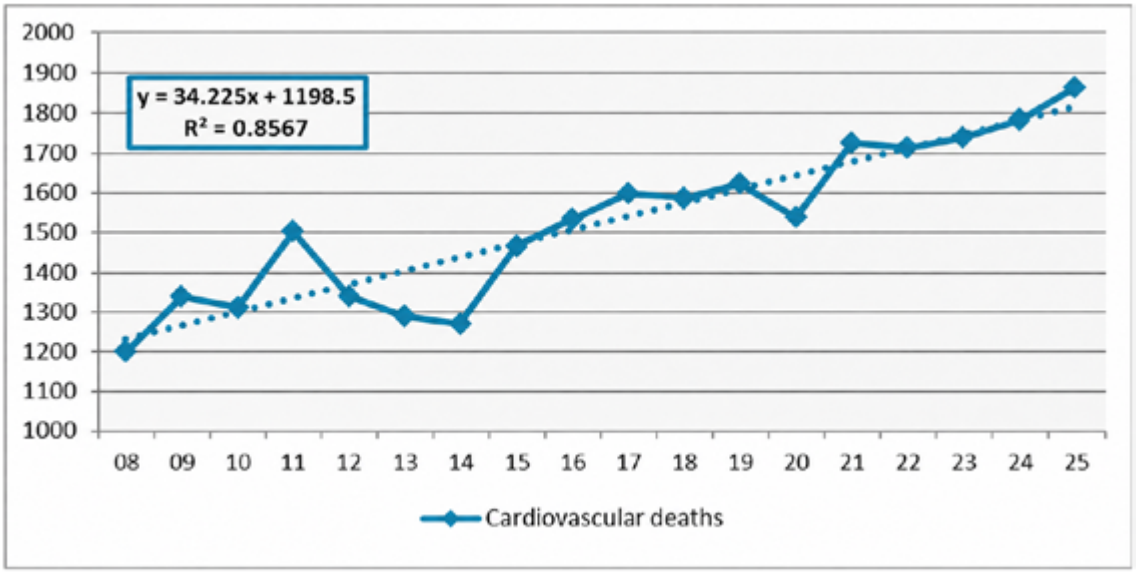
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outcomes may vary over time, including due to underreporting of cases, which tends to be more prevalent at the beginning of the historical series, when reporting and recording systems may not yet be fully optimized.

Results

In the descriptive time series, the annual number of cardiovascular deaths increased from 1,200 in 2008 to 1,862 in 2025, the year with the highest recorded number of deaths. Despite temporal fluctuations, the trend line showed an upward trajectory, with a slope coefficient of 34.22 and an explanatory power of 85.67% for the observed variability **(Figure 1).**

Figure 1. Total number of cardiovascular deaths in the state of Espírito Santo between 2008 and 2025, represented by the solid blue line, with the dotted line indicating the trend.



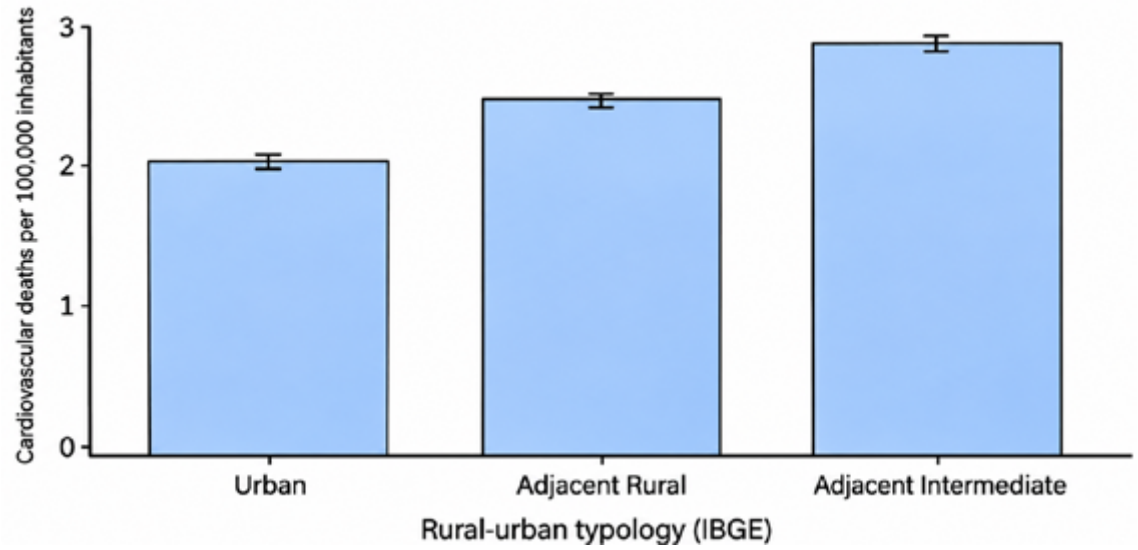
Descriptive comparisons revealed differences among the three urbanization categories. Urban municipalities accounted for the highest absolute numbers of cardiovascular deaths but had the lowest mortality rates per 100,000 inhabitants. In contrast, adjacent intermediate municipalities had

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the highest mean mortality rates per 100,000 inhabitants, with statistically significant differences among the three categories ($p < 0.05$) **(Figure 2).**

The distribution of healthcare resources also varied across groups. In absolute terms, urban municipalities had greater availability of specialized care beds, inpatient beds, and healthcare personnel. After adjusting for municipal population size, urban municipalities continued to show higher mean availability of specialized care beds and healthcare personnel than the other categories. However, inpatient bed availability per 100,000 inhabitants was comparable between urban and adjacent intermediate municipalities, with both categories showing significantly higher values than rural municipalities **(Figure 3).** Urban municipalities also had the highest absolute number of individuals aged 60 years and older, but the proportion of this age group relative to the total population was significantly higher in rural municipalities than in urban and adjacent intermediate municipalities **(Figure 4).**

Figure 2. Mean and standard error of monthly cardiovascular deaths per 100,000 inhabitants across different urbanization categories (Urban, Adjacent Rural, and Adjacent Intermediate), as defined by the IBGE for the classification of municipalities in the state of Espírito Santo.

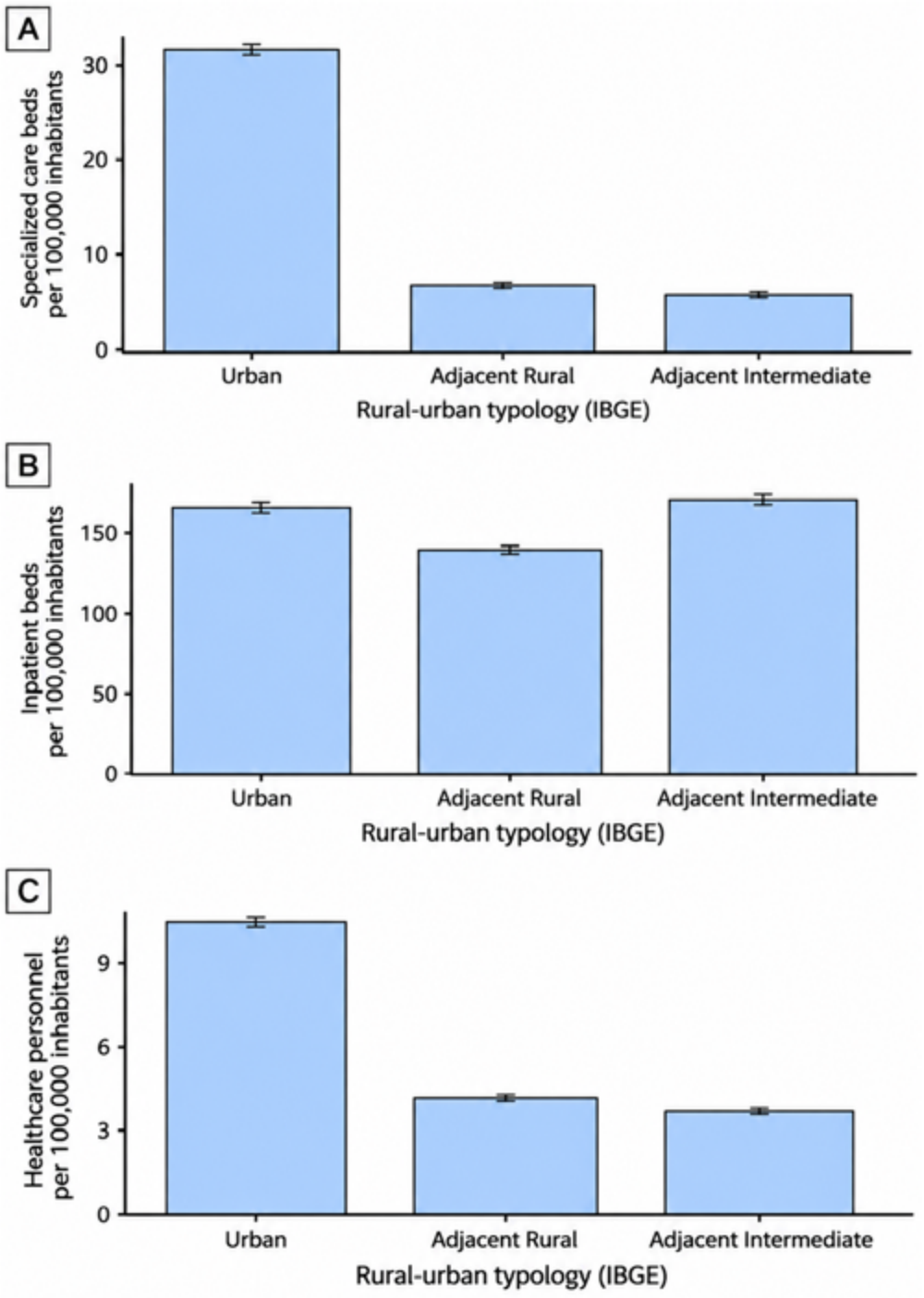


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The main model explaining the distribution of cardiovascular mortality data from 2008 to 2024 yielded $R^2 = 0.370$, adjusted $R^2 = 0.370$, and an overall χ^2 statistic of 8,313 ($p < 0.001$). Compared with urban municipalities, the adjusted rate ratio was 2.17 (95% CI: 2.08–2.26; $p < 0.001$) for adjacent rural municipalities and 1.79 (95% CI: 1.72–1.87; $p < 0.001$) for adjacent intermediate municipalities. The proportion of the population aged 60 years and older was positively associated with the outcome (RR = 1.029; 95% CI: 1.024–1.034; $p < 0.001$), whereas the Healthcare Infrastructure Index showed an inverse association (RR = 0.977; 95% CI: 0.972–0.982; $p < 0.001$). The same pattern of associations was observed in the model restricted to data from 2021 to 2024, indicating the consistency of the findings in a more recent period, despite potential underreporting bias in the early years of the historical series. The control model yielded $R^2 = 0.363$, adjusted $R^2 = 0.361$, and an overall χ^2 statistic of 2,408 ($p < 0.001$). Compared with urban municipalities, adjacent rural municipalities had an RR of 2.13 (95% CI: 1.97–2.30; $p < 0.001$), whereas adjacent intermediate municipalities had an RR of 1.62 (95% CI: 1.49–1.76; $p < 0.001$). The proportion of older adults remained positively associated with mortality (RR = 1.024; 95% CI: 1.013–1.034; $p < 0.001$), while the Healthcare Infrastructure Index maintained an inverse association (RR = 0.981; 95% CI: 0.973–0.991; $p < 0.001$) **(Figure 5).**

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Figure 3. Mean values and standard errors of the availability of specialized care beds (A), inpatient beds (B), and healthcare personnel (C) per 100,000 inhabitants across municipalities, according to the different urbanization categories (Urban, Adjacent Rural, and Adjacent Intermediate) defined by the IBGE for the classification of municipalities in the state of Espírito Santo.



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Figure 4. Mean and standard error of the percentage of the population aged 60 years and older across different urbanization categories (Urban, Adjacent Rural, and Adjacent Intermediate), as defined by the IBGE for the classification of municipalities in the state of Espírito Santo.

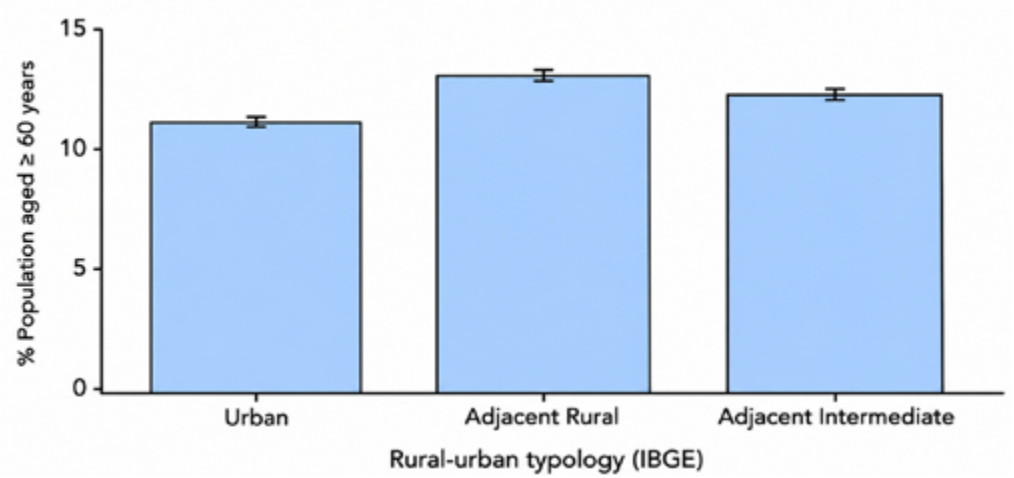
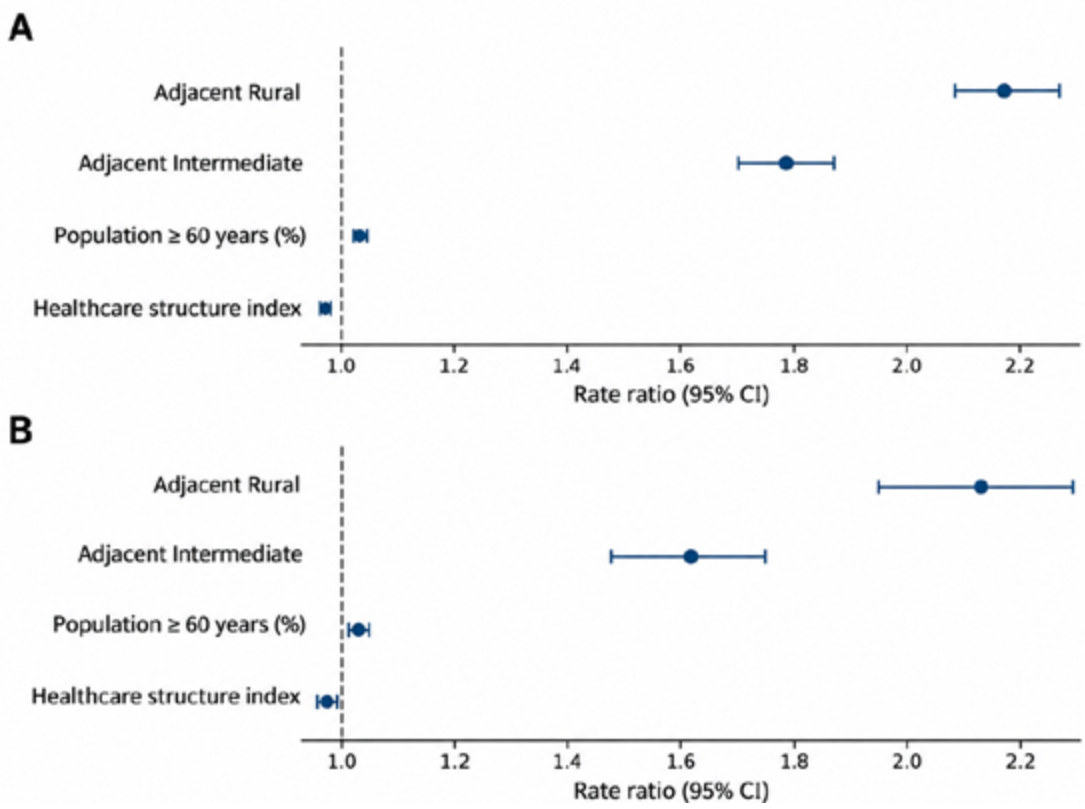


Figure 5. Adjusted rate ratios and respective 95% confidence intervals (95% CI) for factors associated with cardiovascular mortality in the municipalities of Espírito Santo, estimated using generalized linear models (GLM). (A) Main model, considering the period from 2008 to 2024. (B) Control model, considering the period from 2021 to 2024. The urban category was used as the reference for the rural-urban typology.



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Discussion

The hypothesis that greater primary healthcare coverage for cardiovascular care in the municipalities of Espírito Santo is associated with lower cardiovascular mortality was confirmed, even after controlling for the effects of population size and the proportion of individuals aged 60 years and older, an age group considered at increased risk for this condition.

According to the main model, after adjusting for total population, population aging, and healthcare infrastructure, urban municipalities in the state of Espírito Santo had a lower risk of cardiovascular death than adjacent rural and intermediate municipalities. This pattern persisted in the analysis restricted to the 2021 to 2024 period, indicating that the findings were not attributable to potential incompleteness of records in the early years of the historical series. From this perspective, the lower mortality observed in urban settings may be related to greater accessibility to healthcare services and the effectiveness of healthcare interventions, since health outcomes depend not only on resource availability but also on accessibility, healthcare service organization, and associated socioeconomic factors (Garcia Arias et al., 2024). Previous studies have shown that healthcare service utilization is lower in rural areas than in urban areas, despite both being linked to the same municipal healthcare system (Vieira et al., 2020). In the state of Paraná, access to cardiologists and reperfusion centers, as well as rates of angioplasty and revascularization, showed different associations with ischemic heart disease mortality across regions. Furthermore, greater proximity to reperfusion centers alone did not ensure effective access or improved outcomes (Dutra et al., 2021). Cardiovascular events tend to be more lethal as the time between event onset and medical care at a specialized facility increases (Ungvari et al., 2026). In municipalities located farther from urban centers, access to medical care

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tends to be delayed, often requiring intermunicipal travel (Oliveira et al., 2021). This may help explain the observed pattern of lower cardiovascular mortality risk in municipalities with higher degrees of urbanization.

The present study indicates that adjacent intermediate municipalities have more inpatient beds per 100,000 inhabitants than urban municipalities. However, bed availability alone is insufficient to ensure fewer cardiovascular deaths. Previous research has demonstrated that the provision of specialized cardiovascular care, including high-complexity procedures, diagnostic examinations, and cardiology consultations, is unevenly distributed geographically, with greater concentration in urban centers. Combined with the need for patients to travel to healthcare facilities, this suggests that resource availability is often insufficient to ensure effective and timely access to specialized care following a cardiovascular event (De Marqui Moraes et al., 2023). These factors are compounded by socioeconomic vulnerability (Godoy et al., 2007) and low educational attainment, which may contribute to unfavorable outcomes in smaller municipalities (Brant et al., 2025). Thus, the lower risk of cardiovascular mortality in urban municipalities highlights the need for strategies to mitigate territorial inequalities in access to healthcare, particularly in rural and intermediate municipalities.

Conclusion

Potential inconsistencies in historical records and the absence of indicators capable of assessing effective access to healthcare services and the quality of care limit the conclusions of this study. However, the consistency between the patterns identified in the model covering the entire historical series and those observed in the model restricted to data from 2021 to 2024 reduces the likelihood that underreporting bias influenced our findings. Overall, the results highlight the importance of recognizing

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territorial inequalities in the availability of and access to healthcare infrastructure capable of reducing morbidity and mortality from cardiovascular events, thereby supporting improved planning of public health strategies in the state of Espírito Santo. Accordingly, our findings may inform decisions regarding resource allocation, the organization of healthcare delivery networks, and the strengthening of specialized cardiovascular care, particularly in rural and intermediate municipalities. Future studies may incorporate indicators of accessibility, travel time, primary healthcare coverage, and socioeconomic conditions, contributing to a better understanding of the mechanisms underlying the observed territorial differences and guiding strategies to reduce cardiovascular mortality.

Author contributions

Conceptualization: MMO; HCB; LD; MACA; PCD; LMBA; LMBF; GRT; MWCS; BSS; NWS

Formal analysis: ACBO; AAM

Methodology: RTZF; RVL

Writing – original draft: LWGA; YSR; SFN; GPZ; ISA; BMPB

Writing – review and editing: JMS

Conflict of Interest

The authors declare no conflicts of interest related to this study. This work was conducted independently, without influence from institutions, organizations, or sponsors that could affect the results or the interpretation of the data presented.

Data Availability

The authors declare that the data supporting the results of this study are available in the article. Derived data supporting the study's conclusions that are not found in the article may be requested from the corresponding author.

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Funding

This work was conducted without specific funding from public, commercial, or non-profit funding agencies.

New Researchers

The first author declares that they meet the eligibility criteria for the 'New Researchers' category and requests that the manuscript be submitted under this category.

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Submission history - Submitted: 2026-11-03 - Acepted: 2026-11-11

DOI: 10.63923/smhs.2026.155

Responsible Editor: Gustavo Martins Rocha

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