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Territorial inequalities in cancer mortality in Chile, 2002–2022: a rurality-continuum analysis using spatiotemporal Bayesian models

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ABSTRACT

Objective: To examine how cancer mortality in Chile varied across a continuous rurality gradient and to identify territorial differences in mortality risk and temporal trends.
Methods: We analyzed cancer deaths in 343 continental municipalities between 2002 and 2022. A continuous Index of Relative Rurality was constructed using indicators of population concentration and spatial accessibility. Municipal mortality was modeled using Bayesian spatiotemporal models adjusted for age and sex. Exploratory analyses of the rurality gradient identified a threshold with a change in mortality-risk patterns, which was used to compare trajectories.
Results: A clear inflection in the mortality–rurality relationship emerged around an index value of 0.30, separating two territorial mortality profiles. Mortality declined nationally but reductions were slower in more rural municipalities. Cancers historically linked to structural disadvantage—such as stomach, gallbladder, and cervical cancer—showed higher mortality risks in more rural areas. In contrast, breast, lung, and colorectal cancers showed higher risks in less rural municipalities. Several cancers, including colorectal, lung, kidney, and bladder, also displayed less favorable temporal trends in more rural territories.
Conclusions: Distinct trajectories along the rural–urban continuum reveal territorial inequalities that may remain hidden in national averages. These findings support targeting prevention efforts to higher-risk territories.

1. Introduction

Cancer is a leading cause of death across Latin America, and its burden reflects persistent social and territorial inequities (Piñeros et al., 2022). In Chile, a high–Human Development Index country, cancer mortality shows marked sex differences and heterogeneous epidemiological profiles (Bray et al., 2024). However, national averages conceal substantial internal heterogeneity across territories (Alfaro et al., 2025). Rural populations often experience structural disadvantages related to geographic accessibility, socioeconomic conditions, and the territorial distribution of health services, which may influence both cancer incidence and survival (Bhatia et al., 2022). In Chile, nearly one-quarter of the population lives in municipalities with higher levels of monetary and multidimensional poverty and more limited access to health resources (Undurraga et al., 2020; Contreras et al., 2023). These territorial disparities frequently coincide with regions historically characterized by structural disadvantage and reduced availability of specialized services (Barozet et al., 2021).

Despite increasing recognition of geographic health disparities, rurality is still commonly operationalized using predefined categorical classifications, most often based on population density (Erly et al., 2024). These approaches assign territories to fixed rural–urban groups from the outset, which can obscure meaningful territorial gradients and limit the detection of heterogeneity within categories (Macharia et al., 2023). Once rurality is collapsed into predefined groups, it becomes difficult to evaluate whether health outcomes follow different patterns across the rural–urban continuum. This limitation is particularly relevant in countries such as Chile, whose elongated geography, fragmented

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settlement patterns, and historically centralized health system generate complex spatial dynamics. In this context, national cancer indicators may mask localized areas where mortality patterns diverge from broader trends, limiting the capacity of surveillance systems to identify populations experiencing different risk trajectories.

Continuous measures of rurality offer an alternative framework by allowing territorial gradients to be examined before categories are defined. By preserving the full rural–urban continuum, such measures make it possible to explore how health outcomes vary across territories and to derive empirically informed thresholds when categorization is required for planning or resource allocation. When combined with small-area spatiotemporal models, these approaches can stabilize mortality estimates in small populations while identifying localized patterns that may remain hidden within national averages.

In this study, we developed a continuous, multidimensional index of rurality and applied spatiotemporal Bayesian models to national mortality data from 2002 to 2022. We evaluate how cancer mortality varies along this gradient, identify empirical thresholds associated with shifts in mortality risk, and characterize two decades of territorial inequalities. By examining mortality patterns at the municipal level, this study provides new evidence on how territorial structures shape cancer outcomes and offers a framework for identifying populations whose mortality trajectories diverge from national trends, supporting more geographically informed surveillance and resource allocation strategies.

2. Methods

2.1. Study design and population

All cancer mortality data in Chile from 2002 to 2022 were obtained from the Department of Health Statistics and Information (DEIS (Department of Health Statistics and Information) (Chile), 2026) and categorized into three age groups (0–59, 60–79, and ≥ 80 years) due to low death counts in several analytical units. We defined the study period starting in 2002 because earlier years were affected by political-administrative changes in the country's municipal structure—including the creation, merger, or redefinition of municipalities—which limit territorial comparability over time. The upper bound of the study period reflects the most recent official data available at the time of data extraction, with records consolidated through December 31, 2022. The

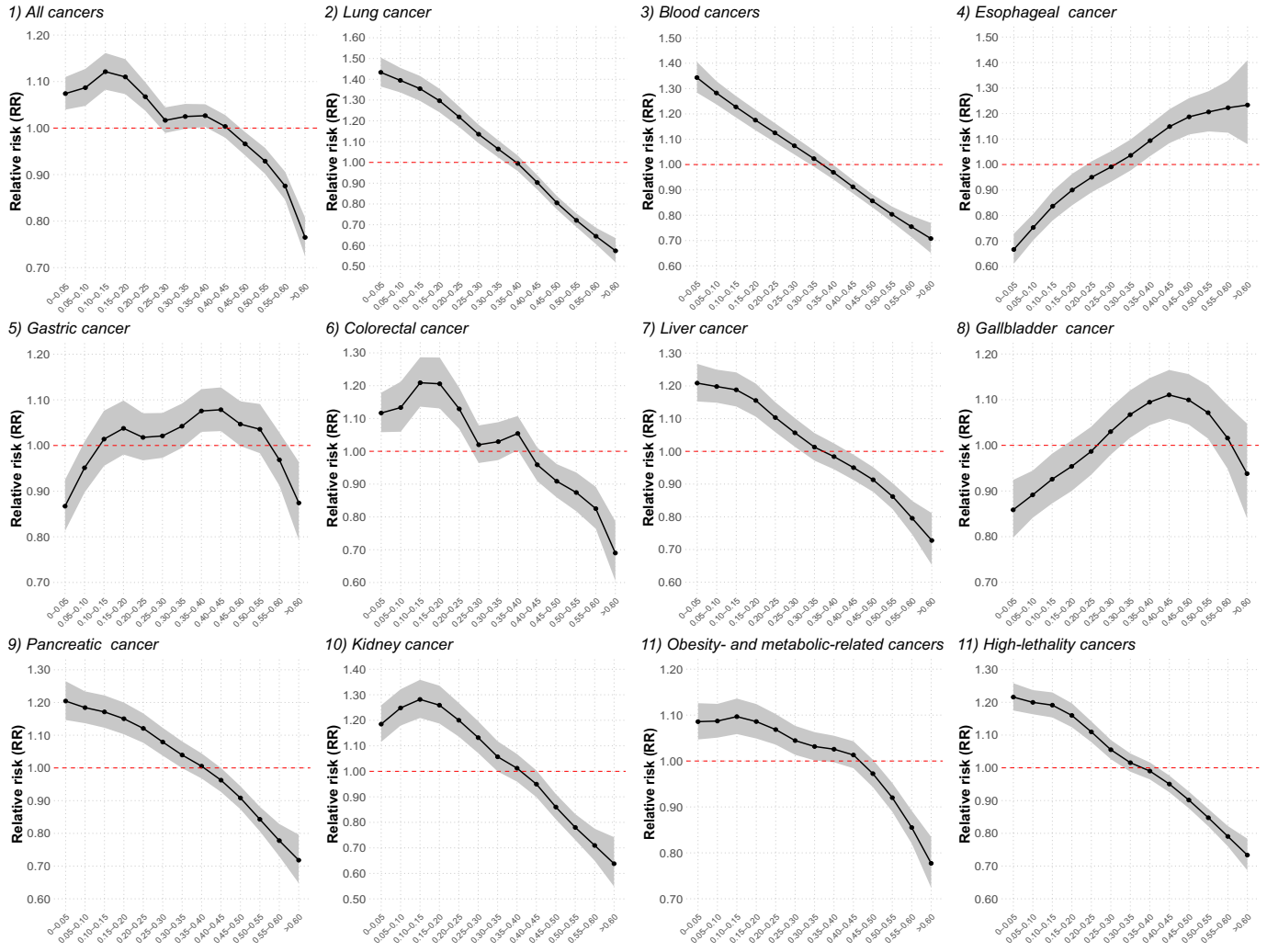

Fig. 1. Association between rurality and standardized cancer mortality among men and women in Chile, 2002–2022.
Notes: Relative risks (RR) with 95% credible intervals were estimated across the Index of Relative Rurality (IRR) continuum from 0 (predominantly urban) to 1 (predominantly rural) using Bayesian spatiotemporal models incorporating spatial structure and yearly variation. Panels show estimates for all cancers combined, site-specific cancers (lung, blood, esophageal, gastric, colorectal, liver, gallbladder and biliary tract, pancreatic, and kidney cancers), and selected cancer groupings based on shared etiologic or health-system characteristics, including obesity- and metabolic-related cancers and high-lethality cancers. RR values are interpreted relative to the national average for the same cancer during 2002–2022; RR = 1 indicates equality with the national average, values >1 indicate higher risk, and values <1 indicate lower risk.

institutional ethics committee approved the study (Project 241,015,012). We used publicly available, fully anonymized data.

We conducted the study in continental Chile, which comprises 16 regions grouped into five macrozones plus the Metropolitan Region (MinCiencia (Ministry of Science, Technology, Knowledge and Innovation) (Chile), 2019) (Fig. 1A). We used municipalities as the unit of analysis because they guide health planning and resource allocation. Of the 346 municipalities in the country, we included 343 continental municipalities and excluded island and Antarctic territories due to their distinct accessibility and health system characteristics. We obtained population estimates from the National Institute of Statistics (INE), based on the 2017 Census and intercensal projections. We sourced cartographic data and information on health care facilities from the national Geospatial Data Infrastructure (IDE) (Ministry of National Assets (Chile), 2026), and we used municipal-level poverty indicators and National Health Survey (ENS) data to contextualize socioeconomic conditions, health behaviors, and access to screening (INE (National Institute of Statistics) (Chile), 2018).

2.2. Measures

We defined exposure using a continuous Index of Relative Rurality (IRR), based on the framework proposed by Waldorf and Kim, which integrates population size, population density, the proportion of urban population, and travel time to the nearest urban center to characterize the rural–urban continuum (Waldorf and Kim, 2018). This index has been previously applied in Chile using comparable national data sources (Flores-Angulo et al., 2026), generating a continuous score ranging from 0 (more urban) to 1 (more rural) for each municipality and year, allowing rurality to be analyzed as a territorial gradient. As outcomes, we analyzed cancer mortality from death certificates coded according to the International Classification of Diseases, 10th Revision (ICD-10) (WHO (World Health Organization), 1992), including lung (C33–C34), hematologic (C81–C86, C88, C90–C94), gastrointestinal (C15–C20), hepatobiliary and pancreatic (C22–C25), and genitourinary cancers (C50, C53, C61, C64–C68, C67), as well as all cancers combined. In additional analyses, we grouped cancers according to shared etiologic or health system characteristics, including categories related to chronic infections, obesity and metabolic conditions, screening dependence, occupational or environmental exposures, and patterns associated with epidemiological transition in rural settings. We included age and sex as primary confounders and incorporated contextual indicators such as municipal poverty, level of care of health facilities (primary, secondary, and tertiary), and population behaviors and access to preventive services derived from the 2016–2017 National Health Survey to characterize territorial conditions associated with cancer mortality.

2.3. Statistical analysis

We applied a two-stage hierarchical Bayesian framework (Gause et al., 2024) to model annual cancer death counts by municipality. In the first stage, Poisson or negative binomial models were fitted depending on the presence of overdispersion, using the logarithm of the population as an offset while retaining zero counts. To explore the functional form of the association between rurality and mortality risk, the IRR was initially represented using ordinal categories of equal width along the rural–urban continuum. This exploratory specification allowed the relationship between rurality and mortality risk to be evaluated without imposing a predefined functional form and facilitated the identification of potential changes in slope along the gradient. Based on this exploratory analysis, rurality was subsequently operationalized using two strata defined by an empirically identified threshold along the rurality gradient. Municipalities below this threshold were classified as relatively more urban, whereas those above it were classified as relatively more rural. In the second stage, temporal trajectories of the relative risk (RR) from 2002 to 2022 were modeled both overall and stratified according to the empirical threshold identified in the exploratory analysis, adjusting for age and sex (or age only in sex-specific analyses). Temporal trends were summarized using indicators of annual percent change derived from the posterior RR trajectories.

Alternative spatiotemporal specifications were evaluated, including first- and second-order random walk temporal processes (RW1 and RW2) and first-order autoregressive processes (AR1), together with spatial effects modeled using intrinsic conditional autoregressive structures (ICAR), independent and identically distributed random effects (IID), and the Besag–York–Mollié model parameterization (BYM2). In the BYM2 formulation, the mixing parameter φ estimated the proportion of spatially structured variation (Riebler et al., 2016). Penalized-complexity priors were assigned to spatial and temporal precision parameters, and log-Gamma priors were used for dispersion in negative binomial models (Simpson et al., 2017). Model comparison relied on the Watanabe–Akaike information criterion (WAIC), the deviance information criterion (DIC), and conditional predictive ordinates (CPO). The final specification combined a BYM2 spatial structure with a RW2 temporal component, yielding stable estimates of mortality trajectories while preserving spatial dependence between neighboring municipalities. The mathematical formulation of the model, prior distributions, and convergence diagnostics are described in detail in the Supplementary Data.

To better interpret the rural–urban gradient, complementary analyses were conducted. Sensitivity analyses included municipal income poverty as an additional covariate to evaluate the robustness of the rurality–mortality association. Age–period–cohort models were fitted to decompose temporal variation into age, period, and cohort components and assess whether the observed trajectories reflected cohort replacement or period-specific dynamics. Moreover, structural differences around the rurality threshold were explored by describing the distribution of health care facilities by level of care (primary, secondary, and tertiary) and calculating the number of facilities per 100,000 inhabitants across strata. Finally, data from the National Health Survey (ENS) 2016–2017 were used to characterize territorial differences in health behaviors and access to cancer screening using design-weighted generalized linear models (Santos-López et al., 2024). Additional methodological details are provided in the Supplementary Data.

Statistical analyses were performed using R version 4.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Descriptive analysis

Between 2002 and 2022, Chile registered 398,203 cancer deaths (53.6% in men and 46.4% in women), of which 121 occurred in territories excluded from the analysis (island and Antarctic areas). Mortality increased with age and varied across years and municipalities. Fig. 2A illustrates geographic clustering, with consistently higher mortality in the South-Central and Southern macrozones. Among women, breast, gallbladder, and lung cancers had the highest mortality rates, whereas in men the leading sites were gastric, prostate, and lung cancers. Across municipalities, mortality patterns varied along the rural–urban continuum defined by the IRR, with some cancers showing similar levels across strata and others displaying clear territorial gradients (See Table 1). These patterns motivated the subsequent modeling analyses of mortality risk and temporal trajectories along the rurality gradient.

3.2. Mortality risk by rurality and spatial structure

The continuous IRR showed heterogeneous associations with cancer mortality across sites. After adjustment for age and sex, the modeled curves consistently displayed a change in the rurality gradient at IRR values close to 0.30. This pattern was consistent across several cancer types in both overall and sex-specific analyses. Based on this pattern in

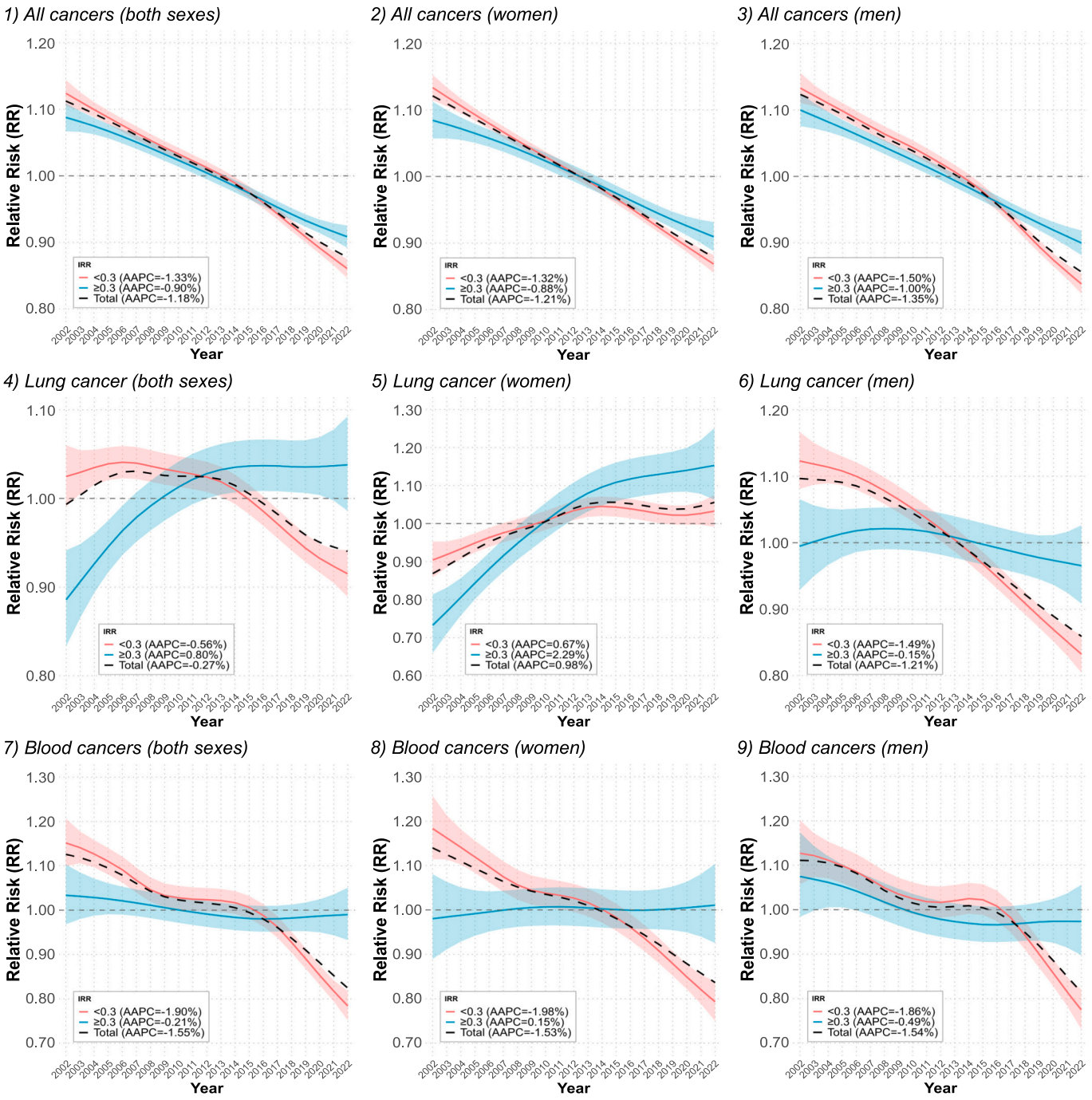

Fig. 2. Trends in adjusted cancer mortality for all cancers, lung, and hematologic cancers by rurality level in Chile, 2002–2022.
Notes: Relative risks (RR) with 95% credible intervals were estimated across the Index of Relative Rurality (IRR) continuum from 0 (predominantly urban) to 1 (predominantly rural) using Bayesian spatiotemporal models incorporating spatial structure and yearly variation. Panels show temporal trends in adjusted mortality for all cancers combined, lung cancer, and blood cancers by rurality level in Chile, 2002–2022. Estimates were adjusted for age and sex in the total population and for age in sex-specific analyses. The red line corresponds to municipalities with IRR <0.30, the green line to municipalities with IRR ≥0.30, and the black dashed line to the unstratified national trend. RR values are estimated separately within each stratum and are interpreted relative to the average of the same stratum during 2002–2022; RR = 1 indicates equality with that average, values >1 indicate higher risk, and values <1 indicate lower risk. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the mortality–IRR relationship, municipalities were subsequently stratified into two groups: lower and higher rurality, for subsequent analyses of mortality risk and temporal trajectories (Fig. 1, 3A, 4A). Municipalities with IRR <0.3 accounted for 297,260 deaths, whereas those with IRR ≥0.3 recorded 100,822 deaths (Table 1A). Across cancer types, the models revealed a territorial gradient associated with rurality: cancers historically linked to chronic infections and long-standing social disadvantage, including stomach, gallbladder, and cervical cancer, showed higher mortality risks in more rural municipalities, whereas cancers more commonly associated with urban lifestyles and behavioral risk factors, such as breast, lung, and colorectal cancer, showed higher risks in less rural municipalities.

Spatial dependence was observed across several cancer groups, indicating that part of the geographic variation in mortality followed

Table 1
Cancer mortality in Chile by cancer type and rurality index, with rural-to-urban mortality rate ratios, 2002–2022.

Cancer	Total		IRR (rurality)				
			<0.3		≥0.3		
	Deaths	Rate	Deaths	Rate	Deaths	Rate	Ratio [c]
All	398,203	62.55	297,260	90.59	100,822	100.14	1.11
Bladder	9751	1.53	7953	2.42	1797	1.78	0.74
Blood	31,043	4.88	24,553	7.48	6481	6.44	0.86
Breast[a]	28,844	8.93	23,075	13.82	5763	11.37	0.82
Cervical[a]	13,173	4.08	9504	5.69	3663	7.23	1.27
Chronic infection-related cancers	103,532	16.26	73,683	22.46	29,820	29.62	1.32
Colorectal	33,246	5.22	25,511	7.77	7728	7.68	0.99
Colorectal and stomach cancers	66,947	18.16	46,079	16.43	20,855	23.65	1.44
Esophageal	13,975	2.20	8671	2.64	5300	5.26	1.99
Female hormone-related cancers[a]	42,017	22.45	32,579	22.83	9426	21.25	0.93
Gallbladder	36,073	5.67	24,221	7.38	11,845	11.77	1.59
Gastric	66,947	10.52	46,079	14.04	20,855	20.71	1.48
Hepatobiliary and digestive cancers	85,241	23.12	62,306	22.22	22,915	25.99	1.17
High-lethality cancers	122,969	33.35	95,747	34.15	27,166	30.81	0.90
Kidney	15,755	2.47	12,232	3.73	3518	3.49	0.94
Liver	23,412	3.68	18,100	5.52	5302	5.27	0.95
Lung	59,826	9.40	48,991	14.93	10,796	10.72	0.72
Obesity and metabolic-related cancers	106,640	16.75	79,679	24.28	26,940	26.76	1.10
Occupational and environmental exposure cancers	116,375	18.28	93,729	28.56	22,592	22.44	0.79
Pancreatic	25,756	4.05	19,985	6.09	5768	5.73	0.94
Prostate[b]	40,190	12.81	28,219	17.50	11,960	23.92	1.37
Rurality and nutritional transition cancers	132,076	20.75	93,541	28.51	38,509	38.25	1.34
Screening-access related cancers	82,419	12.95	60,964	18.58	21,432	21.29	1.15
Tobacco and aerodigestive cancers	73,801	20.01	57,662	20.56	16,096	18.25	0.89
Total gastrointestinal cancers	166,163	45.06	117,056	41.74	49,070	55.65	1.33
Upper gastrointestinal cancers	80,922	21.95	54,750	19.53	26,155	29.66	1.52
Urologic cancers[b]	56,830	31.30	41,433	30.09	15,384	35.11	1.17

Notes: Total population: 17,759,127 (Women: 8,912,334; Men: 8,646,793). Urban: 13,352,762 (Women: 6,796,084; Men: 6,556,678). Rural: 4,189,958 (Women: 2,112,531; Men: 2,086,427). a. Cancers evaluated only in the female population. b. Cancers evaluated only in the male population. c. Ratio of the rural mortality rate to the urban mortality rate; values >1 indicate higher mortality in rural areas and values <1 indicate higher mortality in urban areas.

structured spatial patterns. Stomach, gallbladder, and liver cancers exhibited particularly strong spatial structure, whereas lung and colorectal cancers showed more moderate spatial dependence. Sensitivity analyses incorporating municipal poverty levels produced estimates broadly consistent with the main models, with modest changes in the magnitude of some associations but limited improvement in model fit (Table 2A).

3.3. Temporal trends by rurality

Mortality from all cancers combined declined from 1.11 to 0.88 between 2002 and 2022 (−21.10%; AAPC −1.18%). Figs. 2 and 3 show the modeled temporal trajectories by cancer site, sex, and rurality. Overall, mortality declines were more pronounced in municipalities with lower rurality for several cancer groups including high-lethality cancers, screening-related cancers, and obesity- and metabolic-related cancers. Cancers associated with chronic infections showed sustained reductions in both strata. In contrast, some site-specific cancers displayed divergent trends, with more pronounced increases in mortality in municipalities with higher rurality. This pattern was particularly evident for colorectal, lung, kidney, and bladder cancers. Detailed estimates for all cancer groups and sites are presented in Table 3A.

Age–Period–Cohort models stratified by rurality are shown in Fig. 5A. Relative risk estimates for municipalities above and below the IRR threshold showed overlapping 95% credible intervals across most periods and birth cohorts.

3.4. Risk factors, screening, and health system resources by rurality

Data from the 2016–2017 National Health Survey showed differences in several population characteristics across the rurality strata. Higher prevalence of low educational attainment and lower colonoscopy use were observed in municipalities with higher rurality, together with differences in tobacco and alcohol consumption patterns. Coverage of Pap smear and mammography screening was similar across strata, although the frequency of abnormal results differed (Table 4A).

Differences were also observed in the distribution of health care facilities by level of care. Municipalities with IRR <0.3 had 7.98 primary care facilities, 5.46 secondary facilities, and 1.14 tertiary facilities per 100,000 inhabitants, whereas municipalities with IRR ≥0.3 had 37.53 primary care facilities but fewer secondary (3.76) and tertiary (0.75) facilities per 100,000 inhabitants.

4. Discussion

This study shows that cancer mortality in Chile follows distinct trajectories along the rural–urban continuum. Although mortality declined nationally between 2002 and 2022, reductions were uneven across territories, with faster declines in municipalities with lower rurality. As a result, national averages may conceal important territorial differences in mortality trends. Using a multidimensional rurality index, we identified a consistent inflection in the relationship between rurality and mortality risk around IRR ≈ 0.3 across several cancer types. Previous work suggests that this index captures meaningful territorial gradients in population health outcomes, supporting its use for identifying populations exposed to different geographic contexts in Chile (Flores-Angulo et al., 2026).

Along the rurality gradient, distinct epidemiological patterns were observed across cancer types. Several cancers historically associated with infections and structural disadvantage, including stomach, gallbladder, and cervical cancers, showed sustained declines in mortality in both territorial strata. In contrast, some cancers linked to behavioral risk factors or epidemiological transition displayed less favorable trajectories in municipalities with higher rurality. In particular, colorectal, lung, kidney, and bladder cancers showed increasing mortality trends or slower declines in these territories. The marked reduction in cervical

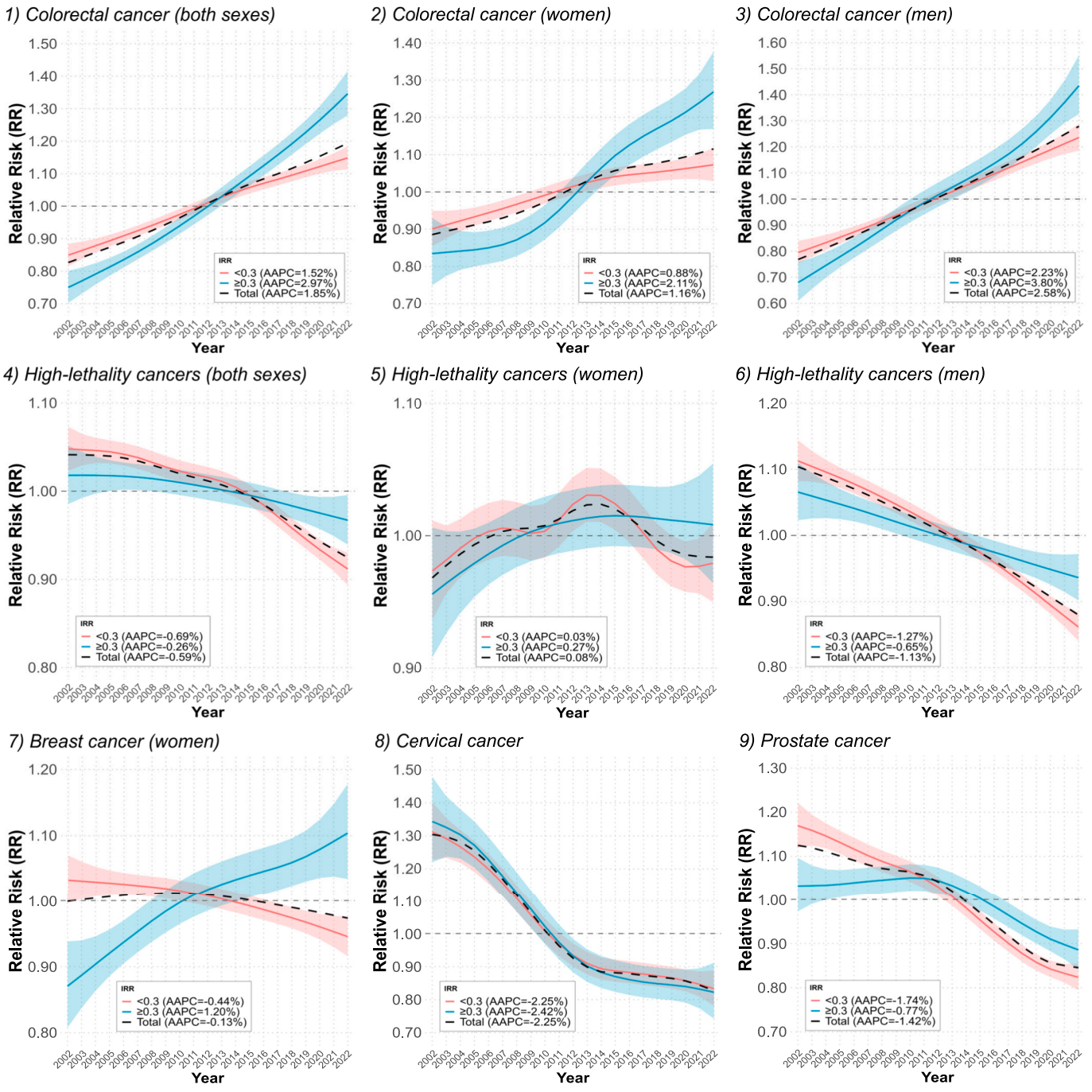

Fig. 3. Trends in adjusted cancer mortality for colorectal, high-lethality, breast, cervical, and prostate cancers by rurality level in Chile, 2002–2022.
Notes: Relative risks (RR) with 95% credible intervals were estimated across the Index of Relative Rurality (IRR) continuum from 0 (predominantly urban) to 1 (predominantly rural) using Bayesian spatiotemporal models incorporating spatial structure and yearly variation. Panels show temporal trends in adjusted mortality for colorectal cancer, high-lethality cancers, breast cancer, cervical cancer, and prostate cancer by rurality level in Chile, 2002–2022. Estimates were adjusted for age and sex in the total population and for age in sex-specific sanalyses. The red line corresponds to municipalities with IRR <0.30, the green line to municipalities with IRR ≥0.30, and the black dashed line to the unstratified national trend. RR values are estimated separately within each stratum and are interpreted relative to the average of the same stratum during 2002–2022; RR = 1 indicates equality with that average, values >1 indicate higher risk, and values <1 indicate lower risk. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

cancer mortality across the country, associated with Chile's decentralized screening and treatment model (Donoso et al., 2006), illustrates how prevention and treatment strategies implemented through territorially distributed health services can contribute to reducing disparities in cancer outcomes.

Breast cancer showed a notable divergence. Municipalities with lower rurality followed a trajectory consistent with the mild national decline reported in official Ministry of Health statistics, whereas municipalities with higher rurality experienced increasing mortality during the study period. National indicators are dominated by larger urban populations, so these opposing trajectories may remain concealed in aggregated statistics (DEIS (Department of Health Statistics and Information) (Chile), 2026). In our analysis, this pattern coincided with differences in the territorial distribution of health infrastructure: municipalities with higher rurality had more primary care facilities per population but fewer secondary and tertiary centers, where diagnostic

confirmation, oncologic surgery, and specialized treatments are delivered. The National Health Survey did not identify rural–urban differences in reported access to mammography, suggesting inequalities may arise later in the care pathway during diagnosis, referral, or treatment. Hormone replacement therapy has also been associated with breast cancer risk; however, its territorial distribution could not be evaluated with available data. Similar dynamics have been documented internationally, where rural populations experience slower improvements in breast cancer mortality despite comparable screening access and face greater geographic barriers to specialized treatment (Carew et al., 2025; Sokale et al., 2023; Theodoropoulos et al., 2022).

To evaluate whether the divergent trajectories observed across the rurality continuum could reflect generational or period-specific dynamics, complementary Age–Period–Cohort analyses were conducted. These models showed largely overlapping credibility intervals across rurality strata, indicating that the differences observed in the time-series analyses are unlikely to be explained by cohort replacement or specific period effects. Instead, the findings suggest that the observed divergences are more consistent with persistent territorial conditions operating across generations. Sensitivity analyses incorporating municipal poverty indicators produced broadly similar estimates, indicating that although socioeconomic deprivation overlaps with rurality, it does not fully account for the territorial gradients observed in cancer mortality.

Methodologically, Chile's heterogeneous geography requires approaches capable of capturing complex spatial and temporal structures. The Bayesian models applied here stabilized small-area mortality estimates by incorporating spatial adjacency and temporal continuity, preserving local signal while reducing statistical noise (Gao and Wakefield, 2024). This aligns with international efforts to strengthen health systems' capacity to detect and monitor territorial inequalities through advanced geospatial analytics (Gomes et al., 2025; Wawrzuta et al., 2025). Although the study relies on secondary data and cannot reconstruct care pathways, it benefits from full national coverage, a two-decade observation window, and a continuous rurality index constructed from publicly available information. Together, these features provide a robust basis for understanding how territorial structures shape cancer mortality and support conceptualizing rurality as a socio-spatial determinant of health.

5. Conclusion

These findings highlight the relevance of incorporating territorial gradients into cancer-control planning. Rather than relying on uniform national policies, health planning may benefit from approaches that explicitly incorporate the rural–urban continuum when allocating diagnostic and treatment capacity. In practice, this could include strengthening referral networks between primary care facilities in more rural municipalities and higher-complexity oncology services, improving geographic accessibility to specialized diagnostic and treatment infrastructure, and prioritizing territorial monitoring systems capable of identifying emerging disparities that may remain hidden in national averages. Integrating continuous measures of rurality into surveillance and planning frameworks may therefore help guide more targeted and equitable cancer-control policies in geographically diverse countries such as Chile.

CRediT authorship contribution statement

Carlos Flores-Angulo: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization, Validation. **Guillermo Marshall:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Conceptualization, Funding acquisition, Investigation, Writing – original draft. **Catterina Ferreccio:** Writing – review & editing, Supervision, Methodology, Conceptualization, Funding acquisition, Investigation, Validation. **Jaime Cerda:** Writing – review & editing, Resources, Methodology, Supervision, Conceptualization, Formal analysis. **Gloria Icaza:** Writing – review & editing, Resources, Formal analysis, Methodology. **Diana Gómez-Barroso:** Writing – review & editing, Resources, Conceptualization, Methodology, Software. **Rebeca Ramis:** Writing – review & editing, Resources, Formal analysis, Methodology.

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Declaration of competing interest

The authors declare that they have **no known financial or personal conflicts of interest** that could have influenced the conduct, interpretation, or reporting of this study. No author has received payments, services, or personal benefits from third parties that could be perceived as a potential conflict. The authors report **no competing interests**.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2026.108575.

Data availability

All data used in this study are publicly available from the Chilean Department of Health Statistics and Information (DEIS), the National Institute of Statistics (INE), and the Chilean Geospatial Data Infrastructure (IDE). Mortality data were obtained from DEIS, population estimates and municipal income poverty indicators from INE, and geographic data including the location of health care facilities from IDE. Analytical code is available from the corresponding author upon reasonable request.

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