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Mortality burden and economic loss attributable to cold and heat in Central and South America

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Background: We quantify the mortality burden and economic loss attributable to nonoptimal temperatures for cold and heat in the Central and South American countries in the Multi-City Multi-Country (MCC) Collaborative Research Network.
Methods: We collected data for 66 locations from 13 countries in Central and South America to estimate location-specific temperature–mortality associations using time-series regression with distributed lag nonlinear models. We calculated the attributable deaths for cold and heat as the 2.5th and 97.5th temperature percentiles, above and below the minimum mortality temperature, and used the value of a life year to estimate the economic loss of delayed deaths.
Results: The mortality impact of cold varied widely by country, from 9.64% in Uruguay to 0.22% in Costa Rica. The heat-attributable fraction for mortality ranged from 1.41% in Paraguay to 0.01% in Ecuador. Locations in arid and temperate climatic zones showed higher cold-related mortality (5.10% and 5.29%, respectively) than those in tropical climates (1.71%). Arid and temperate climatic zones saw lower heat-attributable fractions (0.69% and 0.58%) than arid climatic zones (0.92%). Exposure to cold led to an annual economic loss of $0.6 million in Costa Rica to $472.2 million in Argentina. In comparison, heat resulted in economic losses of $0.05 million in Ecuador to $90.6 million in Brazil.
Conclusion: Most of the mortality burden for Central and South American countries is caused by cold compared to heat, generating annual economic losses of $2.1 billion and $290.7 million, respectively. Public health policies and adaptation measures in the region should account for the health effects associated with nonoptimal temperatures.

Keywords: Nonoptimal temperatures; Mortality burden; Economic loss; Time series; Distributed lag nonlinear models; Multicountry; Central and South America

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Data have been collected within the MCC (Multi-Country Multi-City) Collaborative Research Network (https://mccstudy.lshtm.ac.uk/) under a data-sharing agreement and cannot be made publicly available. Researchers can refer to MCC participants listed as coauthors for information on accessing the data for each country.

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Introduction

Epidemiological studies have already provided significant evidence for the association between ambient temperature and mortality.[1–5] However, most of the evidence for the temperature–mortality association comes from studies conducted in high-income countries.[6] Climate change is currently a global concern, affecting vulnerable populations in low- and middle-income countries, including those in the Central and South American region. Moreover, the region is one of the most urbanized among developing countries,[7] which may increase the impact of nonoptimum temperatures on the growing population.

Several studies examined the temperature–mortality association in the Central and South American countries. Multicity studies have been conducted nationwide in Brazil[8] and Mexico,[9]

What this study adds:
This study provides evidence of the health burden and economic losses attributable to heat and cold in Central and South American countries, covering various climates and populations. Most of the mortality burden for Central and South American countries is caused by cold compared to heat. The results showed geographical and climatic variations, indicating a significantly higher impact of nonoptimal temperatures in countries of the Southern Cone and locations with temperate climates. These findings offer direct evidence to guide policymakers in developing public health policies for mitigation and adaptation to the region's health effects and economic impacts of nonoptimal temperatures.

both reported effects of low and high temperatures on the risk of cardiovascular mortality and nonexternal and cause-specific mortality in the elderly, respectively. Bell et al[10] also reported that elevated temperatures are associated with an increased risk of cardiovascular and respiratory mortality in a study conducted in three major South American cities (Sao Paulo, Santiago, and Mexico City). Moreover, a larger multicity study across Latin American cities reported that a substantial proportion of deaths is attributable to nonoptimal ambient temperatures, with the impact being much strongest for cold than for heat.[11]

Although previous studies have reported estimates of the attributable burden as an absolute or relative excess of deaths, exposure to nonoptimal temperatures also burdens the economy. However, the costs of health hazards have mainly been quantified economically in high-income countries,[12–14] and evidence of the economic loss attributable to nonoptimal temperatures from middle and low-income countries, including Central and South American countries, is still unknown. Moreover, the Central and South American regions comprise a wide range of climatic conditions, from tropical rainforests to arid deserts, each presenting unique temperature-related health challenges. However, the health impact of nonoptimal temperatures according to the climatic zones in the region has not yet been addressed.

In this study, we aim to quantify the total mortality burden and economic losses attributable to the short-term associations of nonoptimal ambient temperatures and determine the relative contributions from cold and heat in the Central and South American countries within the Multi-City Multi-Country (MCC) Collaborative Research Network (http://mccstudy.lshtm.ac.uk/).

Methods

Data

We collected time-series daily data from 66 locations in 13 countries, Argentina (three cities, 2005–2015), Brazil (18 cities, 1997–2011), Chile (four cities, 2004–2014), Colombia (five cities, 1998–2013), Costa Rica (one city, 2000–2017), Ecuador (two cities, 2014–2018), Guatemala (one city, 2009–2016), Mexico (10 metropolitan areas, 1998–2014), Panama (one city, 2013–2016), Paraguay (one city, 2004–2016), Peru (18 regions, 2008–2014), Puerto Rico (one city, 2009–2016), and Uruguay (one city, 2012–2016), and three overseas territories of France (French Guiana, Guadalupe, and Martinique, 2005–2015). The data included observed daily mortality for all causes or nonexternal causes (International Classification of Diseases 9th Revision: 0-799, and 10th Revision: A00-R99) and daily mean temperature for each location.[5] Additional details on data collection are provided in Appendix A; http://links.lww.com/EE/A300.

Statistical analysis

We followed the same two-stage procedure in a previous MCC study.[2] In the first stage, distributed lag nonlinear models in quasi-Poisson regression were separately applied to each location. These models included a natural cubic B-spline of time with eight degrees of freedom per year to control long-term trends and seasonality, indicator variables of weekdays, and the cross-basis for daily mean temperature. The exposure–response curve in the cross-basis was modeled with a quadratic B-spline with internal knots placed at the 10th, 75th, and 90th centiles of location temperature distribution. The lag–exposure curve was defined with a natural cubic spline with three internal knots equally spaced in the log scale. In addition, the lag period was extended to 21 to capture the long delay in the effects of cold. Sensitivity analyses have thoroughly tested these modeling choices in previous studies, showing that the results were not dependent on modeling assumptions.[2,3]

In the second stage, location-specific estimates were pooled to represent the overall exposure–response relationship by cumulating risks during the lag period by country and climatic zone. A random-effects multilevel meta-analytical model was applied, including the average temperature and temperature range as meta-predictors and accounting for variations in risk nested across locations, countries, and climatic zones.[15] We used this fitted meta-analytical model to derive the best linear unbiased predictions of the overall temperature–response association in each location. The best linear unbiased predictions can borrow information from the pooled associations within the same hierarchical level, thus providing more accurate estimates than the first-stage estimates in locations with small daily mortality counts or short time series.

The minimum mortality temperature (MMT) and the attributable deaths were derived from the best linear unbiased predictions of the overall cumulative exposure–response association in each location and country. The total attributable number of deaths caused by nonoptimum temperatures is given by the sum of the contributions from all the days of the series. Its ratio with the total number of deaths provides the total attributable fraction (AF).[16] We calculated the components attributable to cold and heat, including extremely cold and hot temperatures, defined using cutoff values at the 2.5th and 97.5th temperature percentiles, above and below the MMT. Empirical confidence intervals (eCIs) for AFs were calculated using Monte Carlo simulations.[16] The choice of these temperature percentiles was made to ensure comparability with a previous MCC study,[2] during which data from South and Central American countries, except Brazil, was not available. Moreover, these percentiles have also been extensively used by others to define cold and heat effects.[17–20]

Economic assessment

Although it is common to use Value of a Statistical Life (VSL) to quantify the benefit of delaying a death, Armstrong et al[4] provided strong evidence that most deaths associated in daily analyses with cold and heat are displaced by at least 1 year. Consequently, we used the Value of a Life Year (VOLY) in US dollars ($) to estimate the economic impact of the mortality burden attributable to cold and heat assuming a 1-year displacement. This can be considered as a conservative estimate of the economic impact of the mortality burden attributable to cold and heat. However, due to the lack of VSL and VOLY values related to nonoptimal temperature and to ensure comparability between countries, we relied on international income-adjusted estimates of the VSL[21] to calculate country-specific VOLY values (Appendix B; http://links.lww.com/EE/A300). The economic assessment of cold and heat losses is the product of the number of delayed deaths and VOLY values averaged over the study period and population covered for each country and climatic zone.

Results

Table 1 shows the descriptive statistics from each country and climatic zone. The data included almost 10 million deaths in the

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countries included in the analysis. The country-specific annual average temperature ranged from 17.9 °C in Peru to 28.1 °C in Panama and from 19.0 °C in locations with a temperate climate to 25.8 °C in those in tropical climate. The temperature–mortality relationships were mostly J- or V-shaped, although some locations showed a plateau in the exposure–response curve with a large confidence interval for the MMT, suggesting adaptation to a wider range of moderate temperatures. Moreover, most of the locations in tropical climates showed almost flat exposure–response curves, basically not showing any association (Figure S1; http://links.lww.com/EE/A300). We observed the highest cold-related mortality risk over locations in Mexico and the Southern Cone (Argentina, Paraguay, and Uruguay). Although the mortality risk for heat risks was substantially lower than for cold, the highest heat-related mortality risks were also found in some locations in Mexico and Argentina (Figure 1).

At the country level, the minimum mortality temperature percentiles (MMTPs) ranged from the 36th percentile in Costa Rica to the 98th in Ecuador (Table 2). The AFs for cold varied substantially between countries, with the highest in Uruguay (9.64%) and the lowest in Costa Rica (0.22%). The AFs for heat were more homogeneously distributed, between

Table 1.

Summary of the locations, study periods, number of deaths, and temperature distributions for the countries included in the study

	Locations	Study period[a]	Total deaths	Temperature (°C); mean (range)
Country				
Argentina	3	2005–2015	686,333	18.2 (0.4 to 33.9)
Brazil	18	1997–2018	3,895,158	23.4 (3.2 to 35.1)
Chile	4	2004–2014	325,462	13.7 (−1.7 to 27.5)
Colombia	5	1998–2013	956,539	23.4 (10.5 to 31.1)
Costa Rica	1	2000–2017	31,117	22.7 (18.3 to 27.5)
Ecuador	2	2014–2018	112,264	20.9 (10.1 to 30.2)
Guatemala	1	2009–2016	62,715	19.4 (11.8 to 26.5)
Mexico	10	1998–2014	2,980,086	18.8 (0.4 to 35.3)
Overseas France	3	2000–2015	53,300	26.9 (21.8 to 30.4)
Panama	1	2013–2016	11,457	28.1 (23.4 to 31.6)
Paraguay	1	2004–2019	48,037	23.3 (5.6 to 35.1)
Peru	18	2008–2014	633,137	17.9 (−0.2 to 30.7)
Puerto Rico	1	2009–2016	26,564	26.8 (19.7 to 31.1)
Uruguay	1	2012–2016	153,554	18.6 (5.6 to 33.5)
Climatic zone[b]				
Tropical	23		1,890,881	25.8 (11.8 to 35.1)
Arid	13		1,107,450	19.7 (0.4 to 35.3)
Temperate	30		6,734,992	19.0 (−1.7 to 35.1)

[a]The study period may vary according to data available from each location including the climatic zone.
[b]Three cities with polar climate were not considered.

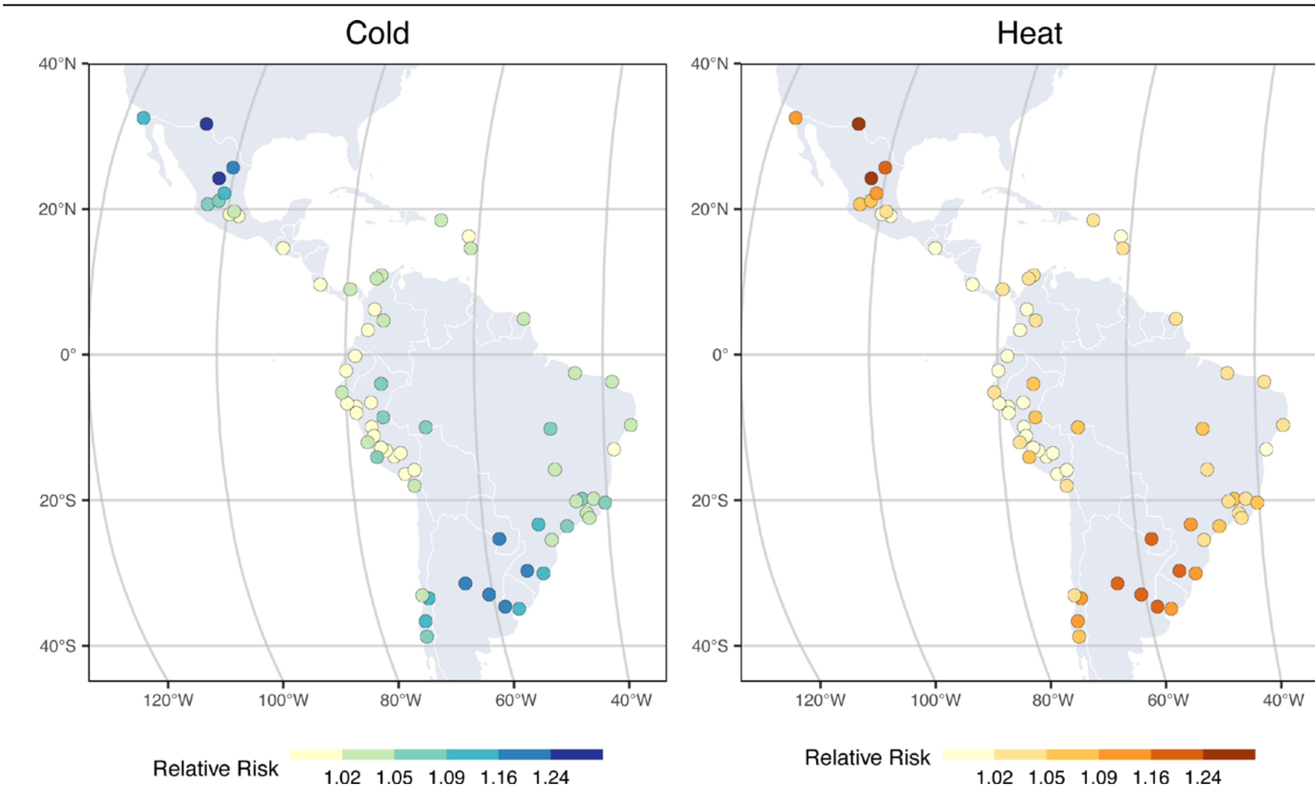

Figure 1. Location-specific relative risk of all-cause mortality due to cold and heat.

Table 2.

All-cause mortality attributable to cold and heat by country and climatic zone

	MMTP (%)	Cold AF (%) (95% eCI)	Heat AF (%) (95% eCI)
Country			
Argentina	79	8.95 (7.16, 10.56)	1.26 (0.97, 1.54)
Brazil	64	3.04 (2.57, 3.49)	0.78 (0.54, 1.01)
Chile	83	7.60 (5.22, 10.01)	0.66 (0.21, 1.05)
Colombia	39	5.24 (1.72, 8.35)	0.49 (0.08, 0.91)
Costa Rica	36	0.22 (−1.24, 1.55)	0.39 (−1.27, 2.05)
Ecuador	98	4.33 (−1.23, 9.48)	0.01 (−0.09, 0.08)
Guatemala	86	2.60 (−0.55, 5.63)	0.12 (−0.17, 0.39)
Mexico	76	5.00 (3.90, 6.17)	0.45 (0.26, 0.65)
Overseas France	39	1.05 (−0.25, 2.23)	0.98 (−0.06, 1.98)
Panama	38	0.77 (−1.13, 2.42)	1.37 (−0.70, 3.19)
Paraguay	77	6.92 (4.10, 9.44)	1.41 (0.77, 1.99)
Peru	96	3.58 (1.95, 4.93)	0.19 (−0.05, 0.42)
Puerto Rico	43	1.71 (−0.13, 3.46)	1.22 (−0.47, 3.00)
Uruguay	76	9.64 (7.12, 12.26)	1.07 (0.61, 1.50)
Climatic zone[a]			
Tropical	44	1.71 (1.15, 2.27)	0.92 (0.55, 1.28)
Arid	80	5.10 (3.94, 6.18)	0.69 (0.49, 0.88)
Temperate	80	5.29 (4.61, 5.94)	0.58 (0.45, 0.71)

[a]Three cities with polar climate were not considered.

the highest in Paraguay (1.41%) and the lowest in Ecuador (0.01%). Although some estimates were uncertain, the results seemed more likely to be caused by the small number of locations in some countries than by a different pattern. By climatic zones, the MMTPs ranged from the 44th percentile in tropical climates to the 80th percentile in arid and temperate climates. Moreover, we observed a similar pattern in arid and temperate climates, showing a higher mortality impact for cold (5.10% and 5.29%, respectively) than for heat (0.69% and 0.59%). However, in tropical climates, the mortality impact of cold was much reduced (1.71%), while for heat, it was slightly higher than in the other climatic zones (0.92%). Location-specific relative risk and AF estimates are reported in Table S1; http://links.lww.com/EE/A300.

We separated the AFs into components related to moderate and extreme temperatures, as the ranges between the MMT and below and above the cutoff values for cold and heat, respectively. In all countries, most of the mortality risk attributable to temperature was related to moderate cold, while extreme temperatures (either cold or heat) were only responsible for a small fraction (Figure 2). However, extremely cold temperatures had a higher impact on mortality than extreme heat in most countries, but in Panama, Puerto Rico, and the overseas French territories, extremely cold temperatures had a higher impact. By climatic zones, arid and temperate climates show a similar pattern, with higher impact due to cold than heat. Conversely,

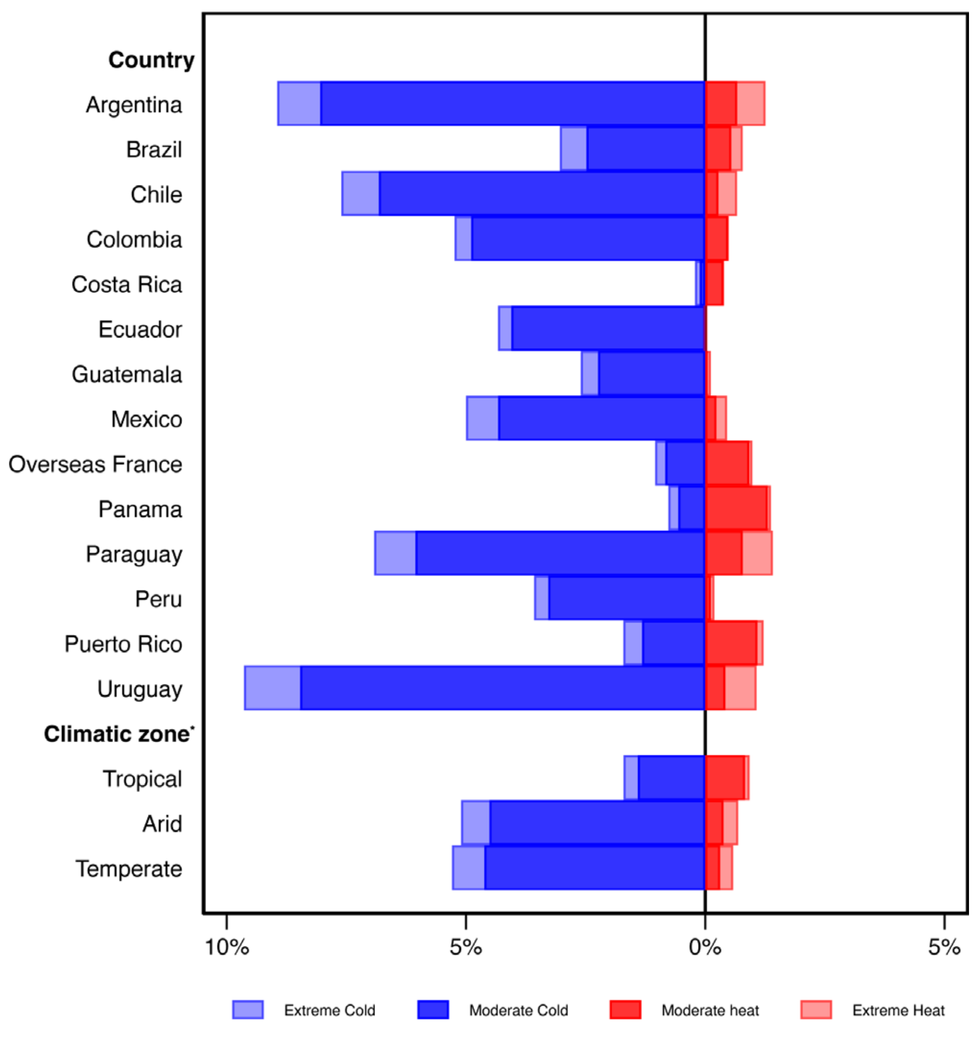

Figure 2. Fraction of all-cause mortality attributable to moderate and extreme cold and heat.

Table 3.

Economic loss (in million US dollars, $) due to all-cause deaths associated with cold and heat

		Total attributable deaths		Annual economic loss		Annual economic loss per 100,000 inhabitants	
	VOLY	Cold	Heat	Cold	Heat	Cold	Heat
Country							
Argentina	85.08	61,075	8,586	472.4	66.4	2.4	0.3
Brazil	68.31	113,528	29,170	352.5	90.6	0.8	0.2
Chile	94.59	23,128	2,018	198.9	17.4	2.5	0.2
Colombia	48.52	47,826	4,465	145.0	13.5	0.9	0.1
Costa Rica	68.30	67	121	0.3	0.5	0.1	0.1
Ecuador	39.55	4,624	6	36.6	0.05	0.8	0.01
Guatemala	23.28	1,608	72	4.7	0.2	0.4	0.02
Mexico	63.79	122,141	11,109	458.3	41.7	1.1	0.1
Overseas France	288.52	557	521	10.0	9.4	0.9	0.8
Panama	77.89	80	142	1.6	2.8	0.3	0.6
Paraguay	28.20	3,297	672	5.8	1.2	1.1	0.2
Peru	40.62	15,141	986	87.9	5.7	0.5	0.03
Puerto Rico	140.17	438	312	7.7	5.5	0.4	0.3
Uruguay	110.41	14,626	1,626	323.0	35.9	18.8	2.1
Climatic zone[a]							
Tropical		32,608	17,639	134.5	69.4	0.5	0.2
Arid		38,812	5,220	170.8	21.4	0.7	0.1
Temperate		336,716	37,132	1,799.3	200.5	1.7	0.2

[a]Economic loss calculated from country-specific VOLY for cities in each climatic zone. Three cities with polar climate were not considered.

in tropical climates, the impact due to cold was substantially reduced, while heat impact was higher than in arid and temperate climates.

The annual economic losses from all-cause deaths related to cold temperatures surpassed those attributed to heat in most countries, except Costa Rica and Panama (Table 3). For cold-related losses, economic estimates ranged from $0.3 million in Costa Rica to $472.2 million in Argentina, whereas for heat-related losses varied between $0.05 million in Ecuador and $90.6 million in Brazil. Moreover, the annual economic loss per 100,000 inhabitants due to cold was significantly higher in the Southern Cone (e.g., $18.7 million in Uruguay, and $2.5 million in Chile and Argentina), while for the other countries ranged between $0.1 to $1.1 million. For heat, the economic loss per 100,000 inhabitants ranged between $0.01 and $0.8 million, being much higher in Uruguay ($2.1 million). Additionally, the annual economic loss associated with cold in temperate climates was nearly 10 times greater than in tropical and arid climates. Conversely, heat-related economic losses were three to seven times smaller in arid climates than in tropical and temperate climates.

Discussion

This study provides evidence for the health burden and economic loss attributable to heat and cold in Central and South American countries covering various climates and populations. Most of the mortality burden in the region was caused by cold days compared with warmer days, generating a considerable annual total economic loss of $2.1 billion associated with cold and $290.7 million associated with heat.

The impact of temperature on daily mortality in Central and South America has been reported in several studies.[8–11] A recent multicity study conducted in Latin America reported similar findings to those we found in our study, showing a substantially higher proportion of deaths attributable to cold (5.19%) than to heat (0.66%).[11] Although our study did not include cities from all Central and South American countries, we included cities with cold-humid winters and hot-dry summers, like those from Chile and Argentina, and cities with cold-dry winters and hot-humid summers, like those from Central America (Mexico, Costa Rica, Guatemala, Panama, and Ecuador) and a few from the Caribbean (Puerto Rico, Guadalupe, Martinique). Our results by climatic zones showed a higher mortality impact from cold temperatures in arid and temperate regions than in tropical zones. The tropical climate may offer some protection against the health impacts of cold due to more homogeneously distributed temperatures and higher humidity levels. Conversely, we found a slightly higher impact from heat in locations in tropical climates, probably due to their higher temperatures compared to those in arid and temperate climatic zones.

A key strength of our study is the estimation of economic loss due to the nonoptimum temperature in the region. The Central and South American regions are in an asymmetrical position since their contribution to total greenhouse gas emissions is quite limited. Yet, it is highly vulnerable to the effects of climate change.[22] An impact that, according to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), will aggravate economic and social inequalities in the region.[23] A recent global study on projections of temperature-related excess mortality predicts a steep rise in heat-related excess mortality that, under extreme scenarios of global warming, is not offset by a decrease in cold-related deaths. The net impact is projected to be stronger in warmer areas of the Americas, particularly in locations with tropical climates, and notably high in arid or equatorial regions.[24]

In our study, we included the largest cities with populations of more than five million, including Sao Paulo and Rio de Janeiro (Brazil), Mexico City (Mexico), Buenos Aires (Argentina), Lima (Peru), Bogota (Colombia), and Santiago (Chile), cities in countries with the highest gross domestic product per capita (Uruguay, Panamá, Chile, and Argentina), and cities in countries with lowest gross domestic product per capita (Guatemala, Ecuador, and Paraguay y Peru). The annual economic loss due to nonoptimum temperatures in these countries was estimated as $2.4 billion per year, with a substantial proportion attributed to cold. In addition, our results showed some geographical variation across countries, more particularly for cold, with the highest economic loss per 100,000 inhabitants notably higher in countries located in the Southern Cone (i.e., Uruguay, Chile, and Argentina). Although direct comparison with economic loss in other locations is difficult, several studies also reported a considerable economic loss due to nonoptimum temperatures in several locations. For example, in the United States, the economic losses from heat-related deaths were estimated at $4.2 million and $5.1 billion in Michigan[13] and California,[12] respectively. A study in Australia reported an economic burden of $6.2 billion annually due to reduced labor productivity due to heat stress.[25] In France, the economic impact of selected health effects of heat waves amounts to €25.5 billion, mainly in mortality.[14] More recently, a study conducted in Wuhan, China, estimated the induced economic losses were around $22 billion.[26] Moreover, Helo Sarmiento et al[27] have already indicated that most research results highlight the high costs of the health effects of climate change in South America.

However, some limitations should be acknowledged. First, our results for some of the countries/climatic zones may not be representative, as not all the cities were included. Furthermore, most locations were urban areas; therefore, the results may not be generalizable to less urban locations. Furthermore, we did not conduct the assessment by age, sex, ethnicity, or specific causes due to the lack of data. Thus, we could not explore the vulnerability. However, previous studies in the region have already reported that the health impacts of nonoptimal temperatures are strongest among older adults,[10,11] although vulnerability by sex and education may vary between city.[10] Finally, further research is needed to expand our estimations, especially concerning economic losses, to other locations in the region, such as rural areas. This will enable a better understanding of the impact of climate change on both health and the economy within the region.

In conclusion, our results provide significant evidence and contribute to addressing the research gap on the health burden and economic losses associated with nonoptimal temperatures in Central and South America.[28,29] Therefore, it is essential to develop public health policies for mitigation and adaptation plans, providing detailed information to guide policymakers in implementing practical actions within the region to address the health effects of nonoptimal temperatures in the current climate change scenario.[30]

Conflicts of interest statement

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