Comprehensive Risk Mapping for Heatwave-sensitive Chronic Diseases Mortality in Argentina

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Abstract

Background

Climate change poses increasing risks to human health, with heat waves (HW) being a notable concern. This study pioneers the mapping of mortality risks associated with heat-sensitive Non-Communicable Diseases (NCDs) in Argentina, considering the simultaneous influence of HW and multiple underlying vulnerability factors.

Methods

The study integrates data from the National Statistical System, climate reanalysis, and remote sensing products by following the methodology outlined by the Climate Change Risk Mapping System of Argentina. Various vulnerability dimensions, including sociodemographic, environmental, pre-existing chronic conditions, and lifestyle-related factors were analyzed to provide spatially resolved risk assessments. To assess adherence between the risk map and mortality from a heat-related NCD, a random-intercept mixed effects model was fitted.

Findings

Between 2006 and 2010, heatwaves (HW) in Argentina displayed varied patterns in both intensity and extent. The vulnerability analyses reveal distinctive spatial patterns, with a notable broad diagonal from southwest to northeast. Maps indicate lower mortality risks in coastal and high-altitude areas of the northwest, with higher risks concentrated in the center-north of the country. Moreover, a positive association (RR 1·68; p<0·001) was found between age-standardized mortality rates from cardiovascular diseases and the overall risk estimates posed by HW.

Interpretation

The resulting risk map, developed through a protocolized methodology, underscores the intricate connections among contextual conditions, lifestyle attributes, and health outcomes. The study contributes empirical evidence to the understanding of the relationship between NCDs and HW.

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Research in context

Evidence before this study

Global climate change intensifies social inequality, ecosystem degradation, and health challenges, disproportionately impacting vulnerable groups. Individuals with Noncommunicable diseases (NCDs) are especially vulnerable to extreme climatic events and pandemics. NCDs, a primary global cause of death, often coexist with communicable diseases, particularly in low- and middle-income countries. Recent research underscores determinants like socio-economic factors, social inequities, childhood adversity, and lifestyle behaviors while recognizing biodiversity's role in diverse diets and food security.

Despite Argentina's access to excellent climatic data, it is underutilized for health interventions. A search from November 1st, 2023, to January 2nd, 2024, retrieved 23 results on Pubmed, Medline, Scielo, Lilacs, and Google Scholar using "heatwave+non-communicable-disease." Frequent mentions included, in descending order, cardiovascular disease, respiratory disorders, diabetes, mental health, and cancer. Additional searches for "satellite data" or "risk mapping" yielded three results, none employing the data for HW calculations or mapping. Most studies highlight a positive nonlinear association between maximum temperature and global mortality, especially impacting individuals with severe illnesses, notably the elderly and those with respiratory, cardiovascular, and diabetes conditions.

Added value of this study

This study marks the initial endeavor to create mortality risk maps for chronic diseases linked to climatic events. It utilizes satellite data and integrates them with vulnerability layers derived from socio-environmental factors extracted from the national census, vital statistics reports, and the "Risk Factors National Survey" datasets. The current study employs a methodology akin to that of another finished national project, the Climate Change Risk Mapping System of Argentina (SIMARCC) and includes, innovatively, satellite data-based environmental metrics and health-risk factors data. This work used satellite data which provided an opportunity to expand these investigations to other fields of study and explore the factors contributing to mortality related to this climatic phenomenon.

While multiple or compound risk maps have been extensively applied in our country over the past five years, predominantly in the realm of infectious or parasitic diseases, such applications have been lacking for NCDs. The spatial distribution of risks, constructed as the product of threat and vulnerability, significantly aligns with the spatial distribution of age-standardized mortality rates for a reference chronic condition, such as cardiovascular diseases.

Implications of all the available evidence

Maps play a pivotal role in guiding adaptation actions to address the effects of climate change, environmental conditions, and their impact on mortality due to Non-Communicable Diseases (NCDs). They serve as a crucial tool in directing efforts towards sustainable development. Considering chronic diseases as a health outcome in complex interaction with climate hazards and vulnerability conditions, along with other recognized health impacts of climate change (communicable diseases), builds knowledge from a syndemic perspective. This approach, rooted in the convergence of health concerns simultaneously and across populations, proves particularly beneficial for low- and middle-income countries grappling with limited resources to address population needs. Furthermore, the collected data, all georeferenced and with national coverage, can seamlessly integrate into existing or emerging digital platforms within the country. This, in conjunction with other tools, streamlines access to pertinent evidence for informed decision-making in the field of health.

Introduction

The frequency and intensity of extreme weather events are increasing because of climate change. This phenomenon can exacerbate existing challenges, including social inequality, urban stress, infrastructure deterioration, ecosystem degradation, and preexisting health conditions in different socio-ecological contexts. As indicated in the latest Intergovernmental Panel on Climate Change (IPCC) report for South America, it is disproportionately affecting the most vulnerable populations[1].

In recent years, scientific literature has increasingly shown the effects of extreme weather events on human health. Among these events, heatwaves (HW) have been associated with a higher incidence of cognitive impairment[2], kidney-related conditions[3], preterm births[4], as well as cardiovascular and respiratory mortality[5–7]. Temperatures have been consistently rising in all South American countries over time, with significant anomalies of 1 °C to 2 °C in various regions in 2021 compared to the period 1981-2010. Particularly in Argentina, higher mortality rates have been already observed during specific periods in which heatwaves of long duration and intensity occurred[8–10]. Several studies quantify the HW of the region [11,12] , however, they were focused on single cities[8,10–12], or they analyzed the effect of HW in a wider area by extrapolating meteorological station measurements[9].

Argentina is a geographically extensive country with the Andes mountain range to the West and vast plains to the East and South. This geographical diversity results in four major climatic zones, including warm, temperate, cold, and arid climates, as well as numerous microclimates[13]. Also, the sociodemographic conditions of this country present marked heterogeneities and long-standing social disparities, with strong differences between regions in terms of population age structure and size, socioeconomic development, and quality of life[14,15]. While the so-called Pampean region (in the center-east of the country) is the country's most populated, urbanized, and economically developed, the Northern region concentrates the most disadvantaged socio-demographic situation, with the highest rates of poverty and social inequality[14,16]. Thus, the climatic and sociodemographic diversity defines a wide variety of vulnerability scenarios to the effects of climate change across the Argentine territory. Therefore, identifying and prioritizing critical sectors is important for carrying out effective public health actions.

Although research on the impact of climate on human health has focused more on infectious diseases or immediate damages related to natural disasters, there is a growing recognition that climate change will intensify the impact on chronic health conditions such as cardiovascular diseases, cancer, and chronic respiratory diseases, among others[17]. Non-communicable diseases (NCDs) account for 63·3% of annual deaths in Argentina[18]. However, the social implications of this issue are often overlooked, and their potential has yet to be fully utilized for disease prevention and health promotion programs in the region. The National Risk Factor Survey[19] has revealed significant disparities in Argentina's diverse environment and intricate geography, influenced by factors such as age, gender, education level, and socioeconomic status. It is important to note, however, that there is limited research on the potential impact of climate change on NCDs in Argentina.

The increasing frequency of HW occurrence poses numerous health challenges and is crucial for health officials and other stakeholders to make well-informed decisions regarding risk management. This is important to not only mitigate the impact of climate change but also to minimize its effects on public health, taking into consideration the varying vulnerability profiles. Conducting comprehensive risk and vulnerability analyses can help identify areas where the community and its residents are most susceptible to climate-related threats. Maps that summarize the multiple environmental hazards and vulnerability dimensions that define specific health risks are crucial tools for visually highlighting the critical issues within a given geographical area.

Comparing risks across different geographic contexts can be challenging without a systematic approach to risk assessment. A lack of geographic context makes it difficult to determine where to focus efforts when developing risk reduction strategies. In this context, a multi-vulnerability perspective includes a range of sensitive targets, such as the population, infrastructure, and cultural heritage. These targets can help identify different hazards that require different capacities for prevention and response[20].

Risk maps are cartographic representations that visualize the distribution of specific risks, such as those related to climate, health, and socio-environmental factors, in a given territory. In the context of climate change, risk maps are created by combining environmental-climatic hazard maps with vulnerability maps, which summarise various indicators. Previous research has demonstrated the usefulness of these tools in exploring climate risk in populations and for policy planning[21]. This work aims to use a risk maps approach to examine the potential mortality risk associated with NCDs that are heatwave-sensitive. As far as we know, this is the first study to focus specifically on the spatial patterns of mortality risk related to chronic diseases and their connection to the climate, environment, and health.

From this framework, this study identifies and maps the levels of risk of mortality from heat-sensitive NCDs in the Argentine territory, using extreme hot temperature events (HW) as a hazard. A multi-vulnerability approach is employed, defining four dimensions that have implications for the effect of HW on populations: socio-demographic, environmental, pre-existing chronic conditions, and lifestyle-related factors. The outcome of the study is a risk map at the second administrative level (departments of Argentina) that will facilitate informed decision-making for policymakers and other stakeholders. We also aim to delineate a precise methodology to assess the risk of mortality by NCDs related to heat stress, so that these maps can be updated as new information becomes available about selected hazards and vulnerabilities.

Methods

Study design and data sources

This nationwide study in Argentina uses vulnerability data from the 2009-2010 period and hazard data from the 2006-2010 period, over 24 provinces (first administrative level units) and 527 departments (second administrative level). Assuming that health risk emerges from the overlap of climate hazards and vulnerabilities (by susceptibility and/or exposure of human systems)[1], we selected variables considering these key aspects. Publicly available data (national surveys, census data, official vital statistics reports, and satellite and reanalysis products) were processed and used to build georeferenced indicators and risk maps, following the methodology outlined by the Climate Change Risk Mapping System of Argentina[22], as detailed below. The study period chosen was 2009-2010 due to the greater availability of health and social data. Furthermore, spatial statistics and modeling were used to assess the correspondence between the maps depicting the distribution of the calculated total risk score and those illustrating the mortality rates attributed to a major heat-related cause of death, cardiovascular diseases (CIE-10 I00-I99, excluding I46). The Directorate of Statistics and Health Information (DEIS, Ministry of Health of Argentina) supplied the death count data, while population estimates were derived through exponential interpolation using the available census information. Thus, 2009-2011 mortality rates (three-year average) were estimated at the departmental level for cardiovascular diseases. Specifically, age-standardized mortality rates (ASMRs) per 100,000 person-year were obtained for the Argentine population of both sexes using the direct method (2010 Argentine population as standard).

Climate hazards: heatwaves data

Recognizing the complexities involved in dealing with multiple climate hazards, we decided to concentrate on a single source of hazard, specifically, HW, given that is the most widely recognized climatic factor related to one of the most prevalent chronic diseases in the country, cardiovascular diseases[23]. However, there is no consensus on the definition of the term heatwave in the literature[24]. As the objective of this work is to develop risk maps that could be used for the definition of public policies, we followed the National Meteorological Service of Argentina criterion, which defines a heatwave as the period in which the maximum and minimum daily temperatures are equal to or exceed the 90th percentile for at least three consecutive days during the warm period of the year (October to March)[25].

To calculate HW, daily maximum and minimum temperatures for the period 1991-2022 were downloaded from the ERA5-Land reanalysis product developed by the Copernicus Program (www.cds.climate.copernicus.eu). ERA5-Land is a state-of-the-art dataset of climatic variables for multiple land applications that have demonstrated added value for a wide range of *in situ* observations, ERA-Interim, and ERA5 reanalysis[26]. After retrieving the minimum and maximum daily temperatures, the 90th percentile (p90) was calculated for both temperatures. This was performed using the R software with the *ncdf4*, *raster*, and *rgdal* packages[27–30]. Cold and hot temperature anomalies were then computed by subtracting the respective p90 values from the daily maximum and minimum temperatures for the years 2006-2010. Then, if three or more consecutive days showed anomalies in both cold and hot temperatures, a heatwave was computed. These HW were aggregated averaging all pixels within each department of Argentina. Subsequently, the number of HW per year and the accumulated HW for the period 2006-2010 were counted and then normalized to a 0-1 scale. The scripts used to calculate HW are available at https://github.com/Dargwin/heat_waves_arg.

Vulnerability dimensions

Considering that NCDs are caused by a variety of factors from different sources, we decided to categorize vulnerabilities into four dimensions: sociodemographic, environmental, pre-existing chronic conditions, and lifestyle-related factors. This approach allows a more comprehensive understanding of the diverse factors contributing to a population's increased vulnerability[20].

To characterize the sociodemographic vulnerability dimension, data from the National Population, Household, and Housing Census of 2010 was utilized[31]. The selected indicators were the population with unsatisfied basic needs, individuals without completed primary school, individuals lacking university education, individuals without health insurance, and the population over 65 years of age. Each indicator was expressed as a percentage of the total department population. Additionally, child mortality rates were factored in, derived from our independent data processing based on the annual report of vital statistics by the Ministry of Health of the Argentine Nation.

For the environmental vulnerability dimension, we included three metrics: tree cover as a protecting factor, bare soil, and urban area percentage as increasing vulnerability. The first two metrics were obtained from MODIS (Moderate Resolution Imaging Spectroradiometer) imagery sourced from the MOD44B product. The percentage of urban area per department was determined using a land cover classification image from the MODIS MCD12Q1 product for the date '2010-01-01.' Specifically, we selected code 13 (urban areas) from the 'LC_Type1' band of this image. This entire process was done using the Google Earth Engine Software, and the script can be found in the provided GitHub repository. The percentage of urban area per department was calculated in QGIS 3.28.9-Firenze (http://www.qgis.org/). We utilized the complement of tree cover in our analysis recognizing the protective nature against heat stress where higher values of this layer indicate greater vulnerability.

The elements encompassed in the vulnerability dimensions of pre-existing chronic conditions and lifestyle-related factors were sourced from the National Survey of Chronic Diseases Risk Factors[19]. The target population for this survey comprises individuals aged 18 and above residing in towns with a population of at least 5000. Conducted every 4–5 years since 2005, this survey is a collaborative effort between the National Health Ministry and the National Institute of Statistics and Census of Argentina. In the current study, to maintain temporal consistency with the other dimensions under examination, we relied on the 2009 edition of the survey. From this dataset, we incorporated indicators at the provincial level for the pre-existing chronic conditions dimension. These indicators included the prevalence of diabetes, hypertension, and obesity. Similarly, for the dimension of lifestyle-related factors, we included the indicators: alcohol consumption, fruit and vegetable consumption, sedentaryism, and smoking. Similar to the approach taken with the tree cover percentage, we inverted the fruit and vegetable consumption layer. This inversion was implemented so that higher values of this variable now reflect higher values of vulnerability. This adjustment allows for a consistent interpretation across the various indicators, where higher values consistently correspond to heightened vulnerability in the study context. In each dimension, the factors were normalized to a 0-1 scale and then averaged to obtain a vulnerability score. Then, a vulnerability scale was defined, ranging from very low (values between 0 - 0.2), low (between 0.2 - 0.4), medium (0.4 - 0.6), high (0.6 - 0.8), to very high (0.8 to 1).

Risk mapping

Following the methodology outlined by the Climate Change Risk Mapping System of Argentina[22], the total risk of Heatwave-sensitive Chronic disease mortality (TR) was estimated by multiplying the hazard (cumulative heat waves of 2006-2010) with the average of all the vulnerability dimensions, as follows:

$$TR = \text{Hazard} \times (0{\cdot}25 \times SV + 0{\cdot}25 \times EV + 0{\cdot}25 \times PCV + 0{\cdot}25 \times LV)$$

where SV, EV, PCV, and LV are sociodemographic, environmental, pre-existing chronic conditions, and lifestyle-related factors vulnerability dimensions, respectively.

This weighting strategy maintains a balanced consideration of all dimensions in the overall assessment of risk. Besides, a specific risk was calculated for each dimension multiplying the hazard with the respective vulnerability score. Hazard, vulnerability, and risk values by department are available on the aforementioned Github page (Table S1) To compare the specific risk maps, it was established a uniform risk scale split into five equal intervals, from the dimension with the widest risk intervals (0 to 0·64).

Spatial analysis

Moran's I statistic was utilized to analyze the spatial autocorrelation, on the total risk and each risk dimension. The weight matrix for spatial lag was calculated using the Queen contiguity method.

In addition, a random-intercept mixed-effects model[32] that accounted for the spatial variability of the dataset (527 departments nested into 24 provinces) was performed, including the cardiovascular diseases ASMR as the response variable and the total risk as a covariate. As ASMRs are count data by nature, it is assumed that the distribution of the response given the random effects, follows a Poisson-like process. Therefore, a mixed-effects negative binomial model and a mixed-effects Poisson model were fitted, including provinces as random intercepts. Akaike's information criterion (AIC) was calculated to identify the better-fitting model, resulting in the negative binomial being the better model.

Results

After the determination and department aggregation of the HW, it can be seen that HW affected Argentina between 2006 and 2010 exhibited variations in both intensity and geographical extent (Figure 1, panels a-e). Each year shows different counts of HW and notable differences in their spatial distribution. For example, in 2006, HWs were predominantly concentrated in the center-west of the country (Figure 1, panel a). In contrast, 2008 shows two distinct zones with a significantly high occurrence of HW, one in the center-east and another in the southwest (Figure 1, panel c). When examining the cumulative HW for the period 2006-2010 (Figure 1, panel f), a southwest-northeast diagonal pattern emerged, characterized by a higher frequency of HW. Additionally, it is noteworthy that the coastal departments below the 40th parallel did not experience any HW.

The map of the vulnerability dimensions shows that the northern region of the country exhibits higher socio-demographic vulnerability (Figure 2a). This is due to factors such as the population with unsatisfied basic needs, without completed primary school, and without health insurance, which have high and very high values (Figure S1). Conversely, mid and low-vulnerability values are scattered throughout the country. Notably, the only region displaying very low vulnerability is comprised of certain departments in the capital districts and its surrounding areas (highlighted in the red box in panel 2a). Regarding the environmental dimension, it seems that northwest departments have high vulnerability values, while the southern departments show medium values, and the eastern departments exhibit low ones. Notably, the district of the capital and its surrounding areas display very high levels of environmental vulnerability (Figure 2b). As for pre-existing chronic conditions such as diabetes, hypertension, and obesity, they do not seem to have a distinguishable geographic pattern (Figure 2c), they vary across the territory, with the lowest values observed in the capital district. The lifestyle-related factors exhibit very low and low values in the northern part of the country, while the rest of the territory shows mid and high values (Figure 2d).

Figure 3 shows the levels of risk of mortality due to NCDs related to HW, broken down by the four proposed dimensions. Using Moran's indicator, spatial autocorrelation was detected for the total risk (Moran's I: 0·697) and each risk component (Moran's I sociodemographic risk: 0·78, environmental risk: 0·604, pre-existing chronic conditions risk: 0·703, and lifestyle-related factors risk: 0·72). All risk dimensions exhibit a notable diagonal of relatively higher risks from northeast to southwest. In the sociodemographic dimension (Figure 3a), the highest risk values are observed in the northeast of the country, mid and low values form a broad diagonal in a north-easterly direction, and very low-risk values are observed in all the coastal areas of Argentina, as well as in the east and northwest of the country. A similar pattern is observed in the environmental dimension, characterized by a broad diagonal in a north-easterly direction with mid and low values. However, there is a distinction in that the highest risk values are situated in the southwest of the country, while the extreme northwest exhibits very low-risk values (Figure 3b). Turning to the risk associated with pre-existing chronic conditions, high and very high-risk values are evident in the center-north of the country, and certain departments in the southwest register high risk (Figure 3c). Additionally, the northwest and southeast display very low-risk values, while the northeast and southwest present very low values of risk. Finally, within the lifestyle-related dimension (Figure 3d), the northwest and coastal southeast exhibit very low risk, while mid, high, and very high-risk values are observed in the north-easterly diagonal described. It is interesting to note how the broad diagonal pattern is reflected in all the dimensions, with lower values in coastal and high-altitude areas.

The map of the Total Risk of Heatwave-sensitive Chronic Diseases Mortality (Figure 4) shows zones with very low risk, such as almost all the coastal areas and the northwest of the country. It also exhibits the broad diagonal described for the risk by dimension, mainly demarcated by departments with mid and high-risk values. High values are detected in the centre-north of the country, and an isolated department in the south. It is interesting to note that all the high-risk departments are surrounded by medium-risk ones. The risk map showed a significant positive association between age-standardized mortality rates for cardiovascular diseases and the total risk score for heatwave-related chronic diseases. Specifically, the study found a significant positive association (p<0·001) between ASMR and the total risk score (RR 1·68; 95% CI 1·26;2·25) for Argentina (Table 1).

Table 1. Association between ASMR from cardiovascular diseases and the heatwave-related total risk score. Argentine, 2010.

Measure of Association		IRR (SE)	95% CI
	Total risk score	1.68* (0.25)	1.26;2.25
Measures of clustering		**Variance (covariance)**	
	Intercept (provinces)	0.21 (0.01)	0.01;0.04

Likelihood Ratio test vs. binomial negative model; χ^2 (p value) = 68.64 (p<0.001)
ASMR, age-standardized mortality rates per 100 000; SE, standard error; CI, confidence interval.
** p value < 0.001*

Discussion

This study provides the first maps that shed light on the mortality risks associated with NCDs linked to climate-related events, specifically the frequency of heat waves, across Argentina. The research used population information from the National Statistical System coordinated by INDEC along with climate and remote sensing data to identify factors that make people more vulnerable to dying from heat-sensitive NCDs. The methodology used in this study enables the creation of new maps as information on the hazard and vulnerabilities becomes available. The findings suggest a broad diagonal zone in Argentina stretching from the southwest to the northeast where mortality risks are higher due to various vulnerabilities rooted in contextual conditions and lifestyle characteristics of the Argentine population. The study also found that coastal and/or high mountain areas exhibit lower risk, highlighting the intricate interplay between environmental factors, regional demographics, and health outcomes in Argentina.

HW observed in Argentina varied both in extent and intensity over the study period, with changing patterns from year to year. This variability aligns with global trends noted in other countries[33], as the definition of HW points to anomalies in temperature that may not follow a consistent pattern. Interestingly, two specific regions, the northwest and coastal areas, experienced relatively minimal impact from these extreme events. The limited occurrence of HW along the coast may be attributed to internal variability processes, such as air cycling between sea and land surfaces, which have favored shorter and less frequent heatwave events in recent years[34]. Consistent with our findings, a recent study revealed a growing trend in the number of HW per year along the broad diagonal described[35]. An additional noteworthy aspect is the methodology's frequent updates and the availability of input data for heatwave identification. This enables a swift renewal of heatwave maps, providing higher spatial resolution compared to other strategies previously employed in the country[8–11]."

Concerning the diverse dimensions of vulnerability and their associated risks, the sociodemographic dimension reveals higher vulnerability values in the northern regions of the country, with intermediate values in areas of northern Patagonia. This sociodemographic pattern, strongly influenced by socioeconomic disparities in Argentina, has been previously documented[14,15] and is evident in the risk map for this specific dimension. Conversely, the spatial pattern of environmental vulnerability differs from that observed for its corresponding risk. The areas with high environmental vulnerability in the northwest of Argentina, characterized by low tree cover and bare soil, exhibited a low number of HW during the analyzed period, resulting in a low average risk over that time frame. Vulnerabilities related to pre-existing diseases and lifestyle habits, on the other hand, displayed moderate and high values in the broad diagonal described, and this pattern is reflected in their respective risk maps. These findings collectively suggest that HW becomes a significant trigger of mortality when unfavorable contextual factors (such as sociodemographic conditions) and individual conditions (including lifestyle habits and pre-existing health conditions) coexist.

This study differentiates among various dimensions of vulnerabilities, laying the groundwork for creating risk maps that can be interconnected with other hazards and/or vulnerabilities. The risk map was developed using the methodology established by the Climate Change Risk Mapping System of Argentina[22], an interactive tool to identify climate risks, spatially referenced, and designed for local interventions. Consequently, there exists potential for future integration between both sets of results. This integration can be the starting point to consolidate these and other numerous initiatives in the country. Related to similar topics, such as strategic climate plans, the country's adherence to an open data policy, and projects supported by PAHO[36].

The vulnerability and risk dimension maps offer valuable insights to define targeted actions in different regions. For instance, the northeast of the country exhibits elevated vulnerability and risk values in most socio-demographic aspects considered. In contrast, the southwest region shows high vulnerability primarily in terms of health coverage and primary education levels. Therefore, a strategic action plan to reduce the risk of heatwave-related deaths in the southwest should focus on these specific socio-demographic aspects. Conversely, in the northeast, a more comprehensive socio-demographic development plan would be warranted.

Recognizing the close relationship between living conditions and health[37], measures to enhance the quality of life in this region are expected to yield intrinsic benefits and significantly reduce the number of deaths from all causes, including non-communicable diseases (NCDs) sensitive to heat. In Argentina, some authors reported that during HW, the risk of death from all causes increased by 14% compared to other days in the hot season, with variations across age groups[8,9]. Argentina, like most countries in the Latin American region[38], still faces significant challenges to reduce its notable levels of social inequality, which widely impact the health of its population.

Specifically for heatwave-sensitive NCDs, this study provided empirical evidence on the relationship between mortality from cardiovascular diseases (a major heat-sensitive NCD reported in the literature)[5–7] and overall risk estimates during HW. This contribution enhances the reliability of the resulting risk maps as a useful tool for generating public health responses to climate change. It is important to note that the effort of this study to integrate the perspective of the epidemiology of NCDs into the analysis of climate risks is justified by a syndemic approach. In recent years, the notion of a syndemic of obesity, malnutrition, and climate change has been promoted, highlighting the importance of finding synergies to promote health and equity and to achieve benefits through double- or triple-duty actions[39]. This is particularly important from a cost-benefit perspective for low- and middle-income countries.

It is important to note certain limitations in this study. Firstly, some of the data used (factors of vulnerability related to lifestyle and previous health conditions) are only available at the provincial level; which could have been more detailed if it was disaggregated. Secondly, the aggregation of data on an annual basis might not identify seasonal variations in mortality due to extreme events like HW. Thirdly, regarding population data, the 2010 census was used, despite a more recent one has been conducted in Argentina in 2022. However, the complete data from the latest census is not yet available. Despite the acknowledged limitations, the findings presented provide a comprehensive insight into the mortality risk landscape, contributing significantly to the comprehension of health risks associated with climate change in the context of public health. Additionally, in this preliminary analysis, equal weight was attributed to each vulnerability dimension. Subsequent studies are imperative to ascertain whether certain dimensions bear more significance than others. If such variations exist, assigning appropriate weights to these dimensions in the formulation of risk maps becomes essential.

In addition, we chose to employ a climatic definition of heatwave. However, for future studies, it may be beneficial to consider indices that incorporate the influence of human sensitivity to extreme heat events. Examples include the Excess Heat Factor (EHF), which accounts for the physiological acclimatization process of the human body[40], or the Heat Index (HI), which calculates an apparent temperature based on a combination of air temperature and relative humidity[41]. These indices would provide a more specific measure for epidemiological studies.

The recognition of well-known avoidable environmental risks contributing to a substantial portion of the global burden of morbidity and mortality underscores the urgency to understand and address the evolving landscape of risks associated with environmental changes. Climate change, a significant driver of global environmental shifts, is altering patterns of vulnerability, risk, and disease, with a particular impact on populations with heightened susceptibility. Among these vulnerable groups, the elderly stand out, facing increased health risks due to their sensitivity to climatic conditions. It is crucial to emphasize that non-communicable diseases (NCDs) play a pivotal role in amplifying the impact of climate change, acting as common comorbidities that further escalate risks, especially in older adults. Aging, identified as a current demographic trend interacting with climate change[42], exacerbates heat-related risks in certain population groups.

Our findings suggest a correlation between the frequency of HW and mortality rates associated with heat-sensitive non-communicable diseases. Further research is essential to delve into this connection, leading to the development of strategies to mitigate its impact. Given the spatio-temporal variability of hazards and vulnerability factors, updating the risk map is crucial to ensuring its efficacy as a planning tool. In this regard, tools based on Geographic Information Systems prove highly effective due to their versatility in incorporating new information as it becomes available and updated[43]. Understanding the diverse spatial and temporal patterns of climate threats, in complex interaction with vulnerability conditions, provides a clearer insight into the impact of climate change on health, thereby guiding effective health interventions.

Declaration of interests

The authors declare no conflict of interest.

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Data Sharing Statement

The table with hazard, vulnerability, and risk values by department (Table S1), as well as the scripts utilized to calculate the heatwaves are available on https://github.com/Dargwin/heat_waves_arg. Any additional data is available on request from the corresponding author, [S.M]

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Figure Legends

Figure 1: Heatwaves that impacted Argentina depicted by department (administrative division of second level) during 2006-2010 (panels a-e), and cumulative number of heatwave events for the years 2006-2010 (panel f).

Figure 2: Different dimensions of vulnerability: (a) sociodemographic, (b) environmental, (c) pre-existing chronic conditions, and (d) lifestyle-related factors.

Figure 3. Maps showing the risk level of suffering mortality by a heat-sensitive noncommunicable disease according to the different dimensions of vulnerability: (a) risk due to socio-demographic factors, (b) risk due to environmental factors, (c) risk due to pre-existing diseases, and (d) risk due to lifestyle habits.

Figure 4: Map showing the risk level of mortality by non-communicable diseases, and heat-sensitive diseases integrating all the vulnerability factors assessed in this study.