Impact of Climate Change in Health in Colombia and Recommendations for Mitigation and Adaptation

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Impact of Climate Change in Health in Colombia and Recommendations for Mitigation and Adaptation

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1 Agence Française de Développement (AFD) implements France's policy on international development and solidarity. Through its financing of NGOs and the public sector, as well as its research and publications, AFD supports and accelerates transitions towards a fairer, more resilient world. It also provides training in sustainable development (at AFD Campus) and other awareness-raising activities in France.

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INTRODUCTION

Climate change has been called the most important threat to human health in the 21st century. It is estimated that if the temperature rises and its impact on the other climatic variables continues unchanged, it will kill more than 83 million people (1 percent of the world's population) in the next 80 years (Watts et al. 2020)—13 times the toll of the COVID-19 pandemic (World Health Organization 2023). Historically, only pandemics or world wars have posed such threats to human health. As a result, the issue has aroused unprecedented attention. In 2021, the World Health Organization (WHO) declared climate change the greatest health threat facing humanity (WHO 2021). Now, more than 195 governments have included climate change mitigation and adaptation as pillars in their multi-year plans,[3] and government health sectors have been developing plans to measure and respond to the impact of climate change on health. However, recognition of the links between climate change and health remains nascent, so these efforts have not yet been accompanied by strategic and actionable approaches to measure the impacts and ground the responses. This report contributes to

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3 In 2015, 195 countries signed the Paris Agreement. The agreement aims to limit global warming to well below 2o Celsius (C), preferably 1.5oC, compared to pre-industrial levels. To achieve this goal, countries have committed to reducing their greenhouse gas emissions.

addressing that gap by providing a framework for understanding the impact of climate change on human health in Colombia and by outlining the most effective actions to mitigate the threat.

In Colombia, a health sector response to climate change is especially urgent due to geographic vulnerabilities which impact the health risk to its people. Most people in Colombia live in the Andes region, which is prone to landslides and floods. Floods account for 45 percent of all natural hazards in the country and landslides account for 19 percent. Melting glaciers and rising temperatures have increased the frequency of these dangers. Droughts are also increasing—now occurring 2.2 times more often than in previous years and generating direct health consequences as well as indirect ones through impacts such as lower agricultural production. In addition, the El Niño Southern Oscillation phenomenon causes abnormal weather conditions, such as more intense droughts or extreme rainfall patterns. For example, the 2010–2011 La Niña floods caused 470 deaths due to the proliferation of waterborne diseases such as diarrhea, as well as economic losses of COP 3.4 billion. In total, between 1998 and 2011, weather-related disasters constituted around 90 percent of reported emergencies in Colombia. Significant risks also exist due to many hazards that have not yet materialized but are likely in the future. For example, communities along the Caribbean and Pacific coasts are at risk from sea level rise, storm surge, and temperature extremes. In addition, rising temperatures and

Photo: Chris Ford 'Rolling Hills' (CC BY-NC 2.0)

changes in rainfall patterns may further spread vector-borne diseases such as dengue fever and malaria to higher elevations in the country and cities such as Bogotá, which is home to more than 7 million people. For all these reasons, there is an urgent need for a schematic analysis and a comprehensive response to the threats of climate change to health in Colombia.

Although there are global and regional level efforts to address this threat, its complexity has made analysis and development of comprehensive strategies difficult. While the direct impacts of climatic variables are limited to increases in temperature, humidity, and precipitation, these variables also have numerous indirect impacts on health. Reporting by groups such as the Intergovernmental Panel on Climate Change (IPCC) has highlighted not only direct risks to health, but also impacts on infrastructure, productive activities, biodiversity, and ecosystems, which in turn affect health. For example, these variables can precipitate geological disasters that can damage health or affect the infrastructure necessary to ensure continuity of care. In turn, these impacts increase pressure on budget management, effective implementation of policies and programs, and identification of critical actors essential for timely responses to climate change hazards.

Photo: © Scott Wallace / World Bank 'Woman in flooding area. Colombia' (CC BY-NC-ND 2.0)

When evaluating the impact of climate change on health, it must be taken into account that we are dealing with a highly complex phenomenon. Simply put, the relationship between climate and health is very complicated. First, climate projections have a high degree of uncertainty, which then carries over to adaptation and mitigation plans that rely on those projections. Second, climate components are networked and interdependent, so a variation in one component affects the entire system. Third, the relationship between causes and effects is not linear, so small changes can have big impacts. For example, an increase of 1°C (Celsius) in global temperature can intensify the water cycle, which increases the probability of droughts and floods that threaten food security and displace people. On top of this, there is uncertainty about the long-term effects of climate change on health (Sarmiento-Suárez 2016). Further complicating the picture is the fact that climate change is only one of the global environmental changes and challenges associated with the Anthropocene (our current era in which human activity is the dominant force in changes to how Earth systems operates). Other examples include the loss of biodiversity and desertification, both of which trigger a cascade of direct, indirect, and ecosystem-mediated effects on health (McMichael et al. 1998). Finally, the picture is even more complex because these changes are all inter-related, so there are both additive and multiplicative impacts on health. Table 1 attempts to summarize this complicated picture by presenting these impacts, the global environmental changes associated with them, and the driving forces linked to the causal mechanism.

Table 1. Health Impacts Due to Climate Change

Driving forces and human pressures on the environment:	**Global environmental changes:**
economic growth, use of fossil fuels, greenhouse effect, population growth, and deforestation	climate change, depletion of the stratospheric ozone layer, loss of biodiversity, depletion of freshwater reserves, desertification, and land degradation

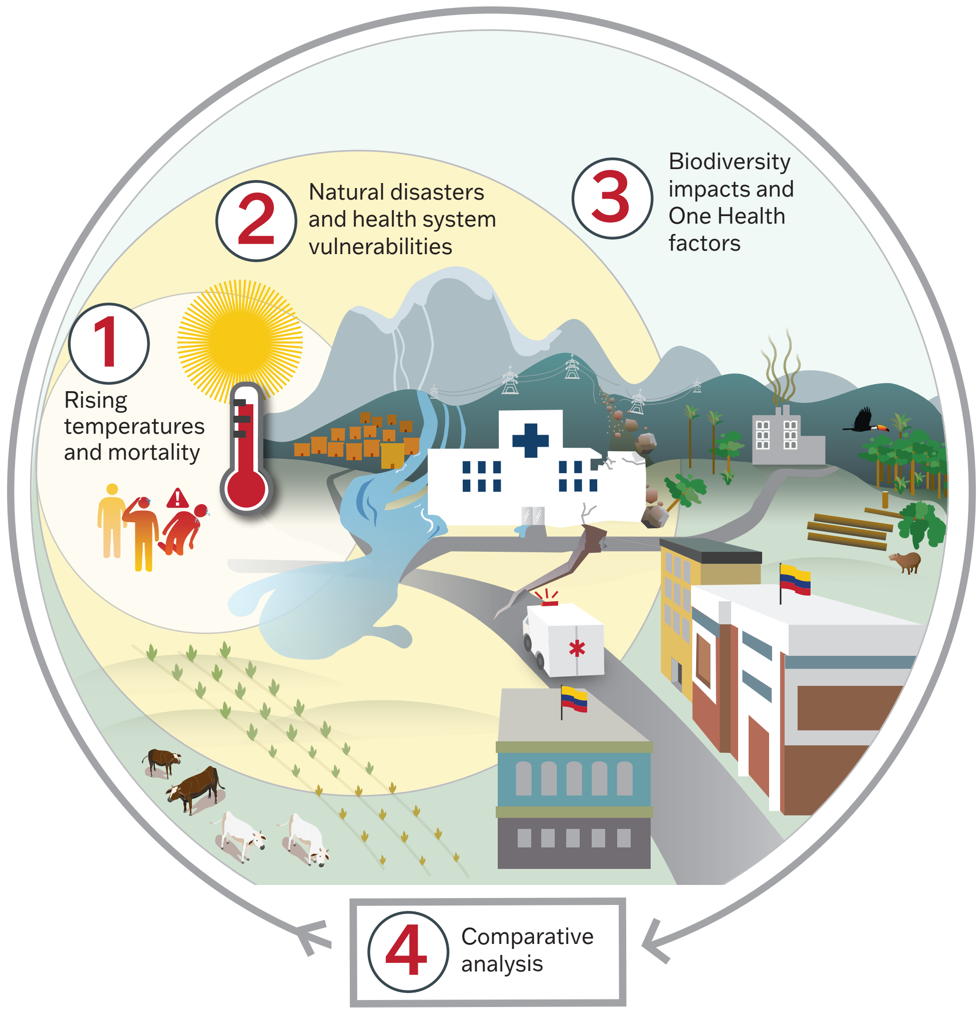
***Direct* health impacts**	***Indirect* health impacts**	**Health impacts caused by ecosystem changes**
Floods	Population displacements/ climate refugees	Changes in the dynamics of vector-borne diseases
Heat waves	Loss of livestock	Higher exposure to animal contact because of changes to the species' ecological niche
Increased exposure to ultraviolet radiation	Conflict	Emergence of new infectious diseases
Landslides	Damage to health infrastructure	Droughts and crop decline
Exposure to pollutants (forest fires, urban air quality)	Inadequate mitigation and adaptation strategies	Malnutrition
Increased burden of chronic diseases	Inequities	Loss of natural medicines
Increase in skin and respiratory allergies	Poverty	Urban blight

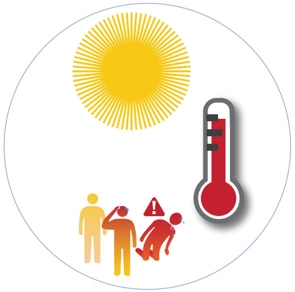
Due to the inherent complexity of the relationship between environment and health, environmental epidemiology has developed different models to address it. The most widely used models are (i) the model of socio-environmental determinants of health developed by the WHO; (ii) critical epidemiology; and (iii) the Ecosocial theory of disease distribution. Different strategies have emerged from these models, such as the ecosystem approach to health, with variations, including Ecohealth, the One Health approach, and the Planetary Health movement (Lebel 2005; WHO 2017; Planetary Health Alliance n.d.). These initiatives are all based on shared paradigm shift in the approach to public health: moving from an anthropocentric (human-centered) approach to a biocentric one that treats human, animal, and environmental health as inextricably linked. For example, the Ecohealth approach is centered on analysis of the determinants of health in socio-ecosystems, multidisciplinary approaches to develop a deeper understanding of environmental health problems, and the participation of civil society in the process. These principles focus on sustainability, social and gender equity, and translating knowledge into action. In recent years, academia and scientific societies in Latin America have made advances in environmental health understanding on the conceptual and methodological levels, but research funding is very low compared to scale of the needs and problems. Within this rubric, the relationship between climate change and health is one of the priority research topics (Rodríguez-Villamizar 2015).

Conceptual frameworks such as Planetary Health and One Health are useful to understand the interactions amongst human health, climate change, and biodiversity. These frameworks highlight three key challenges for climate change and health: (i) protecting health from the full range of climate impacts; (ii) building resilient and sustainable health systems for the 21st century; and (iii) promoting the health co-benefits of climate action. This report responds to these three challenges by providing data and tools useful for mapping vulnerability and sensitivity to temperature across Colombia, and for developing adaptation strategies focused on vulnerable populations and subnational areas. It also considers alternative pathways such as ecosystems and biodiversity, and the economic implications of those impacts.

This flagship report is focused on providing a holistic, actionable analysis of this complex but urgent issue—analysis rooted in methodologies specifically designed to assess the impact of climate change on health in Colombia, considering the complexity the factors involved and the particularities of the Colombian context. It is particularly designed to support policymakers in Colombia. Specifically, it lays the groundwork for policy action in Colombia and provides a starting point for World Bank collaboration with the government in understanding the phenomenon and taking concrete actions to tackle it, thereby improving health outcomes for all Colombians, and contributing to improvements in healthcare all around the world in the face of a global threat. It also offers insights for policymakers and academics around the world seeking ideas and toolkits to confront this daunting challenge.

Using an actionable approach for policymakers that considers the complexity of the Colombian context, this report divides the interaction of climate change and health into four components. Component 1 looks at the direct impact of climate change on human health by analyzing the effect of temperature increases on mortality at the subnational level. Component 2 expands upon Component 1 and analyzes climate change-induced natural disasters, such as landslides and floods, and their potential impact on human population, health infrastructure, and access to health services. Component 3 addresses indirect interactions between climate change and health, with a focus on the One Health approach and particularly the biodiversity implications for human health given their importance in Colombia. Finally, Component 4 brings the first three lines of impact analysis together in a common monetary analysis to illustrate health economic benefits and to facilitate investment and policy decisions. Each of these four components is described in more detail below.



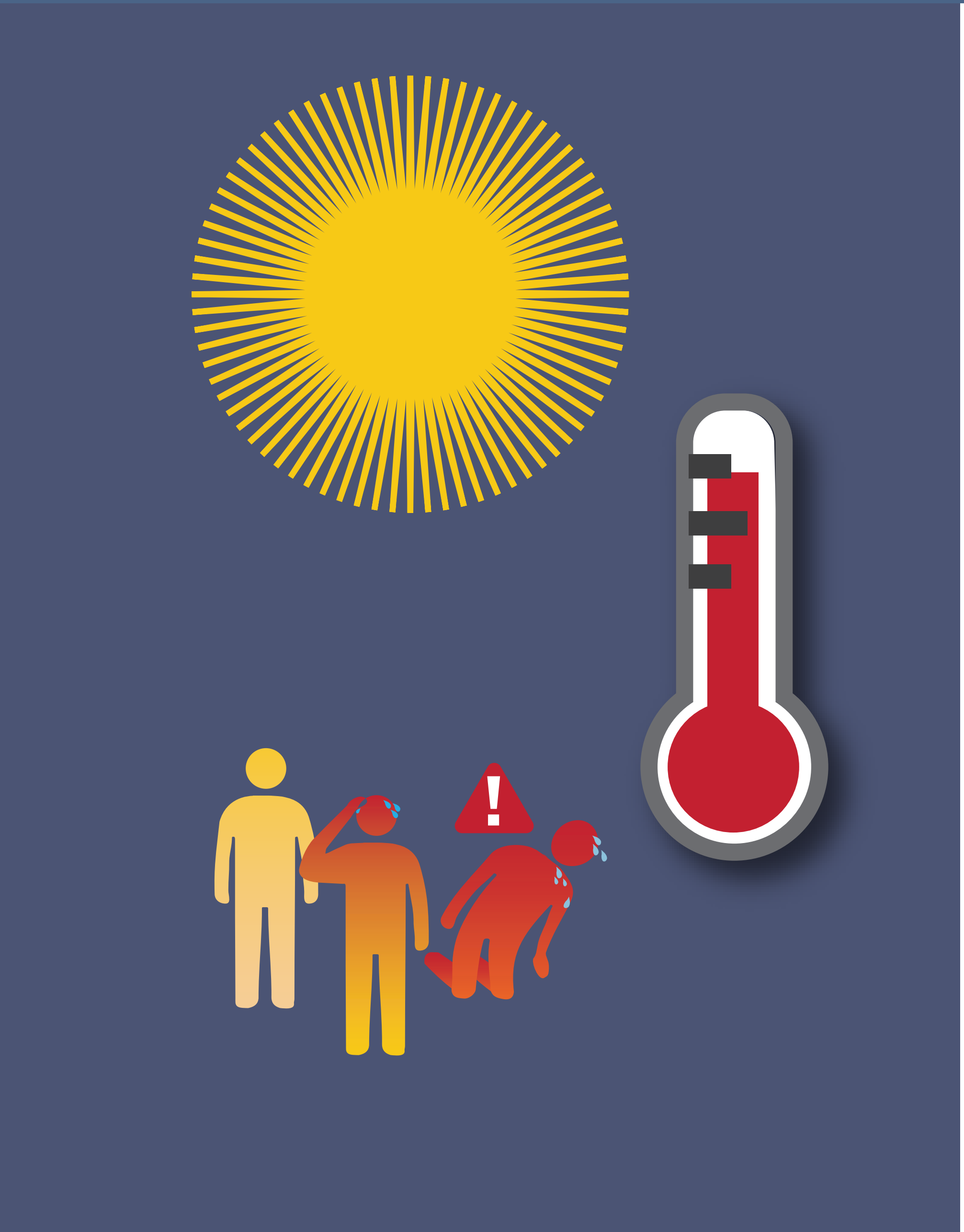


Component 1 addresses one of the major challenges Colombia faces in designing and implementing a policy to protect human health against climate change: namely, quantifying the impact. To build effective adaptation strategies, it is crucial that the government can quantify the health impacts of specific climate hazards and their distribution in each region of the country. This is a top priority for the government as a vulnerability mapping tool to build adaptation strategies. To address this need, Component 1 analyzes daily temperature-related mortality and its costs at the subnational level, by sex, age group, and cause of death, for the 2010–2019 period and 2050 Shared Socioeconomic Pathways (SSP) scenarios. The analysis uses the Global Burden of Disease (GBD) methodology, one of the most comprehensive and widely used approaches; this methodology also allows us to make comparisons with other countries.

Component 2 assesses climate change-induced natural disasters and how they affect health systems and vulnerable populations. It prioritizes resilience investments using developed compound and integrated risk indices at both national and departmental levels. Health facilities are further ranked based on criteria such as staff, supplies, infrastructure, climate vulnerabilities, and the communities they serve, both nationally and at the departmental level. For Bogotá, it identifies communities most affected by disruptions in health services during extreme events. To ensure uninterrupted supply chains and service access, critical road segments requiring cross-sectoral coordination and investment are also identified. The primary goal of these efforts is to offer guidance to policymakers, considering the diverse realities across regions of the country and the specific climate-induced challenges. The impacts and recommendations presented in this analysis align with existing legal frameworks, ensured through employing Frontline Rapid Scorecard to evaluate climate-related laws, regulations, and procedures across sectors. Finally, this data-informed deep dive employs cutting-edge approaches, including Artificial Intelligence and mathematical modeling, for prioritizations.

Component 3 focuses on biodiversity—a particularly important area of indirect climate impacts on health in Colombia. It assesses the drivers of biodiversity loss, emphasizing the interactions between biodiversity and air quality, and outlines the governance mechanisms being used to address environmental and climate-related health risks. Component 3 focuses on the crucial role that climate and biodiversity play as determining factors that shape not only the environment but also the ecological and social processes that take place within them. For example, changes in vegetation can increase global greenhouse gas emissions and impact capacity for absorbing carbon dioxide. Biodiversity can also contribute to adaptation efforts and reduce the risks of climate-related hazards to human health. In Colombia, water and air pollution constitute key environmental risks for biodiversity and health, increasing the burden of disease in the country. Drivers of biodiversity loss such as habitat loss and land use changes due to deforestation (which is the primary source of greenhouse gas (GHG) emissions in the country) threatens biodiversity, increasing channels of exposure for zoonotic diseases. In the context of a megadiverse country such as Colombia, paying attention to the interactions amongst health, biodiversity and climate change is essential. Lastly, Component 3 identifies and analyzes national and subnational governance structures and capacities—a key step for operationalizing effective policies and interventions addressing the interactions between biodiversity and human health.

Component 4 supports decision-making by integrating the findings from Components 1–3 into a comparative analysis the costs of intervention versus the costs of inaction. To this end, Component 4 integrates the findings of the economic burden associated with non-optimal temperature (Component 1), the implications for the cost of reconstruction of infrastructure affected by extreme events (Component 2), and indirect effects of climate change on health (Component 3) and complements it with an estimate of the costs associated with mortality and morbidity of six selected outcomes, using the World Bank's Climate and Health Economic Valuation Tool (CHEVT). In addition, the component identifies climate change adaptation interventions that have been proposed in the health sector and documents their implementation costs. Assessing the cost of inaction contributes to raising awareness and stimulating policy development about current and future health-related challenges that deserve attention. Highlighting the policy interventions from the health sector and their costs, contributes to cementing a roadmap of interventions to tackle the challenges of climate change.



COMPONENT 1

Burden of Disease Attributable to Non-Optimal Temperature in Colombia and Its Costs: 2010–2019 and Future Projections

Colombia is highly vulnerable to climate change (National Planning Department (DNP) 2011). Global warming increases the frequency and severity of extreme hydro-meteorological events such as floods, hurricanes, heat waves, and droughts, that generate health effects—as observed with the overflowing of the Mocoa, Mulatos, and Sangoyaco rivers in 2017 and with Hurricane Iota in 2020 (Fajardo López and Reyes Burgos 2018; Government of Colombia 2020).

The burden of disease due to climate change has a broad spectrum of effects, including direct impacts of natural disasters such as trauma and injuries, and also indirect impacts produced by climate variability (i.e., changes in temperature, humidity, and rainfall), such as the spread of infectious diseases (e.g., malaria, dengue, cholera, and respiratory infections) and increases in chronic diseases (e.g., cardiovascular diseases, respiratory diseases, diabetes mellitus, malnutrition, and mental disorders) (Sarmiento-Suárez 2016). Added to all this is potential infrastructure damage that can impair or entirely interrupt the provision of health services.

It is important to note that climate change affects mortality due to not only high temperatures but also low temperatures. This is because climate change increases both the global average temperature and also the range of the temperature variance. This affects the oscillations in climate or climatic variability that can occur in different time scales: seasonal, intra-seasonal, between years, and over the course of a decade (Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM n.d.). In fact, the displacement of the Intertropical Convergence Zone in a northerly direction as a result of greenhouse gases has altered the seasonal pattern of rainfall and has increased the occurrence of climatic anomalies in relation to the El Niño-Niña-Southern Oscillation cycle (ENSO phenomenon). On the other hand, the increase in the energy of the atmosphere intensifies the water cycle, which contributes to increased precipitation in the rainiest areas and less in the driest areas. As a result of all of these factors, extreme cold and heat events occur more frequently.

The temperature at which mortality is lowest is known as the “minimum mortality temperature” (MMT) and it coincides with the lowest point on a temperature/mortality curve that generally has a U-shape (Lee et al. 2017). “Suboptimal temperatures” are ones that

Photo: ©2010CIAT/NeilPalmer ‘Shadow 1’ (CC BY-SA 2.0) move away from the MMT. According to the Institute for Health Metrics and Evaluation (IHME), in Colombia, the attributable risk for mortality due to high temperature is 3.43 percent due to drowning, 2.21 percent due to interpersonal violence, 1.85 percent due to traffic accidents, and 1 percent due to lower respiratory infections. Meanwhile, the fraction attributable to low temperatures is 4.73 percent for chronic obstructive pulmonary disease (COPD), 3.39 percent for lower respiratory infections, 3.26 percent for ischemic heart disease, 2.92 percent for stroke, 2.34 percent for chronic kidney disease, and 1 percent for diabetes mellitus (IHME n.d.).

These growing effects of climate change on the health of the Colombian population make it necessary to identify strategies and policies to mitigate and adapt to its impact. Due to the geographical and cultural diversity of the country, local-level interventions are required to better adapt to climate change. Therefore, it is crucial to have disaggregated information to support decision-making. In fact, climate change scenarios predict that temperature increases will be uneven across Colombia, with the departments of Arauca, Vichada, Vaupés, and Norte de Santander having the most pronounced increases (+2.6ºC for 2070–2100) (IDEAM 2023).

The complexity of the relationship between climate change and health means that robust methods are required to quantify impact. Recent methodological advances in environmental epidemiology move away from traditional epidemiology because phenomena characterized by the nonlinearity of associations must be studied. Several studies have described the associations of temperature with mortality using distributed lag nonlinear models (DLNLM) and have validated their use as a standard methodology to study the effects of temperature (Gasparrini 2010). On the other hand, the development of methods to estimate the burden of disease using Bayesian methods has allowed the evaluation of the impact of different risk factors, such as suboptimal temperatures, on specific causes of mortality—finding evidence of association for 17 different events (e.g., cardiovascular diseases, diabetes, suicide, violence, and respiratory diseases) (Burkart et al. 2021). However, there is still no consensus on the appropriate method for assessing the impact of the burden of disease at global, regional, and local levels due to exposure to changes in global temperature values.

On the other hand, the economic impact of these temperature changes (mainly in the form of rising temperatures due to climate change) is increasing and is relevant for world economies. Callahan and Mankin (2022) estimated that cumulative losses from 1992 to 2013 from anthropogenic extreme heat could range from COP 5 trillion to COP 29.3 trillion worldwide. These amount to 6.7 percent of gross domestic product (GDP) per capita per year for regions in the lowest income decile, but only 1.5 percent for regions in the highest income decile (Callahan and Mankin 2022).

Several high-income countries have quantified the economic costs of the health hazards caused by high temperatures. For example, in the United States, estimated economic losses due to heat-related deaths ranged from approximately USD 4.2 million to USD 5.1 billion (Knowlton et al. 2011; Gronlund et al. 2019; and Chen et al. 2022). Similarly, a study in Spain on heat-related deaths showed that hospitalization costs for these deaths amounted to EUR 426,087 in 2002–2006 (Roldán et al. 2015). In Australia, for 2013 and 2014, the additional economic burden due to reduced labor productivity caused by heat stress was USD 6.2 billion per year (Chen et al. 2022; Zander et al. 2015).

21 out of every 100 Colombian pesos of GDP loss in Colombia due to people who died prematurely from the nine diseases explored were **caused by exposure to the environmental risk factors** analyzed by the INS (INS 2018)

In Colombia, measurements of the economic impact of climate variability are scarce. There are approximations towards the estimation of the economic burden by environmental risk factors. For 2016, the National Institute of Health (INS) calculated the productive years of life potentially lost (PYPLL) due to environmental risk factors of air, water, and others, and the indirect costs they represented (INS 2018). The deaths caused by the nine diseases analyzed by the INS analysis represented a total of 169,136 PYPLL and COP 2.7 trillion of economic burden, of which 34,524 PYPLL and COP 585 billion were due to environmental risk factors. In other words, 21 out of every 100 Colombian pesos of GDP loss in Colombia due to people who died prematurely from the nine diseases explored were caused by exposure to the environmental risk factors analyzed by the INS (INS 2018).

Because of all these factors, the research presented in this report estimates the burden of disease related to suboptimal temperatures in each department of Colombia for 2010–2019 and 2020–2050. It also estimates the effect of these changes in temperatures on the economic burden of disease due to premature mortality in Colombia.

Objective

The objective of the analysis presented in this section (Component 1) is to estimate the disease and economic burden of mortality attributable to suboptimal temperature in Colombia, by departments, for 2010–2019 and 2020–2050.

Methods

Scope

This is an ecological disease burden study that used the methodology previously published by the GBD-2019 (GBD 2019 Diseases and Injuries Collaborators 2020).[1] The study included a review of published scientific literature on economic burden and disease studies to identify the methodological approaches used to estimate disease burden by suboptimal temperature (see Annex on Methodology for a descriptive analysis of temperature and demographic structure). It also explored national and international sources of information on temperatures, disease burden, vital statistics, demographics, and socio-economic factors.

The disease burden estimate and projections are framed in the non-optimal temperature approach; this is different from the extreme temperatures approach, and is comparable to the GBD attributable burden analysis available for Colombia and other countries (Roque et al. 2021).

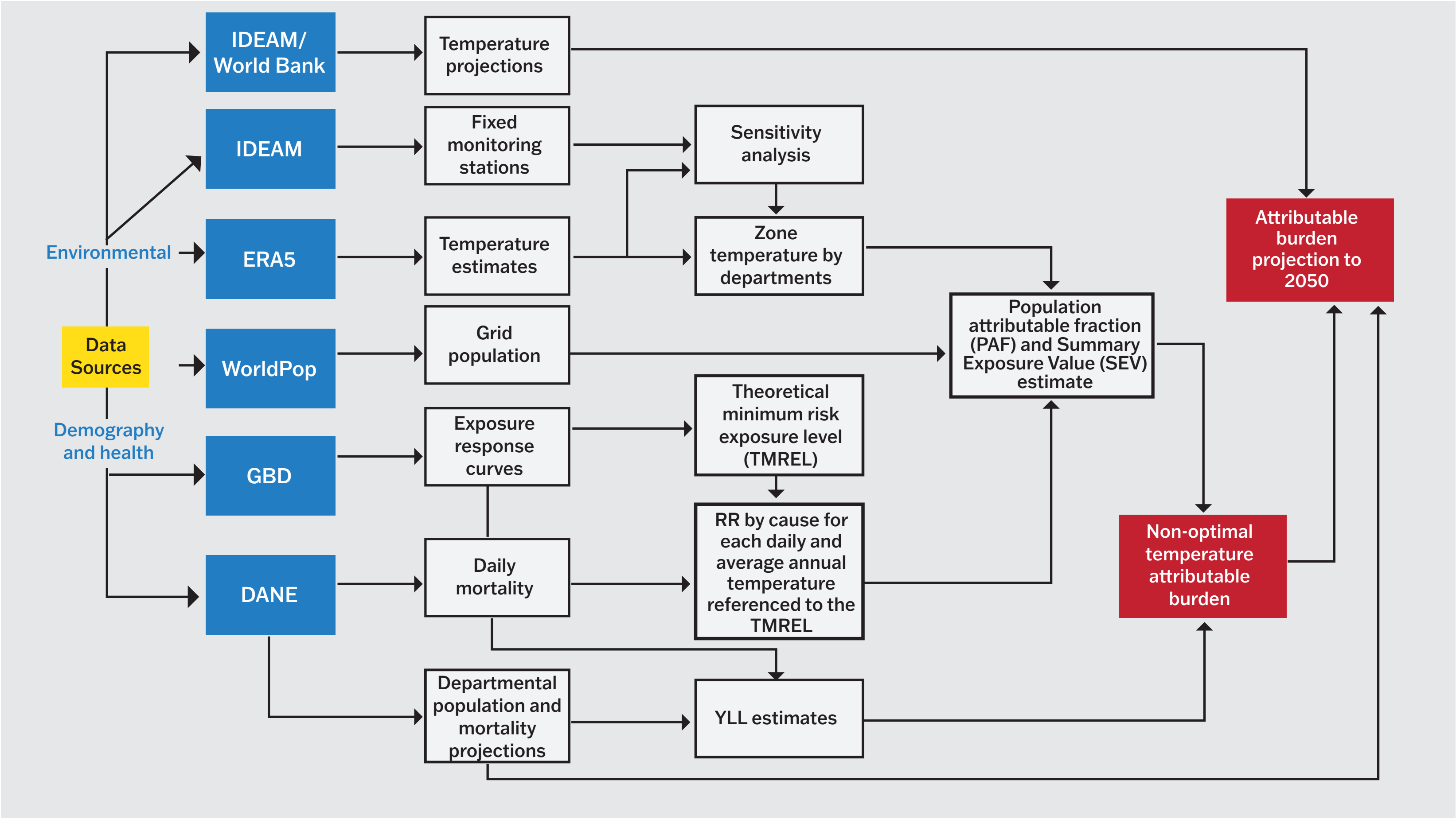
1 GBD = Global Burden of Diseases, Injuries, and Risk Factors Study.

Methods

The study used environmental, demographic, epidemiological, and economic sources of information. The environmental sources included the daily temperature per grid of 0.25 degrees from the ERA5[2] satellite reanalysis; the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) monitoring network for 10 Colombian cities; and the temperature projections for climate scenarios (source: Climate Change Knowledge Portal). Demographics sources included data from population projections and retroprojections (Colombian National Department of Statistics (DANE)), vital statistics (DANE), and spatial distribution of the population (WorldPOP). The epidemiological sources used were the exposure-response curves for 17 causes of mortality associated with temperature variation and the minimum mortality temperatures by climatic zone (TMRELs) of the GBD-2019 for Colombia. For the economic analysis, the study used data on the labor market (DANE), the annual minimum wage (AMW), and average productivity measured in GDP per capita.

2 ERA5 is the fifth generation European Center for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis of the global climate covering January 1940 to the present.

Figure 1. Flowchart: Methodology for Estimating Disease Burden Attributable to Non-Optimal Temperatures



To estimate the burden of disease attributable to suboptimal temperatures, the study calculated the daily mortality risks (2010–2019) for 17 causes based on the response exposure curves for each pixel and then aggregated the risks by climatic zone and department. It also obtained values of prevalence of temperature exposure and proportions attributable to temperature per day, climatic zone, and department. Finally, the study described deaths and determined attributable YLL (years of life lost). For economic burden, it calculated and economically valued productivity loss due to attributable premature mortality (PYPLL) using two scenarios (AMW and GDP per capita).

The estimated disease and economic burden projected for 2020–2050 was calculated using five greenhouse gas emission scenarios in the Shared Socioeconomic Pathways (SSP) of the Intergovernmental Panel on Climate Change (IPCC) (Table 2) to simulate attributable mortality rates using linear departmental regression models for the sum of the causes of death considered.

Table 2. Shared Socioeconomic Trajectories by Emission Scenarios

Shared socioeconomic trajectories	Scenario
SSP 1-1.9	Very low greenhouse gas emissions: CO_2 emissions reach zero by 2050.
SSP 1-2.6	Low greenhouse gas emissions: CO_2 emissions reach zero by 2075.
SSP 2-4.5	Median greenhouse gas emissions: CO_2 emissions remain the same until 2050 and fall but not reach zero by 2100.
SSP 3-7.0	High greenhouse gas emissions: CO_2 emissions double by 2100.
SSP 5-8.5	Very high greenhouse gas emissions: CO_2 emissions triple by 2100.

Source: Adapted from International Panel on Climate Change (2019)

Note: CO_2 = carbon dioxide; SSP = Shared Socioeconomic Pathways

Results

This section presents the temperatures and changes in Colombia's population structure for 2010–2019. It also presents estimates of disease burden attributable to suboptimal temperatures for the 17 causes, disaggregated by sex, age group, and department. The section then provides the attributable economic burden calculations and, finally, the projections of the disease and attributable economic burden for 2020–2050. It presents the most important results for decision making, due to their impact on human health, economics, and novelty: showing the impacts according to the demographic structure and disaggregation by sex for each department to support making local decisions targeted to specific population groups.

Key points

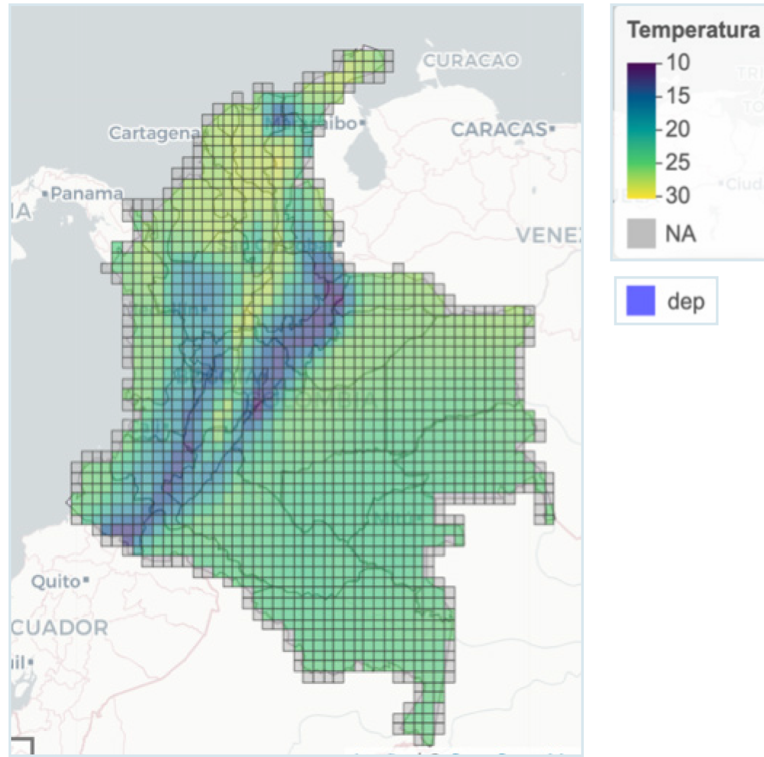
- To our knowledge, this is the first study reporting non-optimal temperature effects disaggregated by mortality cause, sex, age group, and department in Colombia.
- This study's calculations found that 0.43 percent of total mortality (1.05 percent of 17 mortality causes analyzed) in 2010–2019 was attributable to non-optimal temperatures: 24.3 percent was attributable to heat and 75.7 percent to cold.
- Most of the attributable burden occurred in men in the 70+ age group—a group expected to increase in the future due to population demographic transitions.
- Colombia's heat-attributable mortality rate will surpass its cold-attributable mortality rate in 2040 for the climate change projection scenario SSP5 (8.5°C), or in 2049 for SSP3 (7.0°C).
- The economic burden due to cold and heat variations varied from COP 0.26–1.5 and COP 0.38–1.2 trillion, respectively, and it was concentrated in 15–44 year-old people.
- The cumulative economic losses due to non-optimal temperature related with premature mortality ranged from 0.1 to 0.4 percent of the 2019 GDP in Colombia.

Temperatures, Mortality, and Demographics, 2010–2050

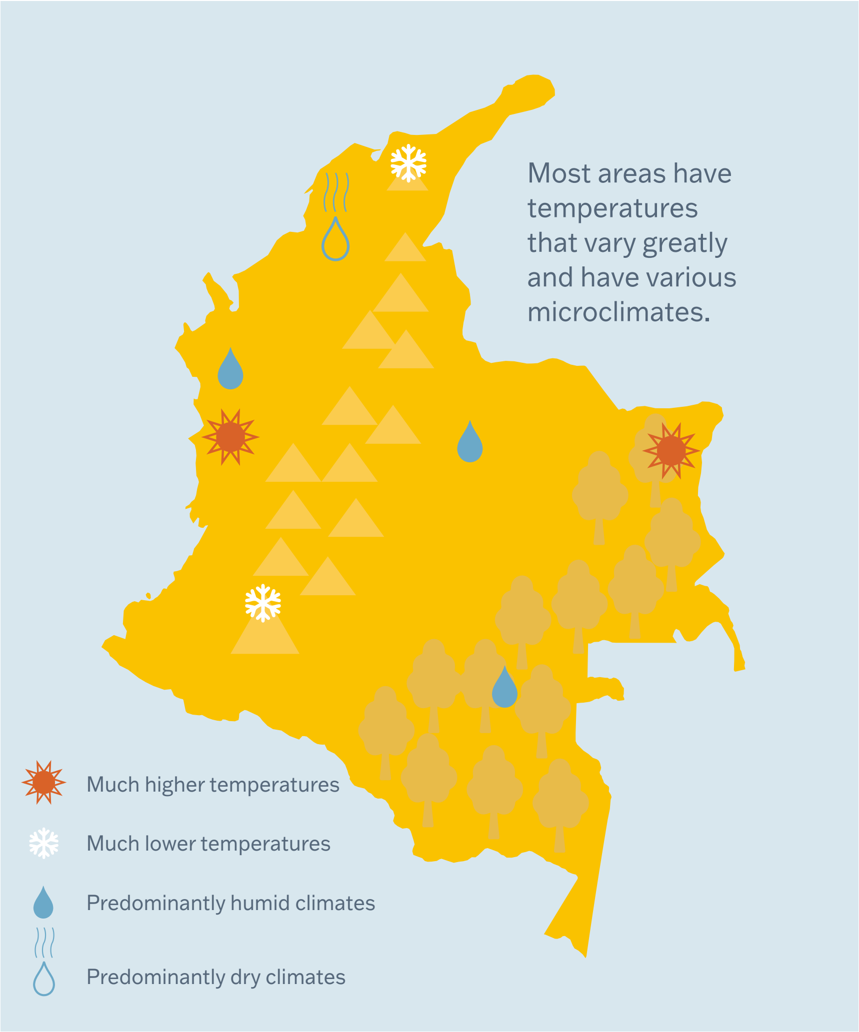
Temperatures

Satellite temperature analysis. For 2010–2019, Sucre was the department with the highest average temperature (28.18°C, SD=±1.26) and Bogotá, D.C. recorded the lowest (13.08°C, SD=±2.52). Temperatures varied greatly in most departments in the Andean region, particularly those in the Magdalena River Valley (Huila, Tolima, Cundinamarca, Caldas, Boyacá, Antioquia, and Santander). Temperatures were more homogeneous in the Caribbean region, except for departments containing the Sierra Nevada de Santa Marta (Magdalena, La Guajira, and Cesar). Throughout the departments of Orinoquía and Amazonia, temperatures were fairly constant (Figure 2). Table A1.5 in the methodological annex to this report presents the statistics by department.

Figure 2. Spatial Distribution of Daily Temperature per Pixel, Mean of Daily Temperatures 2015–2019



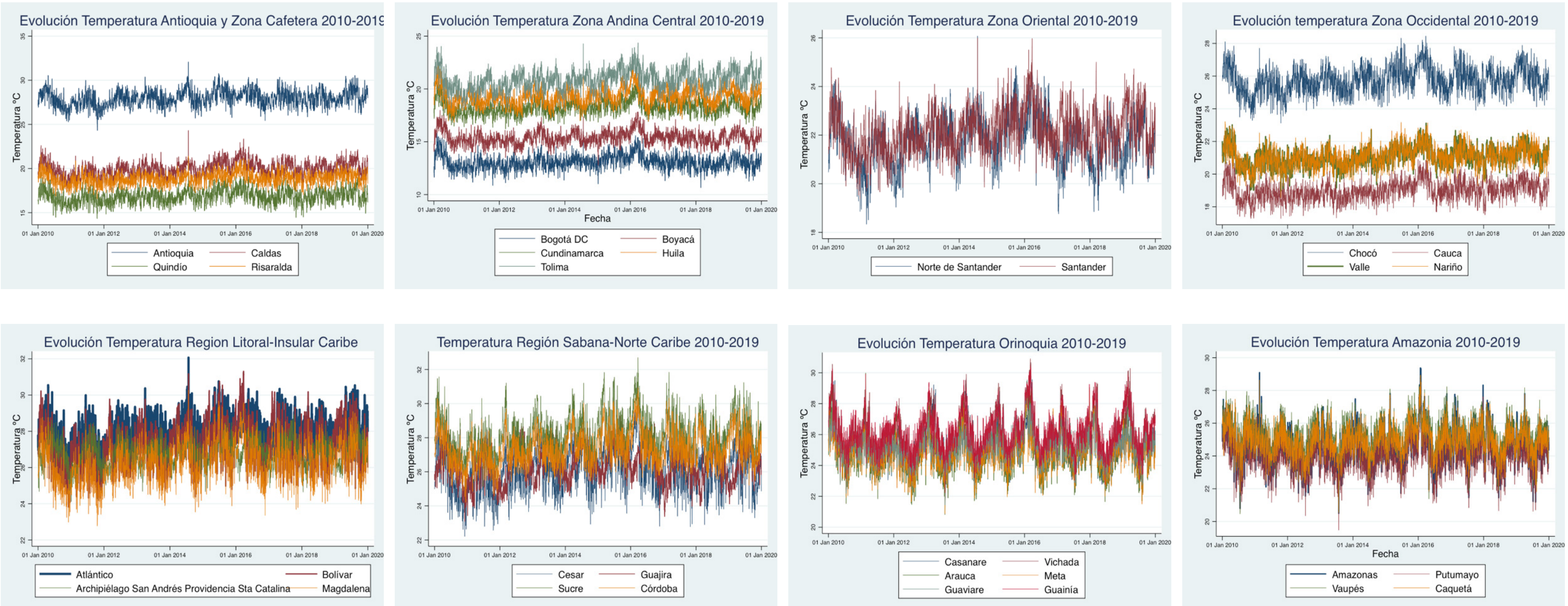
Source: ERA5 (Hersbach et al. 2020)



Temperature changes by regions and zones (Figure 3). Temperatures varied greatly in both the Andean zone (Central and Eastern) and in the Cafetera region and Antioquia. The Western region also had geographical variability in temperatures, except in most of Chocó which has predominately a super-humid warm climate and the highest temperatures in the region. On the other hand, the Caribbean region has mostly dry warm temperatures. But it is also home to some microclimates such as the extreme cold of the Sierra Nevada de Santa Marta; the humid warm climate of the archipelago of San Andrés, Providencia, and Santa Catalina; and the semi-humid climate in the south of Bolívar and in the southern municipalities of Córdoba.

In the Orinoco and Amazon regions, warm and humid temperatures prevailed with the exception of the Andean piedmont which has temperate and cold climates. Temperatures in all departments of these regions follow a similar pattern, with slightly higher temperatures in Vichada.

Figure 3. Evolution of Average Temperature, Analysis by Geographical Units 2010–2019



Source: European Centre for Medium-Range Weather Forecasts (n.d.) (ERA5).

Mortality and demographic structure

Mortality

Between 2010–2019, a total of 2,147,531 deaths were reported in Colombia. The causes of death included in the present analysis accounted for 884,628 deaths, which is 41.1 percent of the total for the period. These deaths occurred mostly in men, in people 70 years and older, and in the departments with the most populous cities such as Cali, Medellín, and Bogotá, D.C. (see Table A1.11 in the annexes for full data results by location and cause of death).

Causes of death. The main causes of death in this study were ischemic heart disease (39.4 percent), homicide (15.6 percent), and chronic obstructive pulmonary disease (14.3 percent) (Figure 4).

This study identified 583,117 deaths from cardiorespiratory causes between 2010 and 2019, with ischemic heart disease accounting for the largest share of these deaths (59.7 percent). Cardiorespiratory mortality causes included stroke, hypertensive heart disease, ischemic heart disease, chronic obstructive pulmonary disease (COPD), lower respiratory tract infection (LRTI), cardiomyopathy, and myocarditis (Methodological Annex, Table A1.11).

Mortality demographics. As shown in Figure 5, nationwide in Colombia, preventable mortality is higher in men; relationship that decreases over time, especially amongst males between 10 and 20 years of age. Also, preventable mortality in older adults increased between 1990 and 2030.

Figure 4. Distribution of Mortality by the 17 Causes Analyzed, 2010–2019

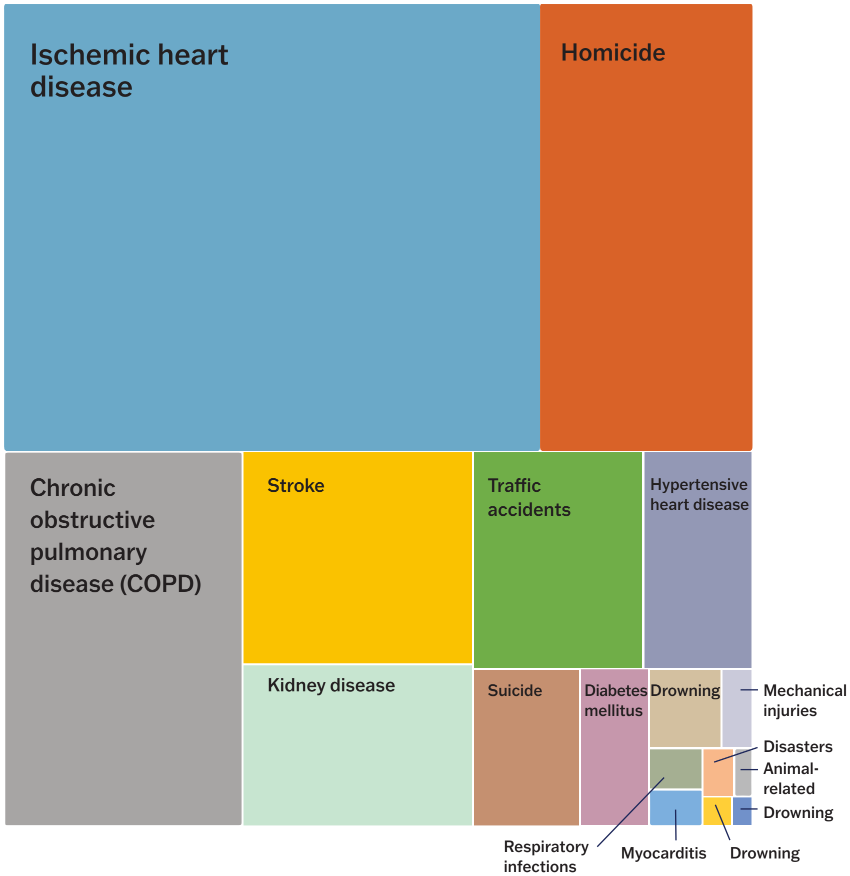
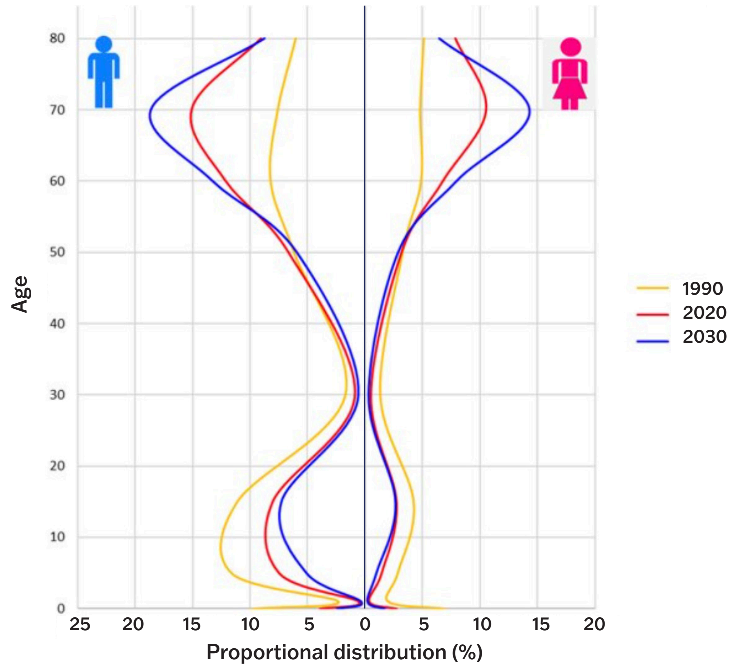


Figure 5. Structure of Preventable Deaths in Colombia

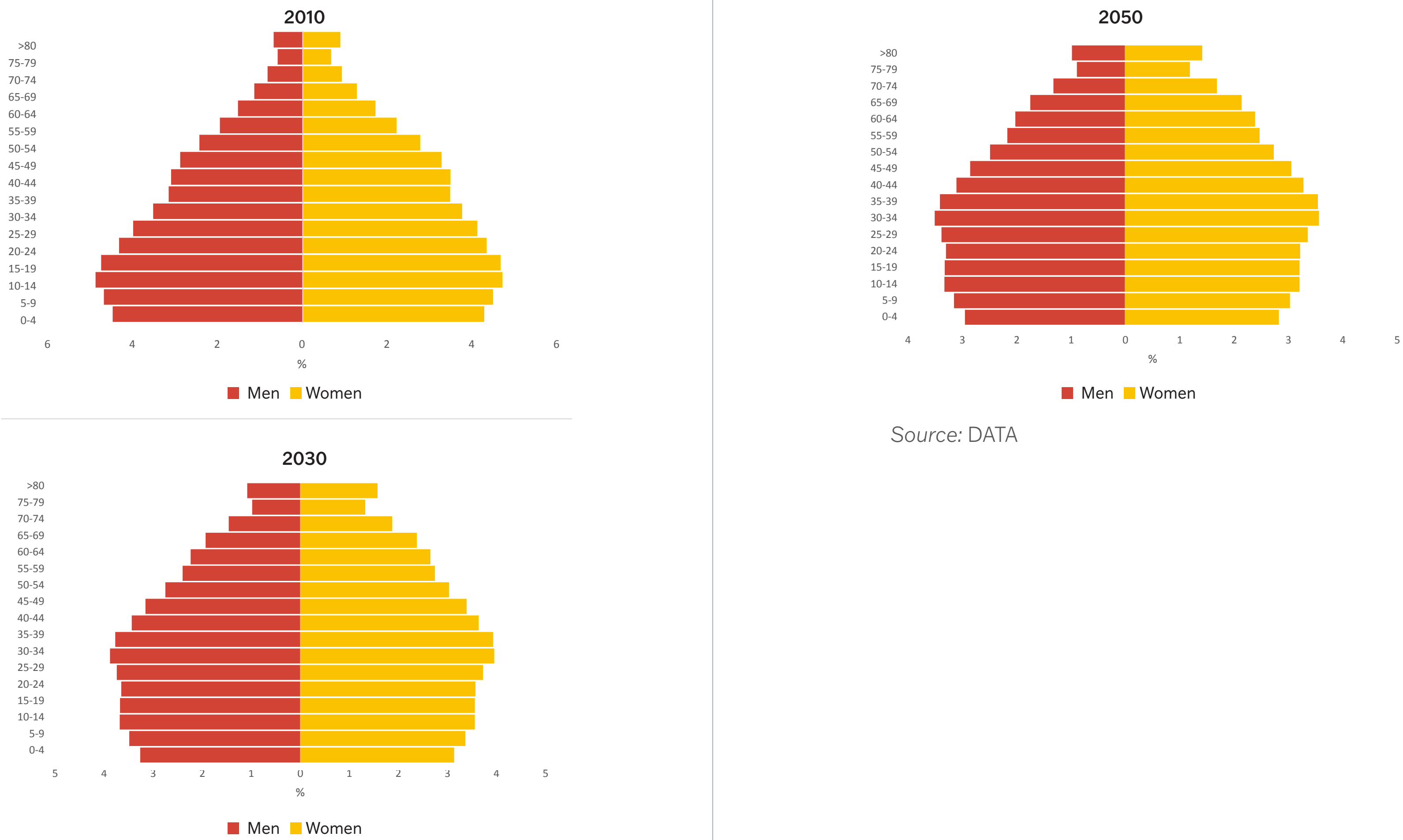


Source: Vega (2023)

Demographic structure

In 2010, Colombia's population was 44 million (51 percent men), with 39.1 percent concentrated in only three departments (Bogotá, D.C., Antioquia, and Valle del Cauca) which are home to the country's most populous cities. By 2050, the total population will increase to an estimated 61.9 million and the distribution by age group will have shifted significantly as the average age increases as part of the demographic transition Figure 6. (For details of the population distribution by departments in Colombia, see the section "Annex to the description of the demographic structure" in Annex 1.)

Figure 6. Population Pyramids of Colombia, 2010–2050



Source: DATA

Historical Analysis: Disease Burden Attributable to Suboptimal Temperatures, 2010–2019

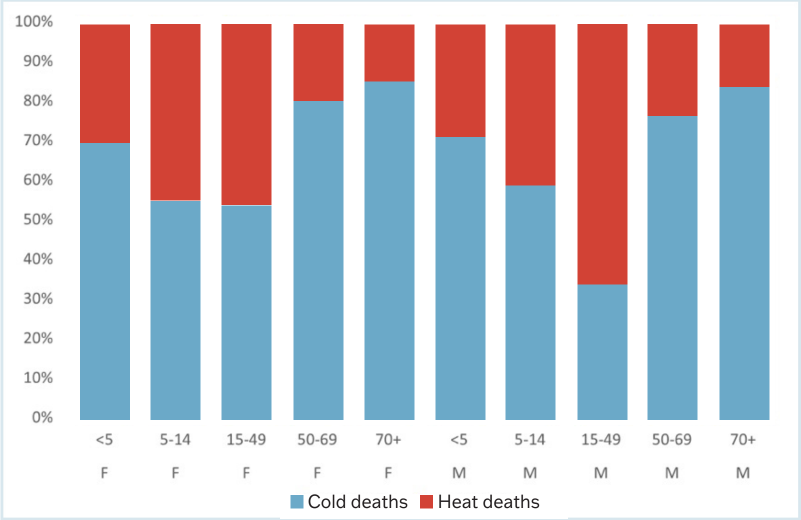
Suboptimal temperature disease burden

Between 2010–2019, the 17 causes studied accounted for 884,628 deaths, of which 9,472 (1.07 percent) were attributable to suboptimal temperatures. Of these deaths, 2,332 (24.6 percent) were attributed to heat and 7,141 (75.4 percent) to cold.

Gender and age distribution. Of 9,283 deaths attributable to suboptimal temperature (5,510 were men and 3,962 were women. The average mortality rate attributable to this risk factor was 20.41 per 1 million, with a slightly higher risk amongst men (24.27 per 1 million) than women (16.72 per 1 million). Cold-related deaths (average rate: 15.41 per 1 million) were much higher than heat-related deaths (average rate: 5.00 per 1 million). Suboptimal temperature was associated with a total of 172,870 YLL and a rate of 37.28 YLL per 100,000 population. During 2010–2019, YLL statistics related to low temperatures (109,313, YLL rate=23.62 per 100,000) were also higher than those associated with high temperatures (63,557, YLL rate=13.66 per 100,000).

According to the distribution by sex, the burden was higher in men, especially related to heat, while the burden related to cold is more homogeneous and tends to be concentrated in those over 70 (Figure 7).

Figure 7. Percentage of Deaths Attributable to Heat and Cold by Age Group and Sex in Colombia, 2010–2019



Note: F = female; M = male

Geographic distribution. The geographic distribution of the burden of disease by temperature, according to the variables analyzed, including sex, age group, and cause of death, is described below.

The highest mortality rates due to suboptimal temperature were in Quindío (37.45 deaths per 1 million population; confidence interval (CI) 95%:34.81–40.23), Tolima (33.47 deaths per 1 million people; CI95%: 30.96–36.08), and Caldas (30.71 deaths per 1 million people; CI95%:28.31–33.22). The highest rates of YLL for suboptimal temperature were observed in Arauca (63.49 years per 100,000 people; CI95%: 60.05–67.09), Quindío (53.60 years per 100,000 people; CI95%: 50.43–56.90), and Tolima (53.05 years per 100,000 people; CI95%: 49.90–56.34).

Figure 8 shows the interannual averages for mortality rates attributable to cold (marked in blue) and heat (in red), disaggregated by department. Higher rates of cold-related mortality were observed for Quindío, followed by Caldas, Risaralda, Tolima, and Boyacá; while higher rates for heat were observed for Sucre, followed by Córdoba, Atlántico, and Arauca.

The average interannual mortality rates attributable to suboptimal temperatures for 2010–2019 can be seen in Figure 9. The departments with the highest rates were found in the center of the country and in Antioquia and Sucre.

The Caribbean region has a large percentage of the heat disease burden with 64 percent of YLL, followed by the Eastern Andean region with 9.2 percent and the Antioquia region and the Coffee Axis with 8.9 percent. The departments with the highest mortality rate from heat exposure were Sucre (21.17 per 1,000.00; CI95%: 19.18–23.26), Córdoba (16.69 per 1,000,000; CI95%:14.95–18.59) and Arauca (16.47 per 1,000,000; CI95%:14.72–18.32). The highest rates of YLL were in Arauca (55.40 per 100,000; CI95%: 52.18–58.76), Sucre (49.80 per 100,000; CI95%: 46.75–52.99), and Córdoba (44.18 per 100,000; CI95%:41.33–47.21).

Figure 8. Interannual Averages of Mortality Rates Attributable to Cold and Heat, by Department, Colombia 2010–2019

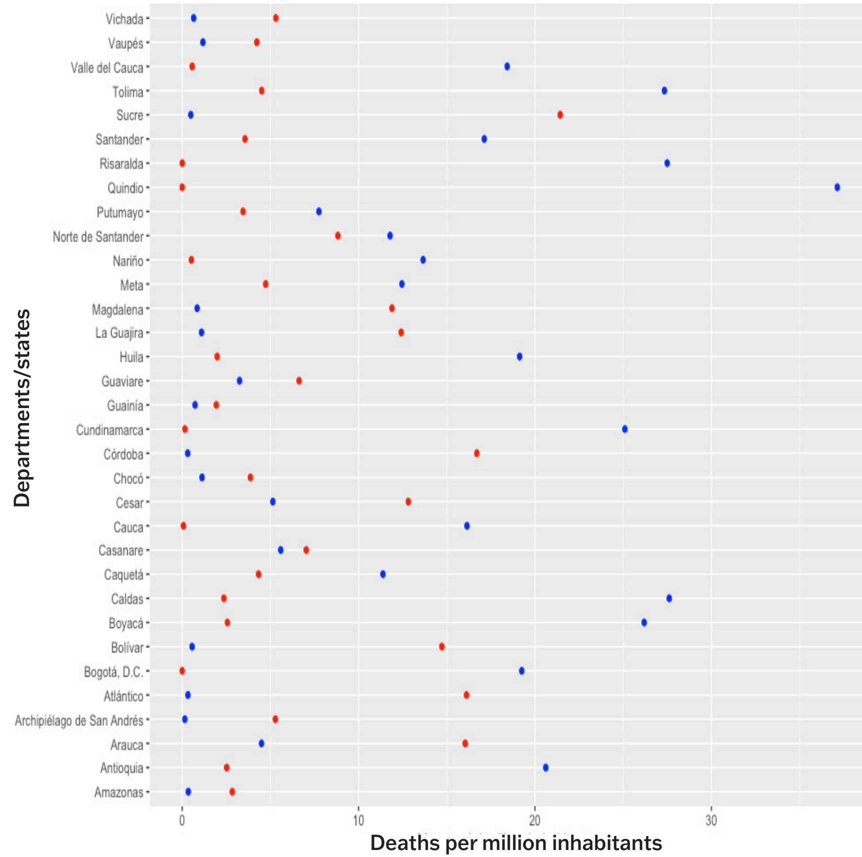
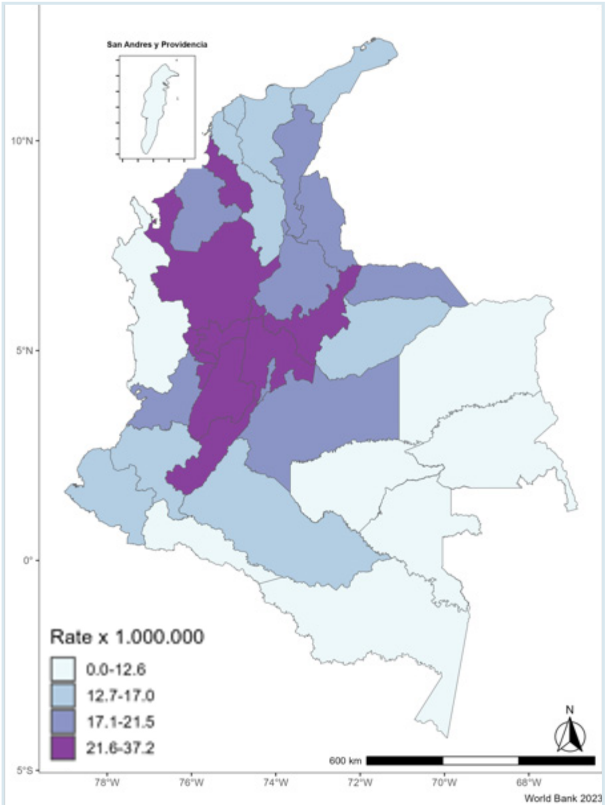


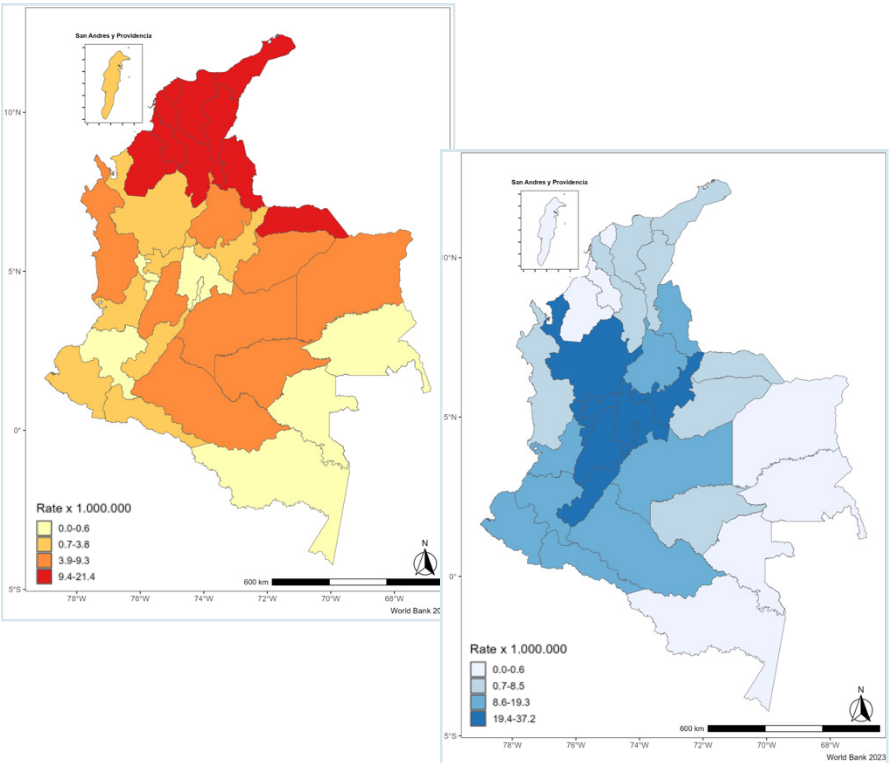
Figure 9. Average Interannual Mortality Rate Attributable to Non-Optimal Temperatures, Colombia 2010–2019



The causes associated with a higher burden of heat mortality were homicides, traffic accidents and ischemic heart disease. In fact, heat-related YLL for homicides were 30,045, with higher YLL in Atlántico (4,850), Bolívar (3,891), and Córdoba (3,720). Traffic accidents were responsible for 10,937 YLL, with the highest figures in Córdoba (1,226), Cesar (1,109), and Atlantico (1,095). Ischemic heart disease caused 9,408 YLL, with higher numbers in Atlántico (1,923), Bolívar (1,311), and Córdoba (1,237) (see Annex 1, Table A1.13 for details). The events with the highest population attributable fraction (PAF) due to high temperatures were homicides (0.76 percent), traffic accidents (0.64 percent), and diabetes mellitus (0.50 percent).

On the other hand, the outcomes with the highest PAF associated with low temperatures were drowning (1.85 percent), COPD (1.11 percent), and lower respiratory infection (1.03 percent). In relation to the cold-related burden, the highest YLL were in the Central Andean region (38 percent of total YLL), followed by the Antioquia region and the Coffee Axis (28 percent), and the Western region (20 percent). The departments with the highest mortality rate due to cold exposure were Quindío (37.45 per 1 million; CI95%: 34.81–40.23), Tolima (28.39 per 1 million; CI95%:26.11–30.83), and Caldas (27.89 per 1 million; CI95%:25.63–30.31). The highest rates of YLL were in Quindío (53.60 per 100,000; CI95%: 50.43–56.90), Risaralda (42.28 per 100,000; CI95%: 39.49–45.24), and Tolima (40.34 per 100,000; CI95%:37.61–43.23) (Figure 10).

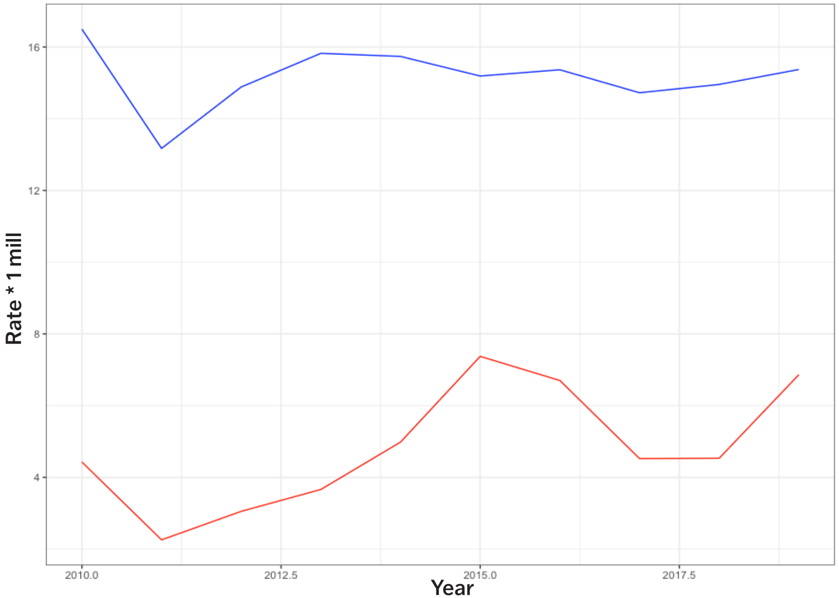
Figure 10. Year-on-Year Average Mortality Rates Attributable to Heat and Cold in Colombian Departments, 2010–2019



The causes that generated a greater impact on cold mortality were ischemic heart disease, COPD, and stroke (cerebrovascular disease). Ischemic heart disease caused 48,906 YLL, with the highest numbers in Bogotá (9,039), Antioquia (8,531), and Valle (6,099). The cold-related YLL for COPD was 18,723, with higher numbers in Bogotá (4,394), Antioquia (3,675), and Cundinamarca (1,997). Stroke was responsible for 10,372 YLL, with the highest figures in Bogotá (2,719), Antioquia (1,593), and Valle (1,081) (see Annex 1, Table A1.14 for details).

According to the annual trend of mortality rates attributable to cold and heat, a peak in the heat mortality rate was observed in 2015, which may correspond to the El Niño Southern Oscillation (ENSO) phenomenon in its Niño phase, which is characterized by an increase in dry and warm periods in the country (Figure 11). As Figure 11 shows, the different scales of climate variability, in particular the ENSO phenomenon, had an impact on fluctuations in heat-attributable mortality rates in 2010–2019. This also would be expected to contribute to different climatic anomalies such as heat waves in the future.

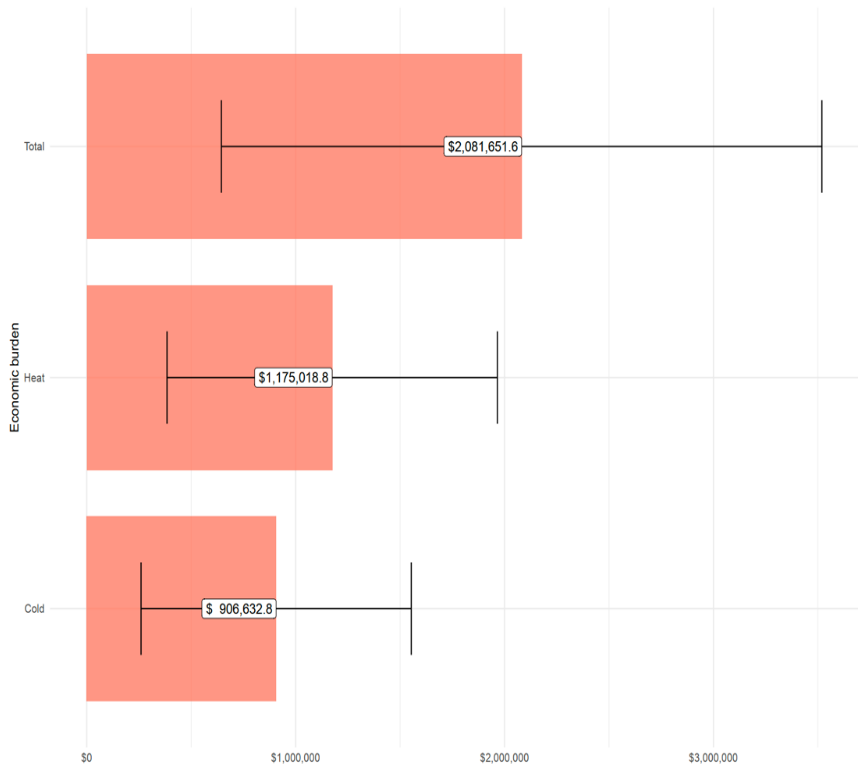
Figure 11. Annual Mortality Rates Attributable to Cold (blue) and Heat (red), 2010–2019



Economic Burden Results

Between 2010–2019, deaths in Colombia caused by the 17 causes analyzed represented a total loss of 7,293,919 PYPLL, meaning on average 21.3 productive years lost for each death of productive age. In this period, the PYPLL of these causes generated an economic burden that ranged between COP 88–522 trillion. Of the total for the 17 diseases, 52,887 PYPLL (0.7 percent) and between COP 0.6–3.3 trillion were attributable to non-optimal temperatures (Table A1.22, Figure 12). Of the total attributable economic burden, the related to cold and heat ranged between COP 0.26–1.5 trillion and COP 0.38–2 trillion, respectively. Of the total PYPLL, 40.3 percent was attributable to cold (21,331 PYPLL) and 59.6 percent to heat (31,556 PYPLL). Likewise, the loss in productive years was equivalent to 30 percent of the loss of years of life due to premature death (PYPLL/YLL) attributable to suboptimal temperatures.

Figure 12. Economic Burden Attributable to Heat, Cold, and Suboptimal Temperature (Total) in Colombia, 2010–2019



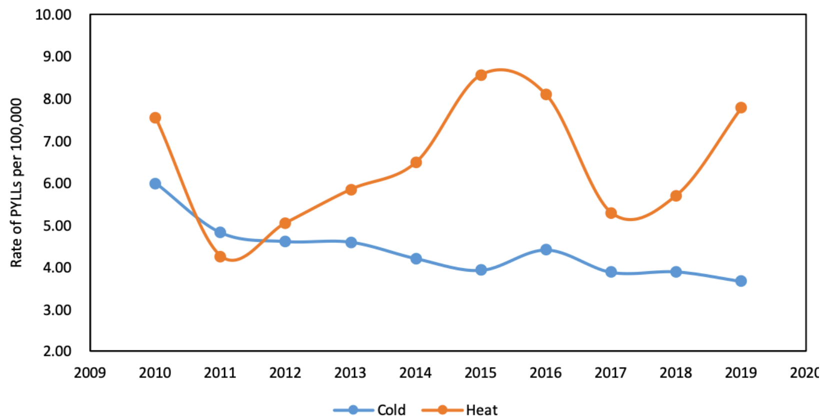
Source: World Bank

Note: Values in million COP

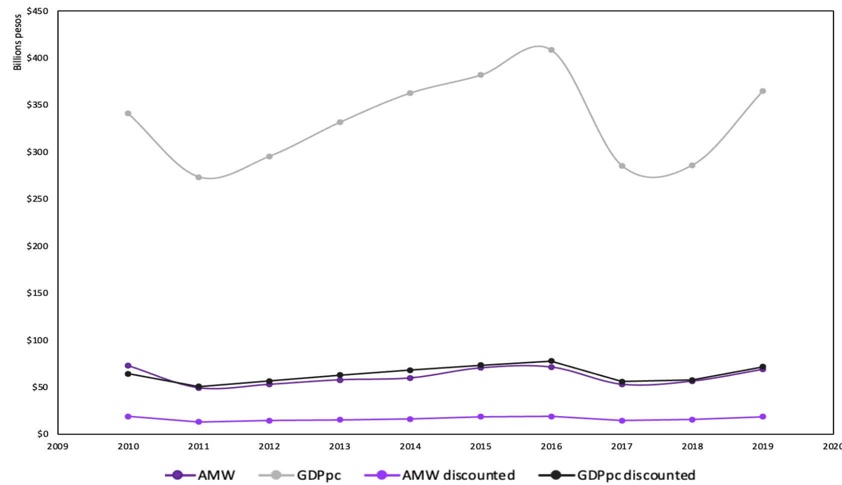
The PYPLL rate fluctuated during 2010–2019. Fluctuations were especially notable for heat, with a decrease in 2011 followed by an increase until 2015, the year with the highest rate of loss of productivity due to premature mortality (8.57 per 100,000). The rate of cold PYPLL experienced a constant decline over the decade (Figure 13). The economic valuation of these PYPLL is shown in Figure 13b. In the floor scenario (valued with the AMW), economic losses due to premature mortality attributable to suboptimal temperatures are relatively constant, with the largest loss in 2011 (COP 75 billion; COP 19 billion discounted) and the smallest in 2012 (COP 51.6 billion; COP 13 billion discounted). In the scenario of the valuation with GDP per capita these values ranged between COP 286–428 billion (COP 53–81 billion discounted) for 2012 and 2016, respectively. This burden adjusted for the time discount can be seen in Figure 13b.

Figure 13. Rate of Productive Years of Life Potentially Lost and Economic Burden Attributable to Heat and Cold in Colombia, 2010–2019

(A) PYPLL rate per 100,000



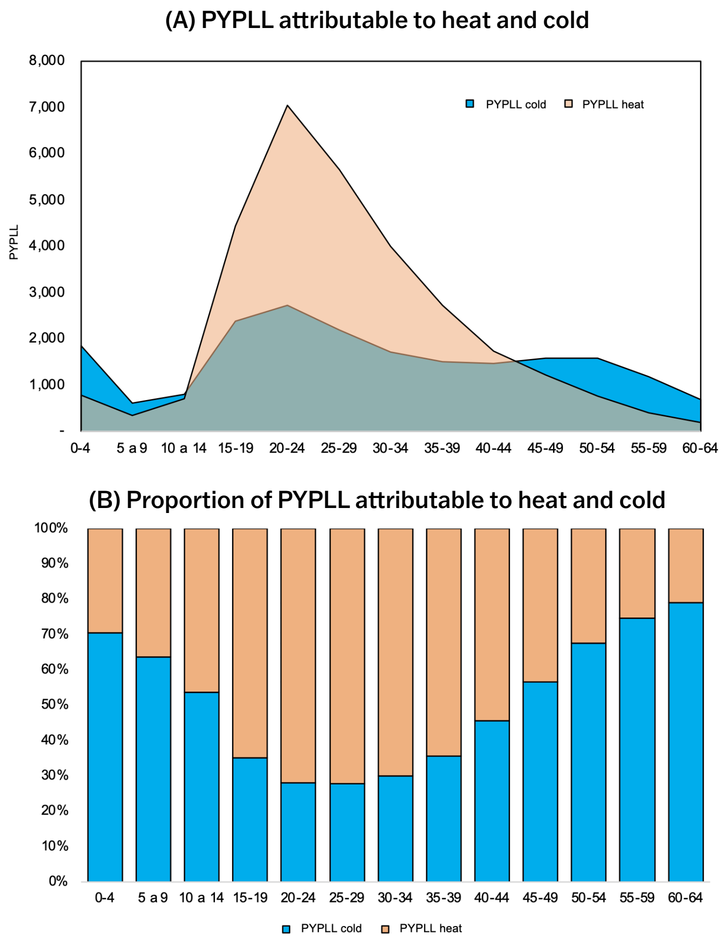
(B) Economic burden in billions of pesos for suboptimal temperatures, with and without temporary discount



Note: GDPpc = gross domestic product per capita

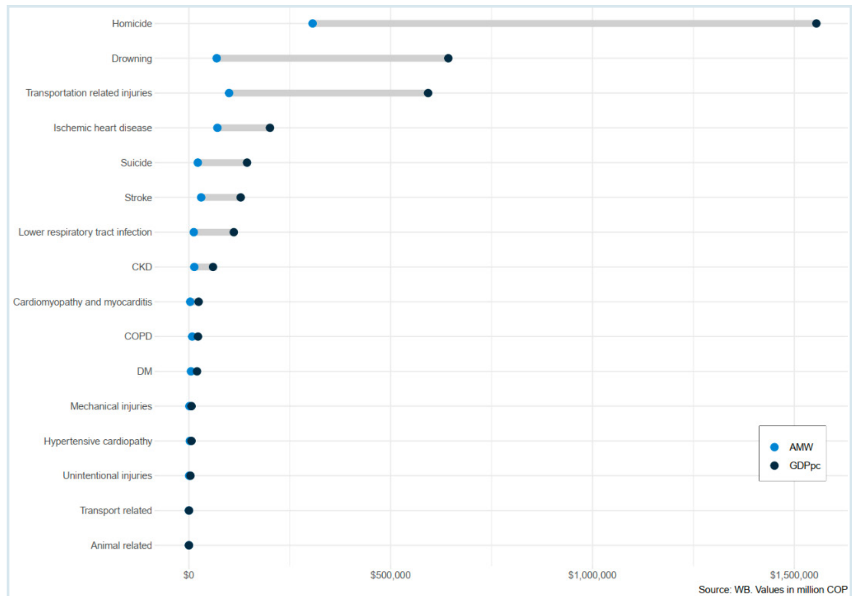
The distribution of the 50,233 PYPLL attributable to suboptimal temperatures is presented in Figure 14, by age group, for 2010–2019. The analysis observed that between 0–9 years and in people over 44 years of age, the attributable PYPLL are higher for cold. On the other hand, between 10 and 44 years of age, they are higher for heat (Figure 14a). The proportions of PYPLL attributable to heat and cold follow the same trend (Figure 14b). The mortality structure presents as a U-shape, expressed in the proportional increase of PYPLL by cold at the beginning of life and at the end of productive life (Figure 14b), and due to the impact of heat on homicides in young men.

Figure 14. Productive Years of Life Potentially Lost and Proportion Attributable to Suboptimal Temperatures in Colombia, by Age Group, 2010–2019



Causes of death. Homicides, drowning, traffic accidents, and ischemic heart disease were the causes that generated the highest indirect costs associated with premature mortality due to suboptimal temperatures (Figure 15). For example, during 2010–2019, economic losses from homicides ranged between COP 0.3–1.6 trillion, losses from drowning ranged between COP 68–642 billion, and from traffic accidents ranged between COP 99–592 billion pesos (Annex 1, Table A1.22, Economic Burden Due to Suboptimal Temperatures in Colombia, 2010–2019; Figure 15 below).

Figure 15. Economic Burden Due to Suboptimal Temperatures in Colombia, 2010–2019

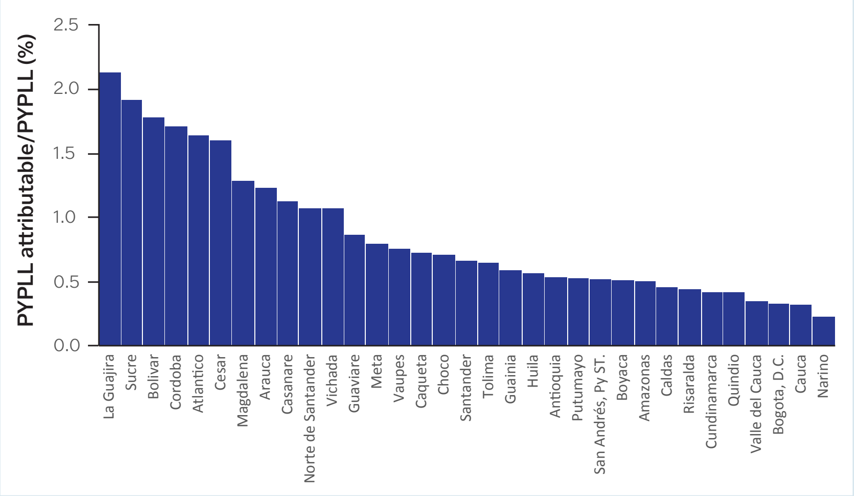


Economic burden by departments. According to the PYPLL findings, the departments with the highest proportion of PYPLL attributable to suboptimal temperatures over the total PYPLL of the 17 causes were La Guajira, Sucre, Bolívar, Córdoba, and Atlántico; the territories with the lowest proportion were Nariño and Cauca (Figure 16). The heat-related economic burden was greatest in the Caribbean region, specifically Atlántico (COP 54–249 billion), Bolívar (COP 46–204 billion), and Cesar (COP 25–126 billion); and the cold-related one was mainly concentrated in Antioquia (COP 59–324 billion), Valle del Cauca (COP 51–251 billion), and Bogotá, D.C. (COP 31–212 billion) (Annex 1, Table A1.23). Figure 17 shows these values in relative terms (per inhabitants) for cold and heat, in the loss valuation scenario with GDP per capita. (See Annex 1, Figure A1.15 for a depiction the AMW scenarios and the economic burden for non-suboptimal temperatures in both scenarios.)

A negative and statistically significant association ($p<0.05$) can be observed between GDP per capita and PYPLL rates attributable to suboptimal temperatures.

Association with heat and cold. La Guajira, Sucre, Córdoba, Cesar, Bolívar, and Atlántico have the highest rates of PYPLL due to heat and also levels of well-being measured by GDP per capita below the national average (Figure 18). On the other hand, the departments of Valle, Quindío, Risaralda, and Antioquia, which have the highest rates of cold PYPLL, are also below the average national GDP per capita for the period. Note that the departments with higher GDP per capita, which are usually in the zone of cold temperatures, report higher rates of PYPLL due to cold.

Figure 16. Proportion of Productive Years of Life Potentially Lost Attributable to Suboptimal Temperatures over Total PYPLL, by Departments in Colombia



Note: PYPLL: Productive year of life potentially lost.

Figure 17. Indirect Costs (GDP Per Capita Scenario), by Population Attributable to Premature Mortality from Heat and Cold in Colombia, 2010–2019

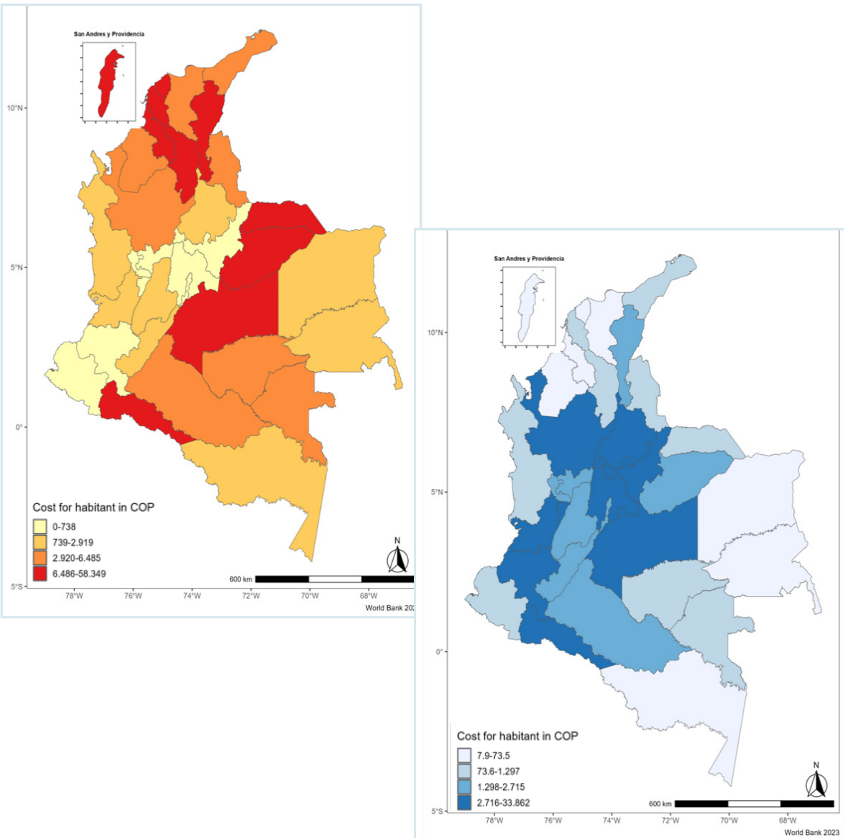
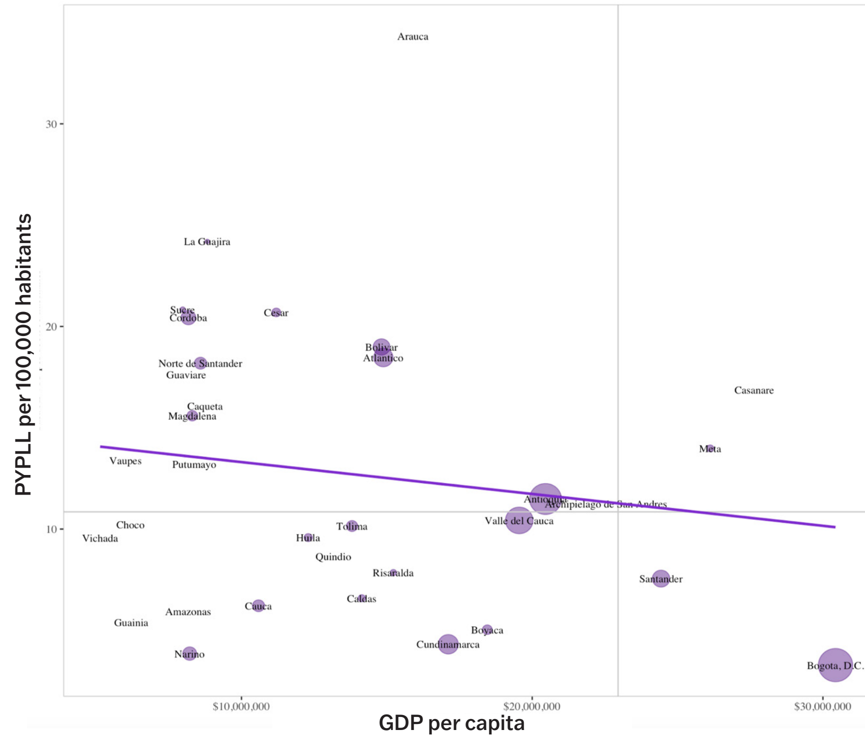


Figure 18. Relationship between Rate of PYPLL Attributable to Suboptimal Temperatures and GDP Per Capita, by Departments in Colombia, 2010–2019



A negative and statistically significant association ($p<0.05$) can be observed between GDP per capita and PYPLL rates attributable to suboptimal temperatures.

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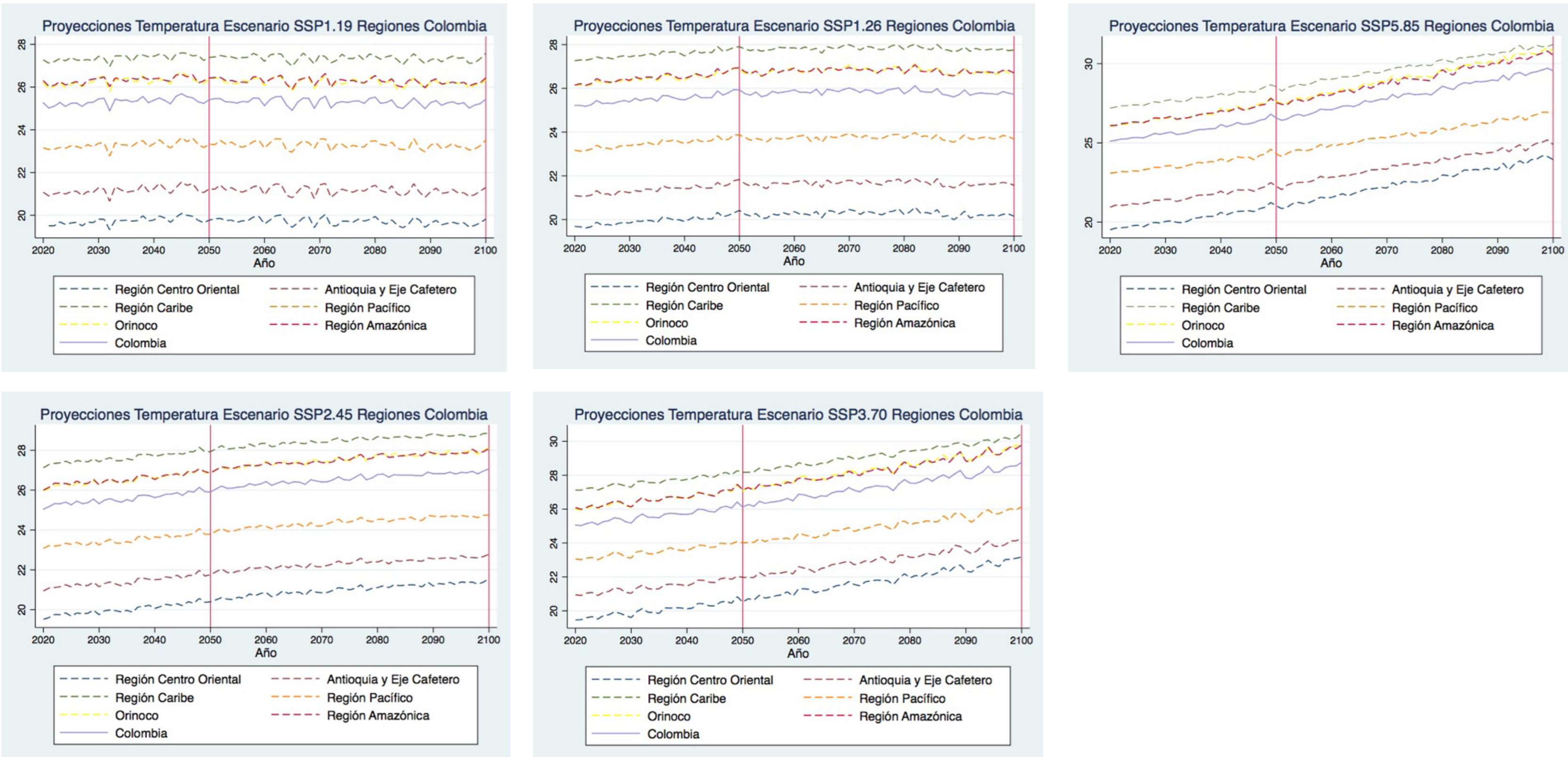
Temperature and Disease and Economic Burden Projections

Temperature projections, 2020–2100

According to the five scenarios of the Shared Socioeconomic Trajectories (SSP), the Caribbean, Orinoco, and Amazon regions will have above-average temperatures. In the SSP5-8.5 scenario, the average temperature in these three regions would be above 30°C by 2100, while in the SSP3-7.0 scenario, only the Caribbean region would exceed the 30ºC threshold. On the other hand, in the SSP1.19 scenario, the average temperature would remain relatively stable throughout the century. The following figures present the time series for each scenario and by region between 2020 and 2100.

Figure 19. Temperature Projections by Shared Socioeconomic Trajectories Scenarios, Colombian Regions, 2020–2100



In the scenarios of high greenhouse gas emissions, temperature projections predict the highest averages will be in the departments of Cesar, Magdalena, Atlántico, Vichada, and Sucre (Annex 1, Table A1.25).

In the scenarios of low greenhouse gas emissions the temperature would remain stable, with low fluctuations and even decrease in some places (SSP1-1.9 scenario). In contrast, high-emission scenarios forecast temperature increases between 1 and 2°C by 2050 and between 3 and 5°C by 2100 (SSP3-70 scenarios and SSP5-8.5 scenarios). In the SSP5-8.5 scenario for 2100, the departments with a greater gradient of change are part of the Orinoco region and Arauca (+5ºC), Casanare (+4.9ºC), Vichada (+4.9ºC), Guainía (+4.7ºC), and Meta (+4.7ºC) (Annexes, Table A1.26).

Disease burden projections, 2020–2050

According to the scenario analysis, the heat attributable burden could decrease by 14 percent between 2020 and 2050 in the very low greenhouse gas emissions scenario (SSP1.19). In the other scenarios it would increase, ranging from 28 percent (SSP1.26) to 63 percent (SSP5.85). By 2050, YLL will almost double for scenario SSP5.85 (YLL 44,703) compared to scenario SSP1.19 (YLL=25,493).

Going forward, the YLL rates attributed to cold tend to decrease in all scenarios. However, the scenario involving high emissions (SSP5-8.5) would have a paradoxical effect on the annual rate of YLLs attributable to cold compared to the other scenarios, since this scenario is associated with an increase in daily temperature variability, so there would be a greater likelihood of extreme cold days (Figure 20). With respect to heat, there is a growing divergence in YLL rates between the very low emissions scenario (SSP1-1.9) and the very high emissions scenario (SSP5-8.5), even seeing a decrease over time in SSP1-1.9 (Figure 21).

Projected heat-attributable YLL rates in the country could vary significantly in different socio-economic and greenhouse gas production scenarios. For example, there would be a 14 percent decrease in the attributable YLL rate between 2020 and 2050 for SSP1-1.9. On the other hand, the rate could increase by 63 percent for SSP5-8.5 (Figure 20 and Figure 21). This shows that, in terms of climate change mitigation, which occurs when fewer greenhouse gases are produced (e.g., as in the SSP1-1.9 scenario, compared to the SSP5-8.5 scenario), there would be health co-benefits of a significant magnitude for YLL rates attributable to heat.

There will be an important turning point: effects of cold are expected to be outweighed by heat effects in SSP5.85 by 2040, and, in SSP3.70 in 2049 (Figure 20 and Figure 21). At this point, the landscape of health effects would change, giving less weight to respiratory diseases, which are more related to the cold, and more weight to cardiovascular effects, aggressions, and traffic accidents, which are more related to the heat. This would occur in a future where there would be many more susceptible individuals due to an aging population.

Figure 22 shows the temperature change in degrees Celsius between 2020 and 2050 for different climate change scenarios, by department. In the SSP1-1.9 scenario the greatest changes will be in departments of the Atlantic coast, Antioquia, Chocó, and Guainía, but in those magnitudes will be smaller than in the other scenarios. On the other hand, for the SSP5-8.5 scenario, the most important changes in temperatures will be seen in the departments of the plains, Bogotá, Boyacá, and the Santanderes.

Figure 20. YLL Cold-Attributable Annual Rates for Five Climate Scenarios, Colombia 2020–2050 (per 100,000 Inhabitants)

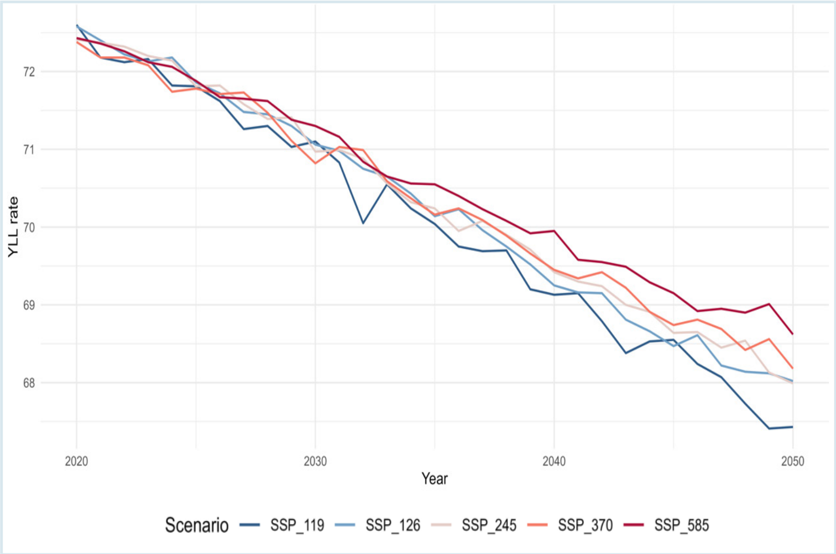


Figure 21. YLL Heat-Attributable Annual Rates for Five Climate Scenarios, Colombia 2020–2050 (per 100,000 Inhabitants)

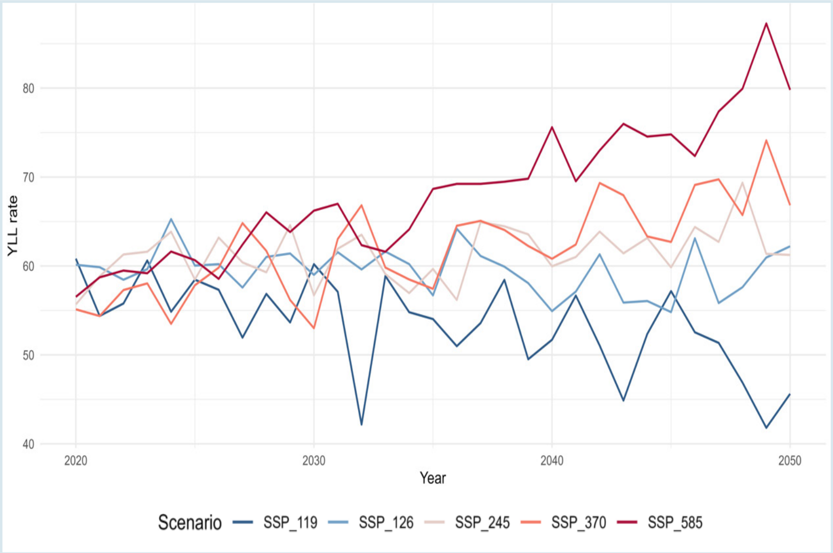
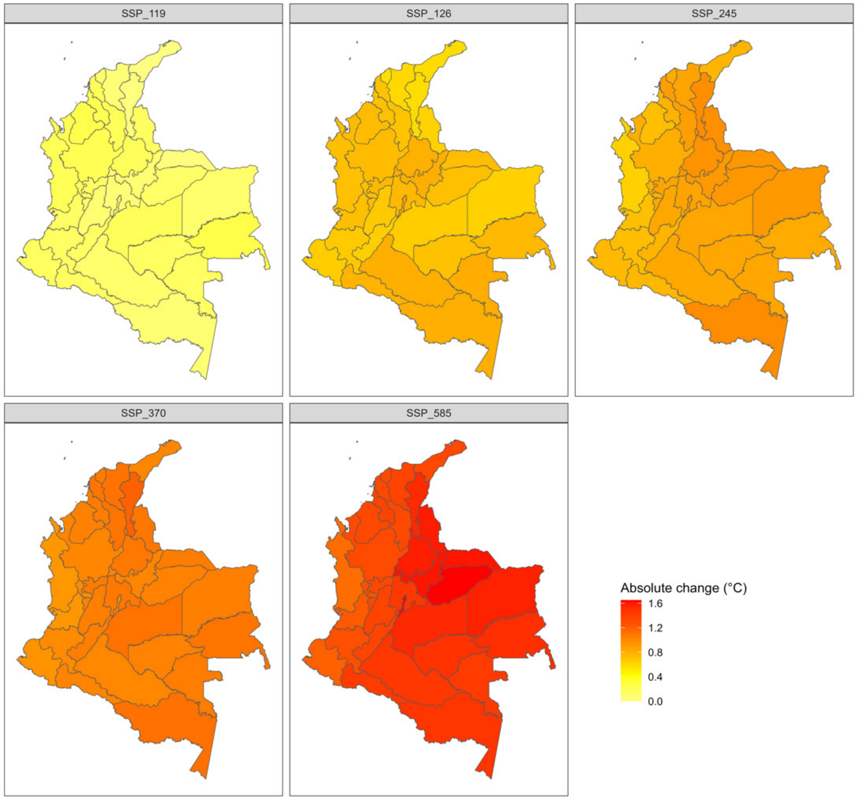


Figure 22. Temperature Difference Between 2020 and 2050 for Five Climate Scenarios



Source: World Bank 2023

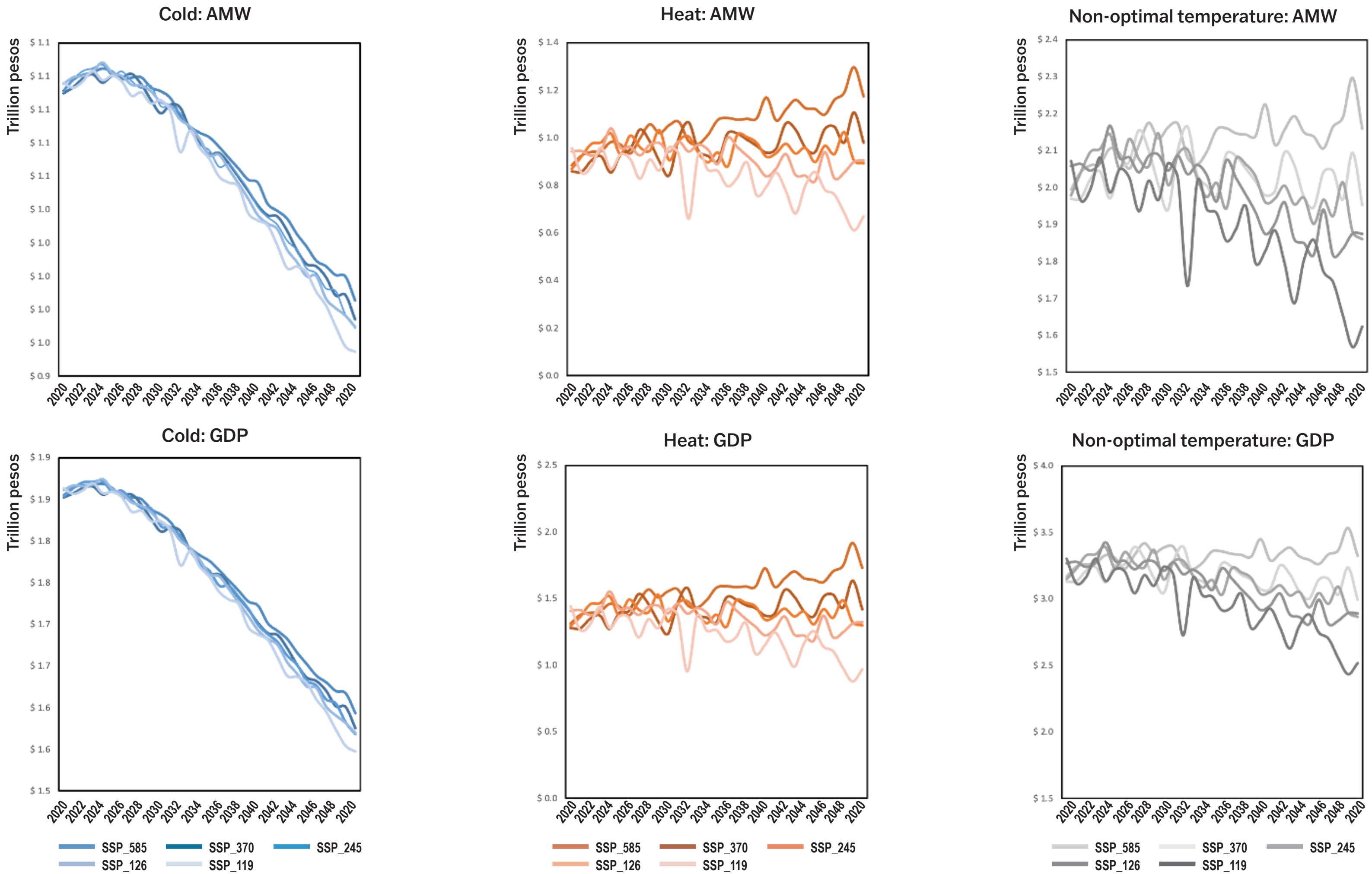
Economic burden projections, 2020–2050

According to the projection analysis of economic burden scenarios, it is expected that by 2050 there will be a reduction in cold-related costs in all greenhouse gas emissions analysis scenarios: with reductions ranging between 11.3 percent (SSP5.85 with AMW) and 17 percent (SSP1.19 with GDP per capita) compared to the year 2020. The analysis also shows that cold-related costs will have a tendency to decrease each year.

Meanwhile, the economic burden of heat for 2050 could increase compared to 2020 in three of the of greenhouse gas emissions scenarios, namely SSP5.85, SSP3.70, and SSP2.45 (dropping 32 percent, 12 percent, and 1.5 percent, respectively). However, in two emission reduction scenarios, which are very low greenhouse gas emission scenarios (SSP1.19, SSP1.26), a reduction in indirect costs attributable to heat would occur during the 2020–2050 period.

A higher projected economic burden resulted in the SSP5.85 scenario, which simulates greenhouse gas emissions similar to those currently observed, with an increase of up to 8.3 percent compared the estimate for 2020.

Figure 23. Costs by AMW and GDP Per Capita Projection Scenario for Five Climate Scenarios, Colombia 2020–2050



Conclusions and Recommendations

Conclusions

1. For 2010–2019, the events with the greatest impact on the rate of deaths attributable to heat were homicides, traffic accidents, and ischemic heart disease, while the events with a greater impact on the rate of deaths attributable to cold were ischemic heart disease, COPD, and stroke.
2. The departments with the highest heat mortality rates were Sucre, Córdoba, and Atlántico, while the highest cold rates were observed in Quindío, Caldas, and Risaralda.
3. The departments of Atlántico, Bolívar, and Córdoba had the highest number of premature deaths attributable to heat, while the departments of Antioquia, Bogotá, and Valle had the highest number of premature deaths attributable to cold.
4. The Caribbean region has had the greatest impact due to heat (67 percent of total YLL attributable to heat) while the Central Andean region has had the greatest impact due to cold on the burden of YLL (38 percent of total YLL due to cold).
5. The highest proportion of attributable mortality occurs in men, particularly those over 70 years of age, although costs are concentrated in young men due to the impact of homicides on this population.
6. The different scales of climate variability, in particular the ENSO phenomenon, had an impact on fluctuations in heat-attributable mortality rates in 2010–2019, and would be expected to contribute to different climatic anomalies such as heat waves in the future.
7. The cumulative economic losses due to premature mortality due to suboptimal temperature amounted to 0.1–0.4 percent of GDP in 2019 in Colombia.
8. Most of the economic burden due to heat occurred in young adults due to external causes such as homicide, transportation-related injuries, and drowning.
9. The effects of cold are expected to be outweighed by the effects of heat in SSP5.85 by 2040, and, in SSP3.70 in 2049.
10. Projected heat-attributable YLL rates in the country would decrease by 14 percent between 2020 and 2050 for SSP1-1.9 or could increase by 63 percent for SSP5-8.5. This shows that, in terms of climate change mitigation, there would be health co-benefits of a significant magnitude for mortality rates attributable to heat.
11. The higher projected economic burden resulted in the SSP5.85 high emissions scenario with an increase of up to 8.3 percent compared to what was estimated for 2020. However, there is a potential for greenhouse gas emission reduction of up to 23 percent if policies are adopted to achieve low greenhouse gas emissions in the SSP1-1.9 scenario.

Recommendations

1. This study can be used as a baseline to carry out health impact assessments of different adaptation and mitigation measures in the different climate change scenarios.

2. This subnational analysis is useful for mapping vulnerability at regional and local levels. It can help identify strategies to counteract the impact of climate change and design heat early warning systems.

3. An approach focused on noncommunicable disease (NCD) preventive programs for elderly people is needed to improve the ability of the elderly to adapt to future heat increases.

4. Developing strategies to reduce the economic burden of heat on external causes of mortality such as homicides and traffic accidents in young adults is highly recommended.

5. The use of temperature with data from the ERA5 satellite re-analysis gives greater representativeness to regions where there are no fixed monitoring stations and shows greater consistency in the data at the temporal level, so this approach is recommended for future similar analyses.

6. Studies at the municipal and province level must also be conducted. This would help reduce uncertainty and better capture the spatial variability of temperatures, mortalities, and sociodemographic characteristics.

7. The approach used here to estimate deaths associated with temperature exposure should also be used to assess the burden of disease related to morbidity; that will be necessary step in any potential health system reform in Colombia.

8. Future analyses should include the estimation of direct medical costs and direct non-medical costs for the diseases studied. This would complement the economic burden of premature mortality from the perspective of costs incurred by society.

COMPONENT 2

People at the Heart of Resilience-Informed Health System Investments: Colombia Hazard Risk Assessment using Artificial Intelligence

Scope

- This set of analyses quantifies the adverse effects of climate change and extreme events on the **vulnerable populations and on the health system**. It prioritizes departments for resilience-sensitive investments based on a compound (multi-hazard) and integrated (multi-factorial) risk index. **Priority health facilities for investment are further identified**, nationally and in each department, and ranked based on medical staff, supplies and equipment, infrastructure condition, and climate vulnerabilities, as well as health system design and people who they serve. For a high-resolution analysis of the city of **Bogotá, it identifies communities most affected by disruptions, directly and indirectly, in accessing health services** due to extreme events. To minimize disruptions in health supply chains and service access, the analyses also identify critical road segments for cross-sectoral coordination and investment needs.

- The principal goal of the study aims prioritize resilience measures that can strengthen overlapping areas of vulnerability in the population and health system to climate-induced hazard impacts, including slow-onset and extreme events. This analysis focused on flooding and landslide events. An analysis of existing legal frameworks and policies helped to translate these priorities into actionable recommendations.

Photo: ©butforthesky.com 'Flood in Santa Marta' (CC BY-NC 2.0)

Methods

- We used the *Frontline Rapid Scorecard* (Thompson et al. 2023) to assess climate related laws, regulations, and procedures for the health sector and others (i.e. transport, energy) that support health system functionality in routine care and emergencies. The high-level assessment informed the design and depth of the country data informed deep dive.

- Data-informed deep dive: Prioritizations are conducted by employing Artificial Intelligence and Mathematical modeling approaches. Data includes poverty, households' characteristics, maternal and child health, population climate related health risks, access to basic utilities, health system capacity, and health infrastructure. Methods identify risks to climate change and extreme events for: (i) populations with direct exposure to hazards; and (ii) primary health care (PHC) centers and higher tier hospitals (categories II and III) which are directly and indirectly affected by extreme climatic events.

Findings

- **The Government of Colombia has worked intensively on policy and legislative instruments for climate change.** It has put in place data mandates and collection efforts for various determinants of climate and health risks, and conducted quantitative risk assessments on which this work is built.
- **Risk exposure of PHC facilities potentially affect primary care services to 17 million and 25 million people facing flood and landslide risks,** respectively, and exposure of hospitals to flood and landslide risks affects services for 16 million and 23 million people, respectively.
- **The departments of Vaupes, Cundinamarca, Boyacá, and Arauca should be prioritized for all of the risks assessed.** Cauca and Norte de Santander should primarily be monitored for flood risks, and Tolima and Cordoba for landslide risks.
- **Approximately a quarter of Colombia's population** (15.7 million people) **is directly exposed to low flood level risks** (5 cm depth). This means they face higher risks of skin, acute respiratory infections, and diarrhea, in addition to wider socioeconomic impacts of floods on well-being and livelihoods. Valle del Cauca has the highest number of vulnerable people facing direct risks: 2.4 million (42.71 percent of its population).
- **About 2.3 million inhabitants are directly exposed to landslides**, which can cause high mortality due to trauma or suffocation by entrapment and injuries. In addition to service disruptions, landslide damage to lifeline infrastructure also leads to loss of access to essential services, water-borne diseases, electrocution, and lacerations from debris (World Health Organization 2023).
- **About 1 out of 5 health facilities are directly exposed to disruptive floods.** This includes 4,416 primary care facilities and 143 hospitals. Indirect impacts of floods are also substantial due to disruption to water, power, and communication networks, as well as impaired access to facilities.
- **549 primary care facilities and 20 hospitals are directly exposed to higher landslide risks**, including the possibility of partial or full collapse. Adequate preparedness measures must be prioritized in these facilities to ensure patient and health workforce safety and to minimize service disruptions.
- **We provide healthcare facility prioritization** to highlight the top facilities at a national level and in each department

for subnational health service delivery planning. Most climate-vulnerable facilities, serving the most vulnerable populations, in areas with lower health system presence are prioritized. Regarding PHC centers, the departments in the north have more at risk of floods, while most affected hospitals are in the west and north. Notably, Bolivar has five of the 10 nationally prioritized PHC centers; Bolivar and Valle del Cauca have PHC centers prioritized for all risks; and Valle del Cauca and Antioquia have prioritized hospitals for all risks.

- **Impacts of extreme climatic events on transport networks slow access** to health services and the effects vary, as shown in the analysis. Northwestern areas of Bogotá are severely affected by floods, with average access time to all health services increasing from 15 to 80 minutes. Delayed access to care is associated with significant costs for patients due to higher risks of morbidity and mortality. Underserved populations further from health systems are less likely to seek care putting them at even higher risks. Disruptions in accessibility also affect supply chain and service availability.

Introduction

In addition to the increased climate-related morbidity and mortalities discussed in Component 1, the last few years have seen increased impacts from climatic extreme events in Colombia, such as coastal and river floods and landslides, which affect people's well-being and essential services, such as healthcare and transport. Extreme climatic hazards are expected to worsen severely due to climate change (World Bank 2021). Floods affect peoples' health, livelihood, and well-being (Walker-Springett, Butler, and Adger 2017). They also have a significant impact on health services and patient care delivery (McGlown and Fottler 1996) through structural damage to buildings (McGlown and Fottler 1996); interruption of care (Yusoff, Shafii, and Omar 2017); loss of lighting, heating, and cooling (Martin 2019); extensive contamination of building structures, equipment, and supplies with microorganisms (CDC 2013); exposure to toxic chemicals and infectious waste (Martin 2019); and fire hazards due to erosion of electrical systems or equipment (Martin 2019). Furthermore, damage to health facilities and the utility services they rely upon (e.g., water, electricity, communication lines), directly and indirectly impacts access to essential services and quality of care (World Health Organization (WHO 2023); International Federation of Red Cross and Red Crescent Societies 2023; Centers for Disease Control and Prevention (CDC) 2018). Injury or illness in the affected population (WHO 2023; CDC 2018) and well-being losses also include and lead to adverse mental health impacts (Akpinar-Elci wt al. 2018; Kennedy et al. 2015). Climate change impacts will also likely be exacerbated by human development through land use changes and the built environment, particularly in areas with laxer regulations and enforcement (Campos Garcia 2011).

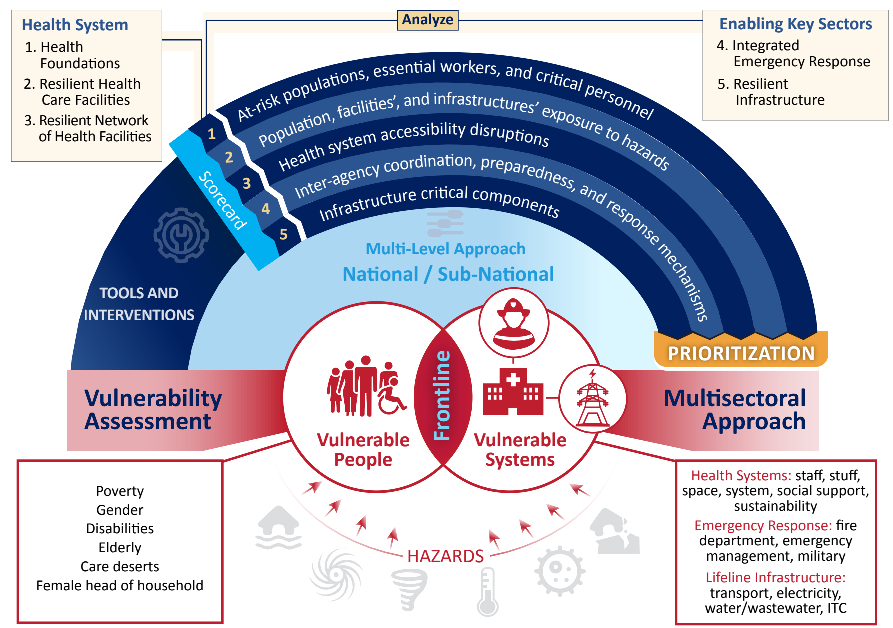
Colombia has taken significant steps to address climate change in national policies, but further research is necessary to enhance the understanding of climate change impacts on vulnerable populations and on the health system to strengthen evidence-based decision-making. **The government has introduced legislation** (Ministry of Environment and Sustainable Development 2017; Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) 2016; IDEAM et al. 2016; Ministry of the Environment 2014; Congress of Colombia 2018; Ministry of Environment and Sustainable Development 2023) **and developed technical documents on risk assessment for floods** (Pérez et al. 2018; Güiza 2013; Sedano Cruz 2017; Vargas et al. 2018; Villegas González 2020), **ground mass movements** (Cerquera Gómez and Novoa García 2021; Aristizábal 2019; Ruiz Peña 2017; Moreno et al. 2006; Gáfaro Duarte 2015; Cobos Romero and Salamanca Pira 2021), **climate change** (Mendoza 2011; Cuartas and Méndez 2016; Cardona et al. 2020), **and the impacts on health** (Rodríguez-Pacheco, Jiménez-Villamizar, and Pedraza-Álvarez 2019; World Bank 2012a), **which have been reviewed and taken into consideration for study design and recommendations.**

Photo: ©butforthesky.com 'Flood in Santa Marta' (CC BY-NC 2.0)

Extreme climatic hazards are expected to worsen severely due to climate change. Floods affect peoples' health, livelihood, and well-being.

A high-level assessment of the health system's adoptive capacity to climate hazards was conducted using the Climate and Disaster Risk Management Frontline Rapid Scorecard (Frontline Rapid Scorecard) (Thompson et al. 2023). The results highlighted how Colombia's health system has benefited from investment in preparedness measures at the departmental and municipal levels and from policy and legislative strengthening. Notable investments in the health system include additional planning measures at the healthcare facility and system levels, such as mandating risk assessments for hospitals under the Disaster Risk Management Plan for Public and Private Entities (PGRDEPP), along with enhanced medical supply and distribution networks. These investments have been bolstered by improvements in the country's wider emergency response sector, which has strengthened its financing and funding measures for disaster mitigation, response, and recovery over the last two decades, including for extreme climatic events and health emergencies. Over the last decade, the government has focused more on its response to health emergencies, complimented by the 2012–2021 Public Health Plan, which identified infectious disease control as a critical mission—an important factor in responding to climate-induced incidents. Through the National Institute of Health (INS), surveillance and medical supply measures were prioritized and later accelerated through response measures during and in the aftermath of COVID-19. From a legislative and administrative perspective, departments and municipalities spearheaded much of the planning and work on response capabilities.

Figure 24. Climate and Disaster Risk Management For Health Systems Prioritization



The scorecard assessment complemented the development of a data-informed, climate-sensitive risk index that combines wider health system characteristics with population-level health and sociodemographic information. To this end, the study acquired and processed related determinants, in consultation with stakeholders, and developed an Artificial Intelligence algorithm for the compound and integrated risk index. Compound refers to multiple hazards and integrated refers to consideration of population and health system climate vulnerabilities simultaneously. *The risk-informed prioritizations empower policymakers to:*

1. **Identify, locate, and target more vulnerable populations directly exposed to climate risks and indirectly impacted by climatic hazards;**
2. **Identify and locate PHC centers and hospitals that are at higher risk of climate-induced hazards and essential for continuity of care; and**
3. **Prioritize mitigation, preparedness, and response interventions in departments based on the most significant climate risks.**

The climate risks and climatic hazards included in the analysis are recurring floods and landslides, as well as the population health risks estimated in Component 1 described in greater detail on page 51 (p. 51). These hazards were selected based on considerations on Colombia's natural hazard exposure risk profile and data availability and quality for systematic analysis. An economic analysis of the impacts of extreme events on populations and health systems is being developed and will be provided as a follow-up note to this report based on the findings herein (Thompson et al. 2023).

Methodology

This section summarizes the methodology used to calculate the Artificial Intelligence-based Integrated Climate Risk Index (Climate-Sensitive Risk Index) (Nunez-del-Prado, Tariverdi, and Barrera 2023) for the populations and health systems affected by climate change, extreme events, and natural hazards. The section explains the computational framework used to determine a department's direct exposure to risks. The section also includes the prioritization criteria for health facilities used to inform climate resilient investments and the methodology for the high-resolution analysis of Bogotá.

Table 3 lists the climate, geospatial, demographic, and health system risk determinants that were used for the model. These determinants were selected based on established methodologies in related fields, along with consultations with country stakeholders and experts in the country. The latest data for each determinant were acquired, cleaned, harmonized, and, where possible, also validated with other sources. All process data are available as part of the outputs of this work. Notably, **Geotagged Health Facility Master List for Colombia** was created through a process developed specifically for this analysis. It is based on official data and open-source information though online platforms (i.e., Open Street Map, Google), and geotagged using data mining techniques.

Table 3. Climate, Population, and Health System Determinants

Factors	Variable	Reference	Geographic availability	Year
Socioeconomic	Female-headed households with no spouse and children under the age of 18	National Administrative Department of Statistics (DANE) (2018)	Department - municipality	2018
	No access to reliable electricity	DANE (2018)	Department - municipality	2018
	No sewerage system at dwelling	DANE (2018)	Department - municipality	2018
	No access to internet	DANE (2018)	Department - municipality	2018
	Dwelling with more than two families	DANE (2018)	Department - municipality	2018
Demographic vulnerability	Native and indigenous population	Cubillos, Matamoros, and Perea (2020)	Department	2019
Health vulnerability	Prevalence of protein intake deficiency by department	Herrera et al. (2015)	Department	2015
	Chronic malnutrition in children 0 to 4 years old	Herrera et al. (2015)	Department	2015
	Mortality rate due to malnutrition per 100,000 inhabitants, females	Herrera et al. (2015)	Department	2015
	Mortality rate due to malnutrition per 100,000 inhabitants, males	Herrera et al. (2015)	Department	2015
	Climate-induced mortality and morbidity	Comp. 1	Department	2
Access to health services	Average distance to primary health care (km)	This analysis	Department - municipality	2015
	Average distance to hospitals (km)	This analysis	Department - municipality	2015

Factors	Variable	Reference	Geographic availability	Year
Health system Climate vulnerability	Percentage of exposed primary healthcare	This analysis	Department - municipality	2015
	Percentage of exposed hospital category II	This analysis	Department - municipality	2022
	Percentage of exposed hospital category III	This analysis	Department - municipality	2022
Health system	Number of beds per department*	Ministry of Health and Social Protection (2022)	Department	2022
	Number of physicians per department*	Ministry of Health and Social Protection (2018)	Department	2018
	Number of nurses per department*	Ministry of Health and Social Protection (2018)	Department	2018
	Location of hospitals	Ministry of Health (2022a)	Latitude and longitude	2022
	Location of primary healthcare facilities	Integrated Social Protection Information System. (2023)	Latitude and longitude	2022
	Primary healthcare and hospital buildings quality state	Ministry of Health (2022b)	National level	2020
Hazards maps	Floods (1 in 100 years return period)	Fathom (2022b)	National level	
	Higher risk of landslides through fault lines	Geological Service of Colombia (2022)	National level	2020
Urban data	Road network	OpenStreetMap Contributors (2017)	Bogotá, D.C.	2017
	Population	Bondarenko (2020)	National level	2020

* The consulted document reports statistics for the year 2016.

People and Health Systems

Vulnerability to climate change varies widely across Colombia (within and across regions). Therefore, knowledge about where people live and health services' locations are critical in identifying risks. As a result, the first step is to identify where people live, what characteristics they exhibit that might identify them as vulnerable, and the type(s) of health facilities that they could access (as a proxy for the complexity and types of health services available). Figure 25 provides an overview; further details are available in Nunez-del-Prado, Tariverdi, and Barrera (2023).

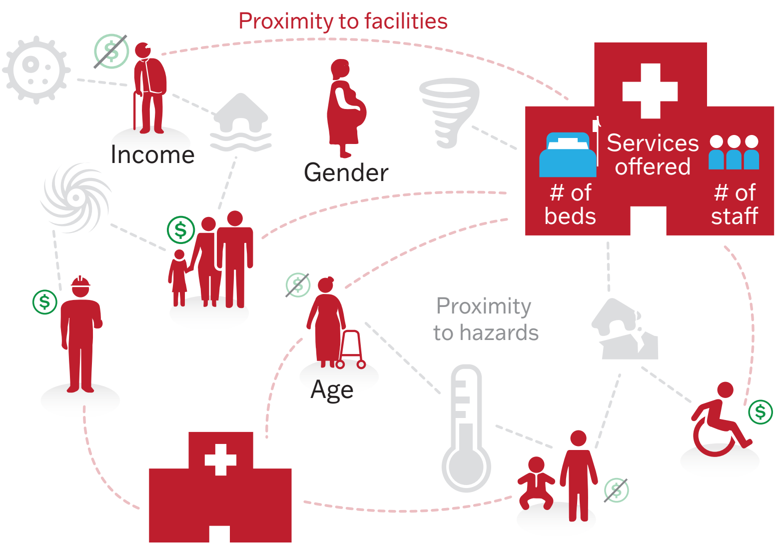
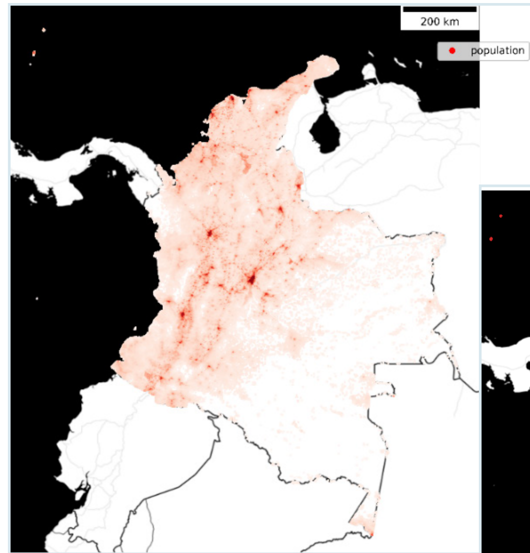
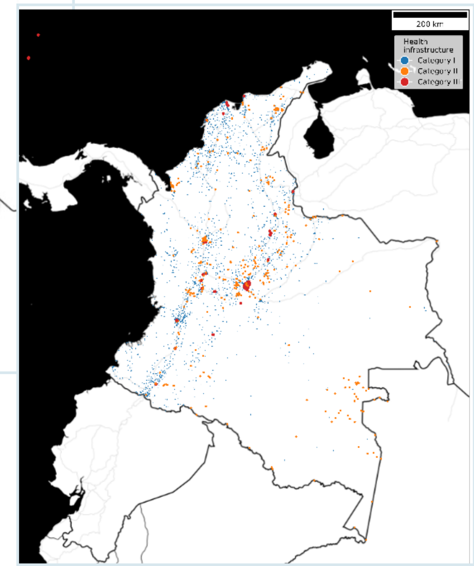


Figure 25. Geotagged Population Density (A) and Geolocated Health Facilities (B)



(A) Population density map



(B) Geolocated health facilities master list

Note: spatial resolution = 100m (meters) * 100m.

Even in a single location, not every person or facility is affected in the same way. For example, senior citizens are more vulnerable to extreme temperatures, and poorer households have fewer means to seek health services during and after extreme events. In health facilities, well-prepared and trained facilities and staff can handle demand surges whereas less resilient facilities and providers might see their capacity drop or collapse entirely. Thus, the analysis uses country specific sociodemographic characteristics and features to represent these vulnerabilities. It also addresses equity considerations for access to health services and reflects income inequality and other measures of social exclusion that are closely related to poverty, as climate events disproportionately affect the poor (Hallegatte et al. 2020).

People at the center: gender, age, and sociodemography

To identify at-risk populations, sources were first used for urban and rural population settlements from WorldPop (Bondarenko 2020) as illustrated in Figure 25a. The estimates are based on population numbers from the Colombian statistics department (DANE) and other sources, which were updated to reflect the population in 2020. Demographic and socioeconomic factors were captured through sources listed in Table 3. The Large Integrated Household Survey (GEIH) for 2021 and Measuring Monetary Poverty and Inequality survey (2021) were processed but did not pass the national and department level standards of coverage and representative thresholds and were therefore excluded from this analysis.

Health systems: assessed based on services and facilities

Our analysis collates and superimposes official information on health facilities' infrastructure and services to identify the locations, types, capacities and capabilities. Health system information such as number of beds, health workers, services, quality, and other indicators are linked to geo-tagged (located) health facilities for facility prioritization analysis. Figure 25b depicts PHC facilities, and category II (secondary referral) and category III (tertiary referral) hospitals mapped in the country. Furthermore, population coverage for analyses was modified to reflect areas where services such as remote consultation or mobile clinics are used.

Exposure of people and health systems to extreme climate events

In addition to morbidity and mortality risks in Component 1, the study focused on two natural hazards based on Colombia's risk profile and consultation with stakeholders: (i) low to moderate floods from river and rainfalls (Fathom 2022a) and (ii) fault lines integrated with risk of heavier rains (Geological Service of Colombia 2022) as a proxy for high-risk of landslide (see Annex Figure A2.3). The flood risk was captured by flood events with a 100-year return period (i.e., a 10 percent chance per decade). These types of flood events are expected to increase in frequency and intensity due to climate change (Tabari 2020) and thus relevant for health system planning for near future.

To estimate population and health infrastructure exposure, the information on population and health system locations have been merged with the data on direct hazard exposure. The information was then aggregated to the desired political boundaries (Annex, Figure A2.1) for the target unit of analysis (e.g., department or municipality).

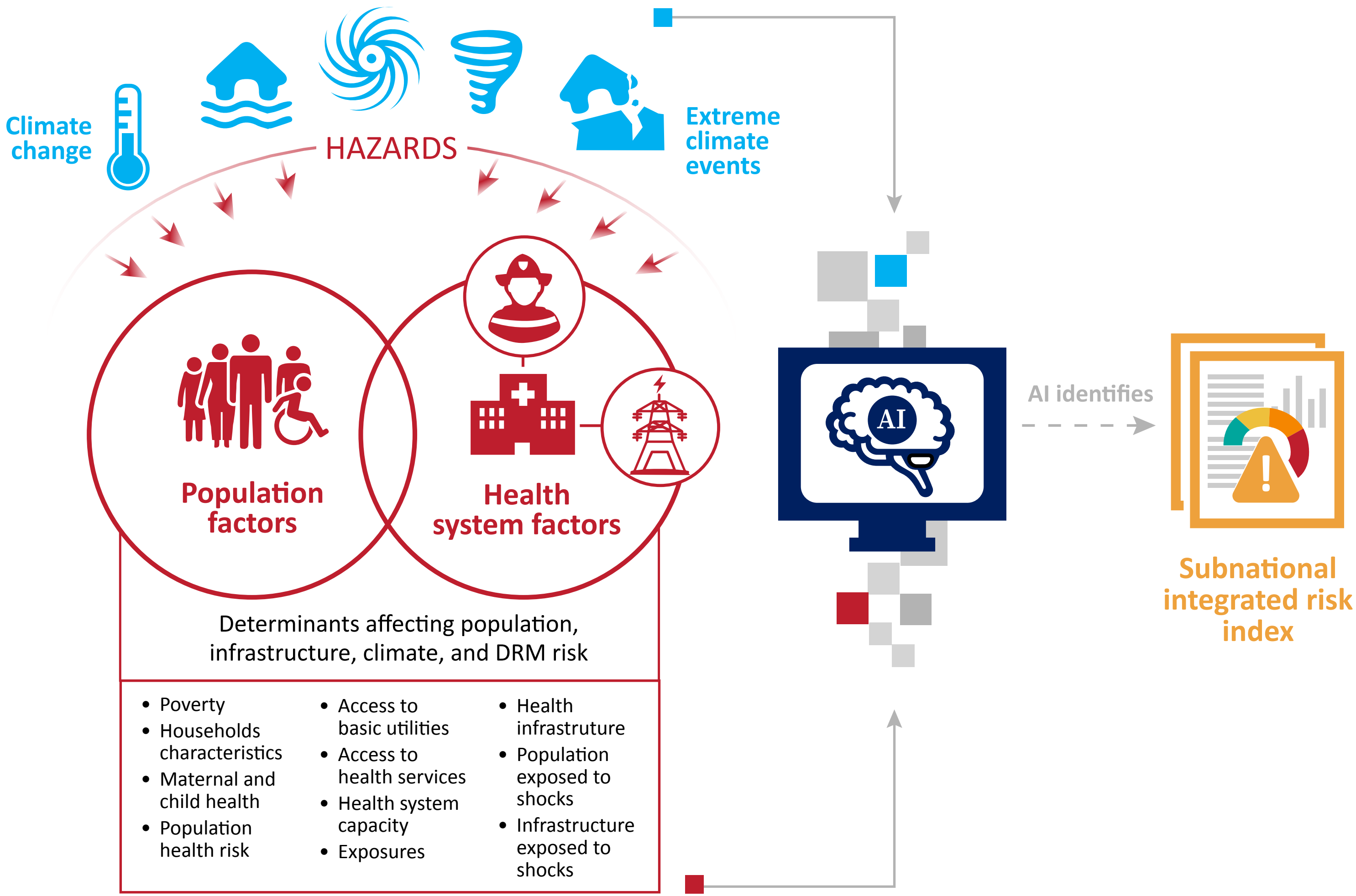
Indirect exposure to extreme climate events is equally important. A rain-induced landslide that blocks a road might not directly affect any populations or health facilities, but could make it harder for people to access health services and it might disrupt supply chains. As shown in Annex Figure A2.10, the study has captured the negative impacts of hazards on accessibility to health services in detail in the urban context of Bogotá. It is important to note that exposure data may underestimate future impacts of flooding, as land use and other human development are exacerbating the effects of flooding in Colombia (Campos Garcia 2011).

Climate-Sensitive Risk Index

The Climate-Sensitive Risk Index has been formulated for individual selected hazards, as well as for a compound scenario, encompassing the combined risk of multiple hazards. The hazard-specific index serves as a foundation for tailored interventions addressing each hazard's unique characteristics. In contrast, the composite risk index guides overarching climate and disaster risk management strategies that transcend specific hazards.

Photo: © European Union, 2020/D. Membreño (CC BY-ND 2.0)

Figure 26. Schematic Process of Calculating Climate-Sensitive Risk Index



Source: World Bank

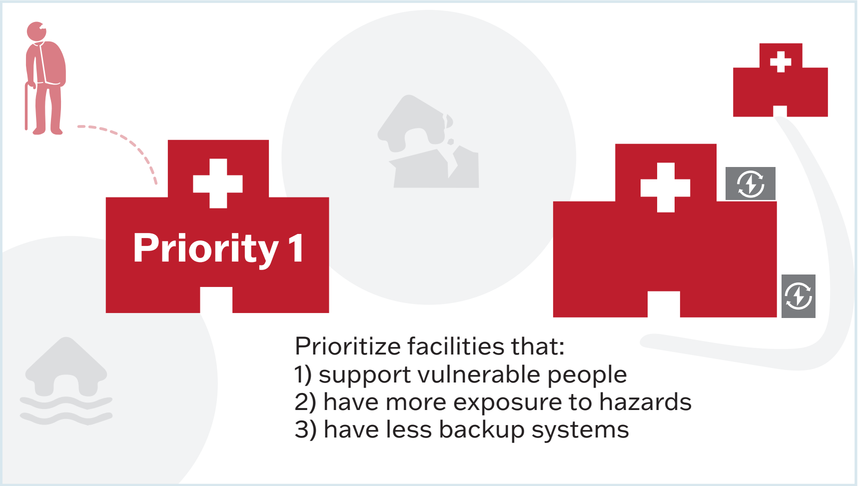
For instance, this could involve implementing flood protection measures for primary care facilities using the flood risk index, while simultaneously devising risk communication strategies for high-risk departments regardless of the specific hazards they face.

Departments are grouped together based on their overall risks. There are over 20 determinants that inform the risk directly (Table 3) in addition to population health risks that were presented in Component 1 at the department level. This analysis uses multiple models for clustering, a class of machine learning algorithms (a subcategory of Artificial Intelligence models), which combines determinants to render a single index for each department. Indices are then grouped. Clustering helps to band similar departments together based on their shared risk profiles.

Figure 26 is a schematic representation of this process. The analysis uses normative targets for all determinants. Normalization is defined based on the "gap" to a target threshold for each determinant in each department. For example, if the health system plan is aiming for nine nurses per 10,000 inhabitants, the corresponding difference of each department's present number of nurses to this target is defined as the gap. These estimated gaps are then used in the AI for grouping departments together ("clustering"). Under the normative analysis, the further a region is from the established target for a determinant, the riskier it is. In other words, regions with similar points share more or less similar risk levels. Four risk levels are selected, and each department is classified according to its scores. Note that in this method, not every risk level has the same number of departments. Details of the AI model are explained in Annex 2 and in Nunez-del-Prado, Tariverdi, and Barrera (2023).

Health Facility Prioritization

To improve health system resiliency to climate risks, the study has identified priority facilities for each prominent climate hazard to inform resilient investments at the facility level nationally and sub-nationally. This prioritization informs recommendations. The prioritization of facilities considers additional information available at the facility level, compare to risk index, namely:

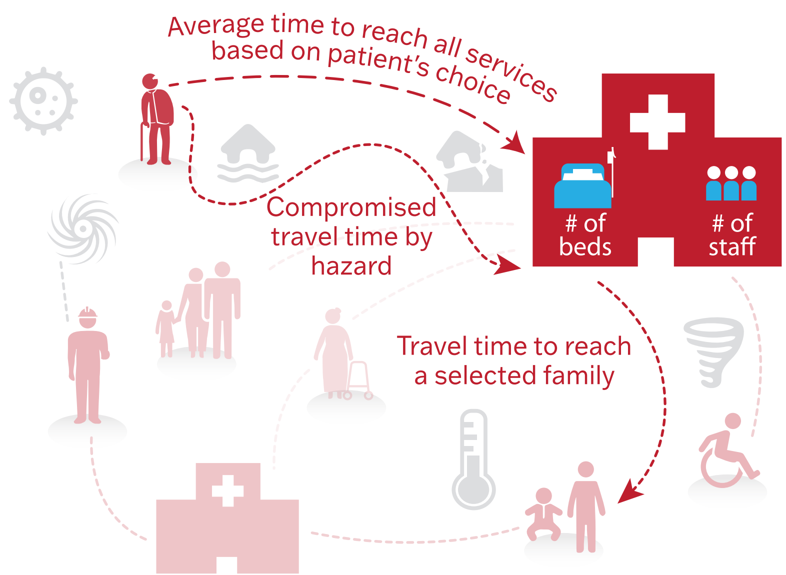


construction or remodeling year and government assessments on the current state of the buildings as a proxy for infrastructure quality, construction material (as fragility to floods and landslides differ by building material), medical equipment at facilities; and catchment population and their health and sociodemographic information. We prioritize facilities based on (i) exposure to climate risks, (ii) the vulnerability of the population in its catchment area, as defined by the determinants, (iii) the current state of the building infrastructure, and (iv) health system reach in each department. For example, if two facilities are serving populations with similar vulnerability profiles, the facility that has fewer back-up options in the region is prioritized. A lack of redundancy can hinder patient referrals and patient care-path alteration in the system. PHC, Category II, and Category III facilities are compared both nationally and at department level to identify the priority facilities for action.

Indirect and Direct Impacts of Climate Hazards on Accessibility to Health Services: Bogotá

The study used a recently developed network analysis tool (Tariverdi et al. 2023) to estimate the average duration that individuals in Bogotá require to access their various health services and preferred health facilities (hospitals). The analysis refocuses attention on people's needs. Within this model, individuals' decisions within every city block regarding healthcare facilities were taken into account: the inclination to opt for a larger,

Photo: ID 476186. 11/06/2011. Cartagena, Colombia. UN Photo/Evan Schneider. www.unmultimedia.org/photo/ (CC BY-NC-ND 2.0) better-equipped facility with insurance coverage as opposed to a smaller, nearer one. Both alternatives were deliberated with their respective probabilities. The road conditions and travel times due to climate-induced disruptions are considered and effect of people's choices are estimated as well. This is part of a broader approach to make health systems more resilient to hazards, like natural disasters or pandemics, as discussed in the World Bank Report Frontline: preparing healthcare systems for hazards from disasters to pandemics (Rentschler et al. 2021). The results identify areas where accessibility times to health services are very high and illustrate how accessibility times change in the event of climate-induced hazards like floods and landslides. The most affected communities and at-risk assets are identified, and delays and access loss are estimated, which inform increased morbidity and mortality risks (Battle et al. 2016; Alegana 2017; Manongi 2014). Results are presented in the next section. It's important to note that the alterations in access time don't pertain to a single facility; hence, each minute disparity signifies notable overall divergence. Furthermore, the travel time assumptions are established considering off-peak travel times, accentuating the magnification of longer journeys during working days. (Battle et al. 2016; Alegana 2017; Manongi 2014).



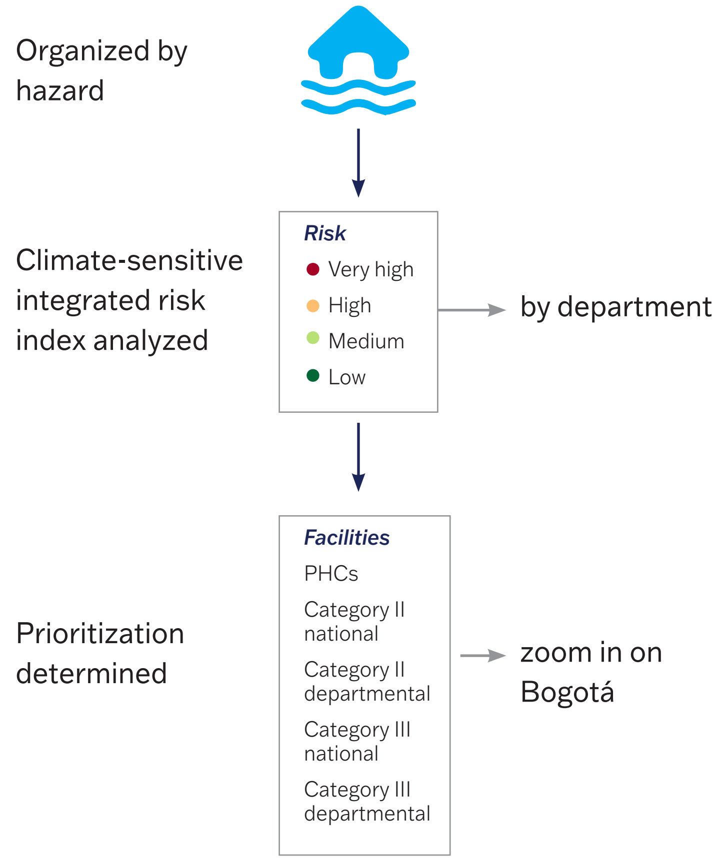
Results

Given that interventions for public health and facilities need to be customized according to the type of hazard they intend to mitigate, the results section is structured based on distinct hazards. It begins with an overview of the climate-sensitive integrated risk index for each department, followed by the prioritization list of primary healthcare facilities and hospitals at both the national and department levels. It then provides a high-resolution analysis of Bogotá, which includes indirect impacts of disasters and climate hazards (accessibility and service disruptions). Detailed interim outputs of population and health sector determinants that were estimated through this work are available digitally and samples are provided in Annex 2.

Climate-Sensitive Risk Index

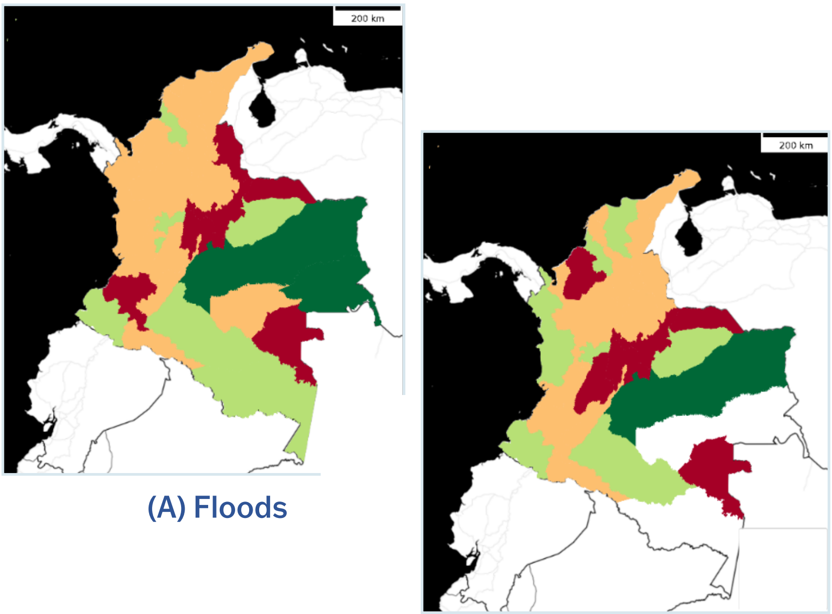
Figure 27a and 27b illustrate the departments grouped in four levels of risk ranging from very high, high, medium, to low risks. Based on all climate risk factors included in this report, Vaupes, Cundinamarca, Boyacá, and Arauca are the highest priority for action. Cauca and Norte de Santander should be observed for flood risks primarily, and Tolima and Cordoba for landslide risks. Looking into multivariate characteristics of departments for very high risk departments (Annex Table A2.5 and Table A2.6), they share population and health system risks, such as high chronic malnutrition, shortages of staffed hospital beds, higher poverty

Results Roadmap



rates, and lack of access to internet services. For hazard-agnostic interventions, a compound risk index is computed as shown in Figure 28. The central areas of the country clearly should take priority for health system strengthening and climate resiliency disregard of hazards. Examples are risk communication strategies, disaster risk management and surge trainings for health workforce, etc. The risk index for departments is included in Annex Table A2.5 and Table A2.6.

Figure 27. Department-level Climate and Health Risks

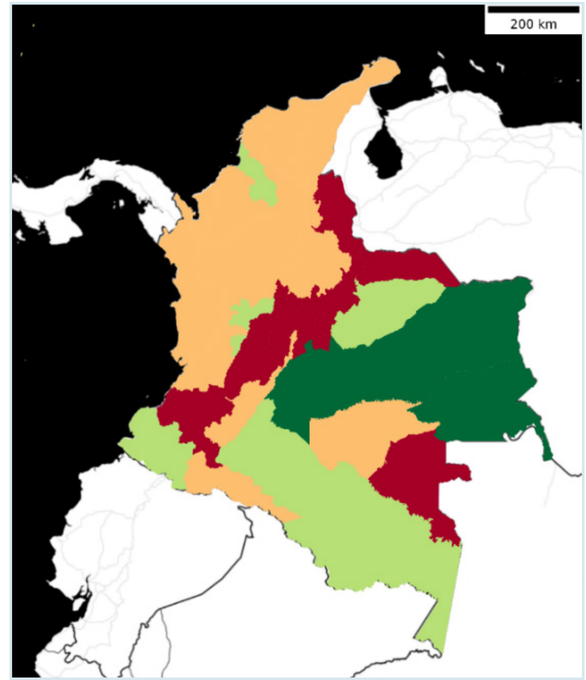


(A) Floods

(B) Landslides

Risk ● Very high ● High ● Medium ● Low

Figure 28. Compound Hazards Climate-Sensitive Integrated Risk Levels



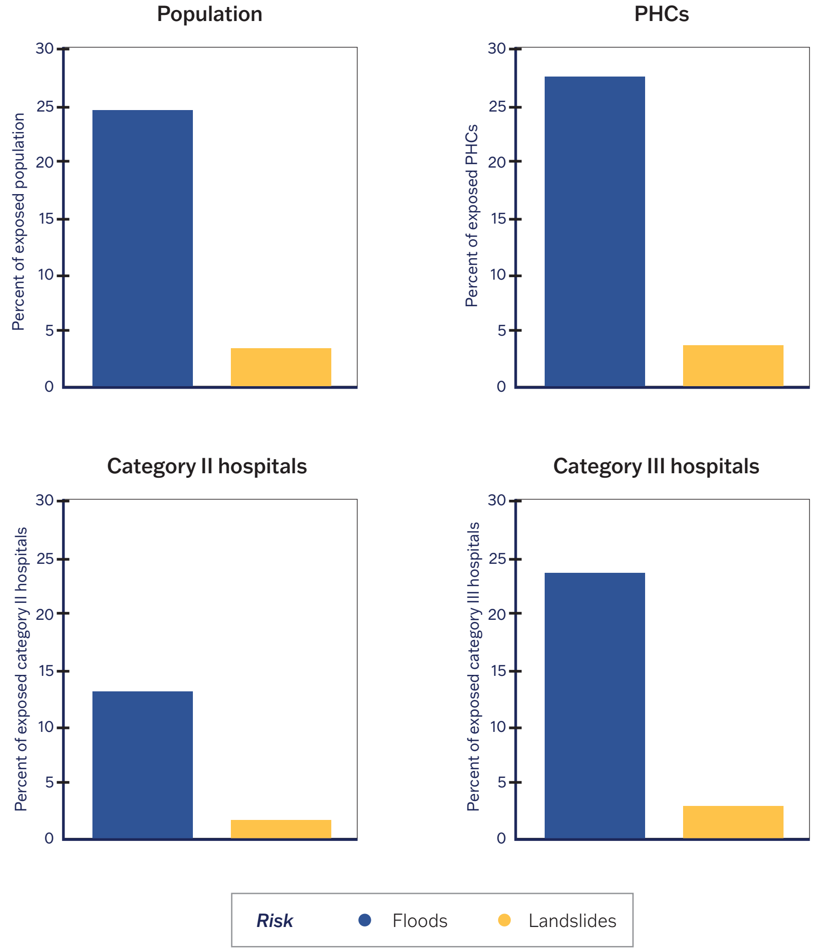
Risk ● Very high ● High ● Medium ● Low

Details of the intermediate information from processed data for population and health sector determinants estimated through this work, are being provided in *digital outputs* for reference.

Exposure Analysis

Colombia's population and healthcare system are subject to substantial and direct exposure to climate hazards (Figure 29). However, the effects of these hazards differ based on the specific nature of the hazard. It is important to highlight that the consequences of moderately frequent floods differ significantly from those of potential landslides, for example. As a result, it is imperative to interpret the findings that accounts for these variations. Tables 4 and 5 summarize the findings of the analysis of the risk exposure to floods and landslides for people and health systems, including adverse disruptive and destructive impacts.

Figure 29. Population and Healthcare Facilities Exposed to Floods and Landslide Risks

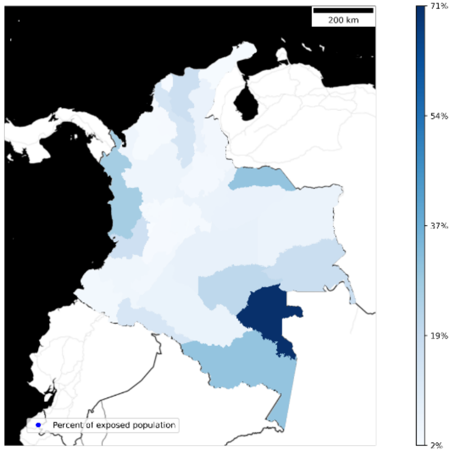


Floods

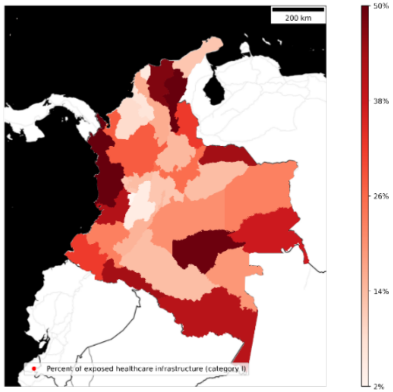
Exposure risks to floods vary significantly at the department level as indicated in Figure 30.

Table 4 provides a comprehensive overview of the findings and outlines implications for individuals, the healthcare system, and critical infrastructure that supports the delivery of quality services. The table encompasses various aspects, such as the population directly exposed to floods and associated health risks, followed by an analysis of the ensuing disruptions of transport on healthcare service delivery.

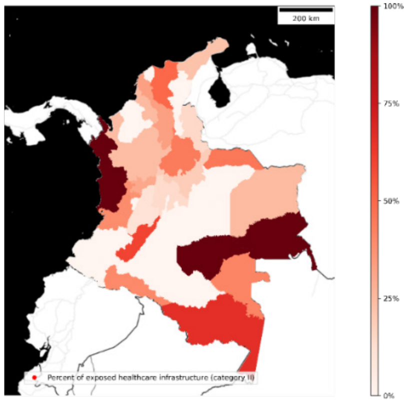
Figure 30. Population and Health Facilities Exposed to Floods, Department Level



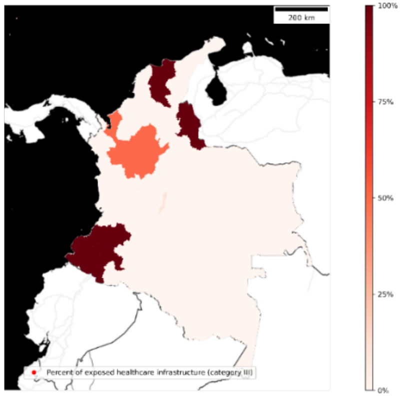
(A) Population



(B) PHC



(C) Category II



(D) Category III

Table 4. Analysis of Exposure to Floods and Related Impacts

Category		Impact
People	Health	Almost one quarter of the population (15.7 million people) is directly exposed to low flood level risks (5 cm depth). Populations exposed to floods can face higher risks of disease outbreaks due to contaminated food and water and vector-borne diseases, and injuries such as skin infections, acute respiratory infections, and diarrhea. They also face broader socioeconomic risks of impacts on well-being and livelihoods. Exposure to flood risk can disproportionately harm vulnerable populations, such as people with chronic disease or disabilities. It can also impact their access to health services. Clean-up and reconstruction efforts can also expose workers to additional health risks. Annex Table A2.1 contains detailed exposure analysis. It shows that among Colombia's departments, Vaupes, Amazonas, and Arauca have the highest percentage of their populations directly exposed to floods.
	Socioeconomic	Poor people tend to live in flood-prone areas (where education levels and income levels are lower). Valle del Cauca, with a poverty rate of 29.7 percent, has the highest number vulnerable people directly exposed to floods (2.4 million people / 42.71 percent of its population). Floods can further exacerbate poverty by affecting sources of income and/or leading to an increased health and education expenses, resulting in long-term poverty.
Health System	Built Environment	About 1 out of 5 health facilities are directly exposed to disruptive floods. This includes 4,416 primary care facilities and 143 hospitals. Indirect impacts on health infrastructure are also substantial due to disruption to water, power, and communication networks, as well as impaired accessibility to facilities. Guaviare, Chocó, and Amazonas are the departments with the most healthcare infrastructure exposed to floods (Table A2.3). Figures A2.8 and A2.9 show the percentage of primary healthcare infrastructure and hospitals exposed to floods at the department level. The inundation of buildings and parking areas by floodwaters can drastically reduce functionality and close facilities in some cases. Highlighted adverse effects of Hospital is listed under "Indirect Impacts on Accessibility: Zoom In on Bogotá" and an economic analysis of exposed health facilities to flooding in (Thompson, Tariverdi, and Nunez *forthcoming*).
	Equipment	Flooding inundation also can compromise critical medical equipment, lifeline functions (e.g., water, electricity), disrupting or halting services and costing millions in damages. The expected inundation levels (5 cm) are unlikely to damage beyond repair most medical and other equipment in major facilities. However, the 5 cm depth used in the analysis is an average value of potential flood level; actual levels can vary significantly. Higher flood levels should be studied in areas with heavier rainfall zones and urban areas with weaker drainage systems.
	People	Flooding also can lead to health impacts from mold growth in health facilities, along with other impacts outlined above. These impacts are also addressed, in part, through the results of Component 1.

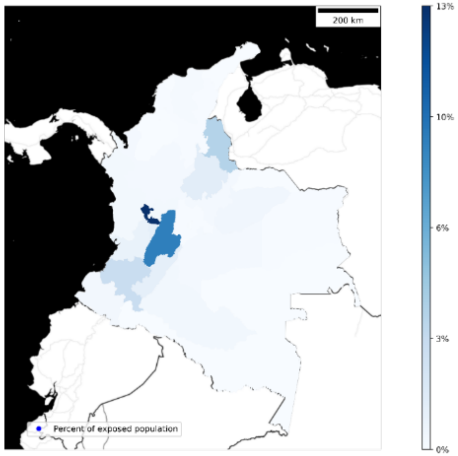
Category		Impact
Lifeline Infrastructure	Transport	Inundation from floodwaters can slow or stop emergency transport, supply chain, health facility personnel, and voluntary admissions in a hospital's catchment area. Transport impacts in the city of Bogotá, are outlined in the section "Indirect Impacts on Accessibility: Zoom In on Bogotá".
	Power	Damage from the flooding of electricity assets can disrupt electrical power to residences, exacerbating the conditions outlined above on impact on population and resulting in other risks due to loss of power (e.g., powering of at-home medical devices). Electricity disruptions also can impair or cease health facility functioning, particularly for facilities without regularly tested redundancies. Collecting data on the existence of electricity and fuel backup in health facilities from nationally mandated risk assessments could enable a targeted assessment of power risks to health systems.
	Water/ Wastewater	Inundation from floodwater can contaminate potable water, which will impact populations via consumption of contaminated waters or reduced access to potable water. Like power, disruptions to water/wastewater networks from flooding can limit or halt basic hospital functions due to a lack of usable water, especially for hospitals with insufficient redundancy measures. Collecting data on the existence of water and wastewater backup in health facilities from nationally mandated risk assessments could enable a targeted assessment of water/wastewater risks to health systems.
	Information Communications Technology (ICT)	Flooding can damage some ICT infrastructure at or near ground level. This can limit emergency, interagency, and other communication and coordination, especially in agencies and health facilities without redundancies for digital or cellular communication. Collecting data on backup communications in health facilities could enable a targeted assessment such disruptions to health systems.

Table 5. Analysis of Exposure to Landslides and Related Impacts

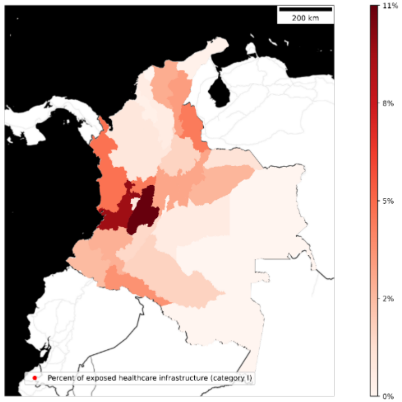
Category		Impact
People	Health	About 5 percent of the population (2.2 million people) is directly exposed to landslides, as shown in Figure A2.4. Risaralda, Tolima, and Norte de Santander are the departments with the most population directly exposed to landslides (Table A2.2). In addition to injury and death, landslides can cause respiratory issues from dust and debris.
	Socioeconomic	Poorer people are more likely to live in weakly built housing made from lower-quality building materials, making them more vulnerable to landslides. As such, they may face displacement or significant rebuilding costs after a landslide, which would worsen the cycle of sustained poverty. Landslides can also disrupt local infrastructure, such as roads and highways. This can impact all facets of life: market access, education, and health services, with longer lasting effects for the most vulnerable parts of the society (e.g., in the form of higher dropout rates after disasters). To overcome these challenges, vulnerable people may spend all their savings or be forced to sacrifice other necessities for survival.
Health System	Built Environment	In Colombia, 3.5 percent of the healthcare infrastructure is directly exposed to landslides risks. This encompasses, 549 primary healthcare facilities and 20 hospitals (Figure 31). As shown in Table A2.4, Tolima, Risada, and Valle del Cauca are the three departments with the highest healthcare infrastructure exposure to landslides. The impacts of landslides on the built environment can vary from inconsequential to complete destruction, with the level in part depending on a building's design (e.g., codes, construction materials) and on the type of landslide (e.g., gradient of the slope, type of material, size of the landslide). Consequently, economic, and functionality losses can vary from minimal to complete loss. An economic estimate of exposed assets to landslides can be found in an addendum to this report (Thompson, Tariverdi, and Nunez *forthcoming*).
	Equipment	Landslide impacts can result in partial or complete destruction of equipment, depending on the severity of the event. Equipment located outside of hospital facility buildings are particularly vulnerable, including backup power generators, fuel storage, and water supplies.
	People	In addition to mortality and severe injuries, landslides can cause respiratory issues from resulting dust and debris. (The impacts of service disruption on catchment area of facilities are investigated in Thompson, Tariverdi, and Nunez (*forthcoming*).

Category		Impact
Lifeline Infrastructure	Transport	Landslides often cause significant disruptions to roadways by blocking roadways with debris, damaging them, or destroying individual sections. Landslide-related transport delays are often more pronounced than other hazard-induced disruptions, like floods, but they also tend to be more localized.
	Power	Landslides often disrupt the power infrastructure by damaging electricity and gas lines. Damage to major electrical infrastructure, in particular, can impact people and health systems far beyond the landslide area and exacerbate conditions outlined in the People section in this table. Electricity and gas outages to hospitals without power redundancies can disrupt health facilities' functionality. Collecting data on the existence of electricity and fuel backup in health facilities from nationally mandated risk assessments could enable a targeted assessment of power risks to health systems as also highlighted in our recommendations.
	Water/ Wastewater	Landslides can produce similar damage to water/wastewater infrastructure as it does to power infrastructure. Prolonged water/ wastewater disruptions can cause health facilities to limit or cease functioning, especially in facilities without redundancies for these systems. Disruptions also can exacerbate conditions outlined in the people section, along with creating new problems due to a lack of water. Collecting data on the existence of water and wastewater backup in health facilities from nationally mandated risk assessments could enable a targeted assessment of water/wastewater risks to health systems as also highlighted in our recommendation section.
	ICT	Landslides can damage ICT infrastructure, which is often particularly vulnerable to damage, since ICT infrastructure is often located in elevated areas that are more prone to landslides. Damages to ICT infrastructure could disrupt standard communications systems, particularly in more remote areas with potentially devastating impacts due to extended delays and resource shortages. Collecting data on backup communication systems in health facilities could enable a targeted assessment of ICT risks to health systems.

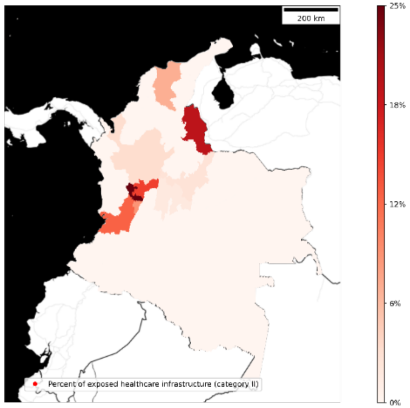
Figure 31. Population and Health Facilities Exposed to Landslide Risks, Department Level



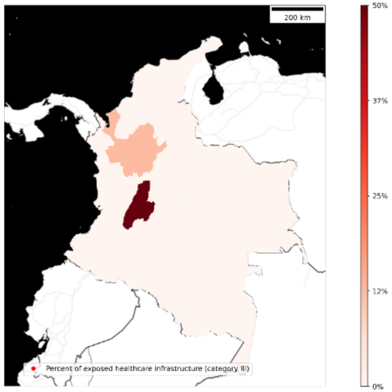
(A) Population



(B) PHC



(C) Category II



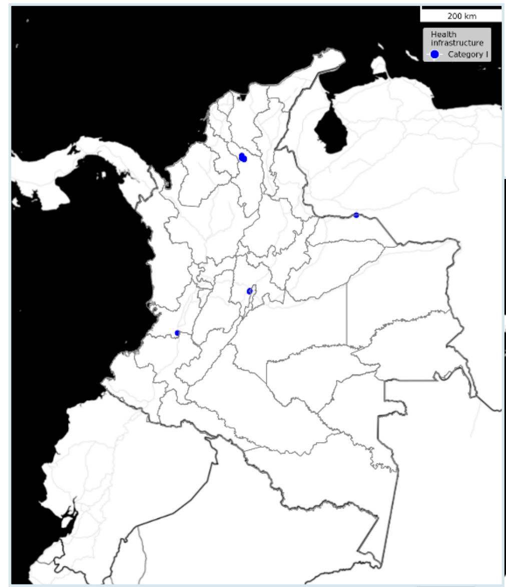
(D) Category III

Resilience-Sensitive Health Facility Prioritization

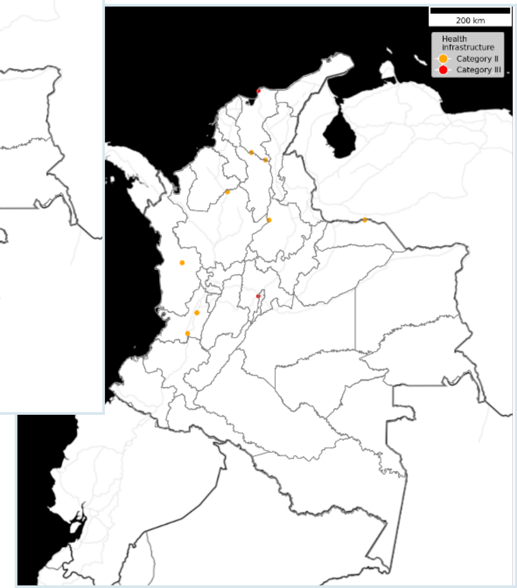
Facility exposure information, though informative, is insufficient for prioritization. In the present analysis, the facility exposure information to hazards was also integrated with population and health system characteristics to establish a ranking of the top ten healthcare facilities (PHCs and category II and III hospitals) that should be prioritized at the national level and within departments separately as defined in the methodology. The analysis showed regions of Bolivar with five out of ten PHCs at risk (Figure 32a and Table 6). The hospital analysis identified Valle del Cauca and Magdalena as the only departments with two category III hospitals at risk of floods (Figure 32b and Table 7). Additionally, Figure 33 presents the three healthcare facilities for each region with the highest exposure to floods. Regarding PHCs, the analysis indicates that the departments in the north have more PHCs at risk of floods, while most affected hospitals are in the western and northern regions of Colombia, as described in Annex Figure A2.7 and Figure A2.8, respectively. Bolivar and Valle del Cauca have PHCs prioritized for floods and landslide risks, while Valle del Cauca and Antioquia have prioritized hospitals for both hazards. Lastly, comparing the exposure maps (REF) with priority figures (Figure 30) and priority maps (Figure 32 and Figure 33), clearly reveals the value of added information on population's characteristics in the facilities catchment area and health system.

Facility prioritization for flood interventions

Figure 32. Health Facility Prioritization, National Level: Top Ten PHCs and Hospitals for Flooding

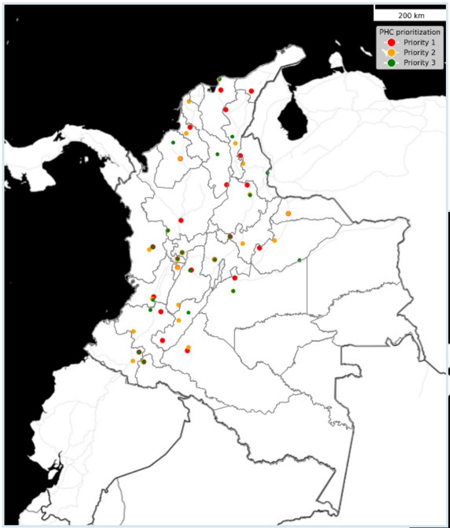


(A) National top ten PHCs to prioritize

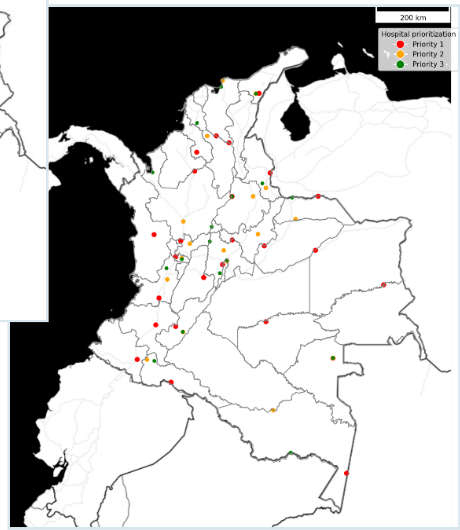


(B) National top ten hospitals to prioritize

Figure 33. Health Facility Prioritization, Department Level: Top Three PHCs and Hospitals per Department for Flooding



(A) Top three PHC to prioritize per department



(B) Top three hospitals to prioritize per department

Table 6. Health Facility Prioritization, National Level: Top Ten PHCs for Flood Intervention

PHC ID	Name	Category	Department
135490035501	--	1	Bolívar
135490009501	E.S.E Hospital San Nicolas De Tolentino	1	Bolívar
135490009504	E.S.E Hospital San Nicolas De Tolentino	1	Bolívar
110010101031	--	1	Bogotá, D.C.
135490009506	E.S.E Hospital San Nicolas de Tolentino	1	Bolívar
257540380801	--	1	Cundinamarca
763640375607	--	1	Valle del Cauca
763641109802	--	1	Valle del Cauca
135490009503	E.S.E Hospital San Nicolas de Tolentino	1	Bolívar
810010053901	--	1	Arauca

** In cases in which the name of PHC is unavailable or in which two PHCs share the same name, each facility is identified through its unique identifier code.*

Table 7. Health Facility Prioritization, National Level: Top Ten Hospitals for Flood Intervention

T Hospital ID	Name	Category	Department
760010511501	Hospital Isaias Duarte Cancino Empresa Social del Estado	2	Valle del Cauca
134680049204	E.S.E Hospital La Divina Misericordia Sede San Juan de Dios	2	Bolívar
51540220101	E.S.E. Hospital Cesar Uribe Piedrahita	2	Antioquia
472450024901	Empresa Social Del Estado Hospital La Candelaria	2	Magdalena
270010116901	Nueva Empresa Social del Estado Hospital Departamental San Francisco de Asis	2	Chocó
768340465201	E.S.E. Hospital Departamental Tomas Uribe de Tulua	2	Valle del Cauca
470010065001	Hospital Universitario Julio Mendez Barreneche	3	Magdalena
810010007701	E.S.E. Hospital San Vicente	2	Arauca
680810079701	E.S.E. Hospital Regonal del Magdalena Medio	2	Santander
110013029640	Unidad de Servicios de Salud San Bernardino	3	Bogotá, D.C.

Economic exposure and disruption analysis from flooding

The integrated risk model was used as the basis to estimate the value of exposed health facilities to floods in a forthcoming analysis (Thompson et al. 2023). The report found that cost of direct exposure of facilities to floods (1 in 100-year flooding) is approximately USD 170.8 million (2023), with aggregate exposure of PHC facilities (USD 149.4 million) constituting the majority of this exposure. Category II and III facilities exposed to flooding face higher levels of financial exposure per facility, which is reflected in their size, quality, and other factors. The departments of Vaupés, San Andres, Vichada, Amazonas, Guainía, Guaviare, and La Guajira possess a greater proportion of exposed category II and category III facilities. Notably, in many of these departments, the exposed category II and III facilities serve as the principal referral facilities.

A comparison of disrupted patient days within different departments suggests that for category II and III facilities in Arauca, Bolívar, Chocó, Magdalena, and Sucre to achieve a comparable impact to the disruption of an average PHC facility in their respective departments, facility restoration times would need to be over 10 times faster, all else being equal. It's important to note that this analysis likely underestimates the speed required for parity, given that category II and III facilities offer more advanced levels of care.

Mitigating risks of 5 cm flood depths through the construction of external mitigation measures, such as a stormwater drainage system, indicate varying levels of vulnerability reduction. Assuming that the constructed flood mitigation measure would completely eliminate flooding in the facility, modeling flood reduction measures in the top 20 most financially exposed health facilities would result in a USD 14 million reduction in asset exposure. This finding is complemented by an analysis of disrupted services due to flooding, which suggests that mitigating disruptions at these facilities would have a more pronounced impact on reducing patient days disrupted than similar interventions in category one facilities.

Simulating El Niño events based on historical or anticipated rainfall models could likely result in significantly greater damages due to higher levels of inundation depth in certain facilities. This consideration warrants further attention in future planning and mitigation efforts against flood events (Thompson et al. forthcoming).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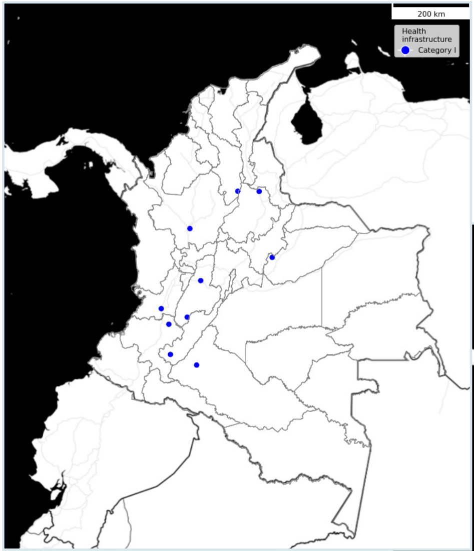
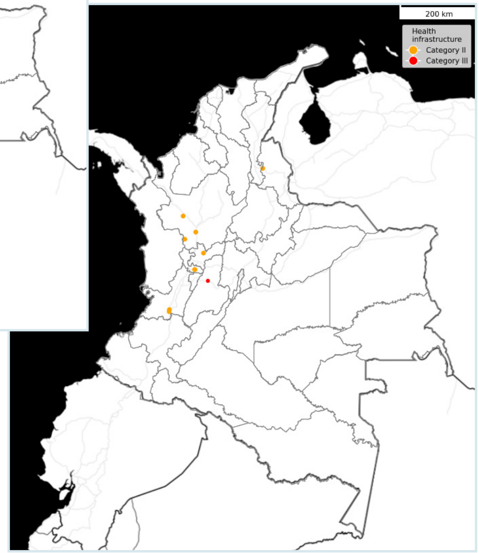
Facility prioritization for landslides interventions

Figure 34a and Figure 34b show the top ten PHCs and hospitals at the greatest risk of landslides at the country level. These healthcare facilities are located mainly in the country's center. Facilities in southern Colombia are less exposed to landslides (see Figure 31). Tables 8 and 9 detail the health facilities most at risk and show that the departments of Tolima and Antioquia have the highest number of PHCs and hospitals among the top ten most exposed facilities. Figure 35 also shows the top three healthcare facilities that should be prioritized in each department. A corresponding list of the respective health facilities can be found in Table A2.9 for PHCs and Table A2.10 for category II and III hospitals.

Figure 34. Health Facility Prioritization, National Level: Top Ten PHCs and Hospitals for Landslides Risks

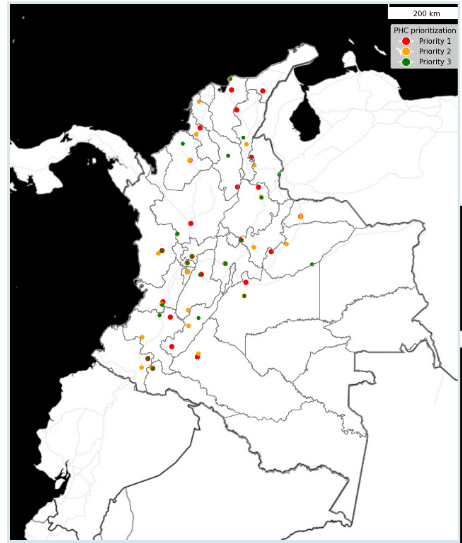


(A) National top ten PHCs to prioritize

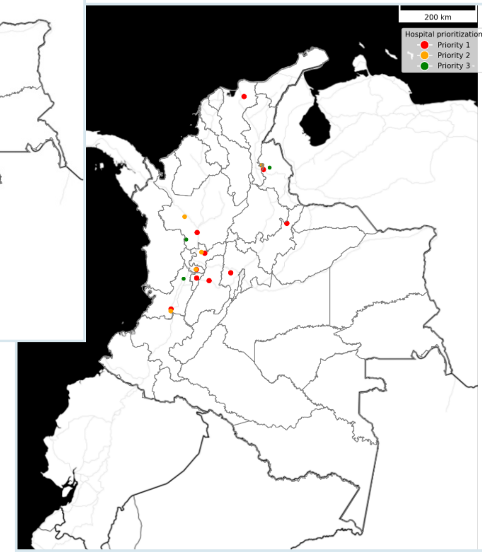


(B) National top ten hospitals to prioritize

Figure 35. Health Facility Prioritization, Department Level: Top Three PHCs and Hospitals for Landslide Risks



(A) Top three PHCs to prioritize per department



(B) Top three hospitals to prioritize per department

Table 8. Health Facility Prioritization, National Level: Top Ten PHCs for Landslides Intervention

PHC ID	Name	Category	Department
852790042217	Red Salud Casanare E.S.E.	1	Casanare
760011261801	--	1	Valle del Cauca
50010210903	--	1	Antioquia
730010297401	--	1	Tolima
413590042402	Ese E.S.E. Hospital San Jose de Isnos	1	Huila
735550103101	Hospital Centro E.S.E. de Planadas	1	Tolima
182560200203	E.S.E. Sor Teresa Adele	1	Caquetá
198210004001	CXAYU'CE JXUT Empresa Social del Estado	1	Cauca
682550239101	--	1	Santander
136700007601	E.S.E. Hospital Local San Pablo	1	Bolívar

Table 9. Health Facility Prioritization, National Level: Top Ten Hospitals for Landslides Intervention

Hospital ID	Name	Category	Department
760010360902	Centro de Rehabilitación En Salud Mental – CRESM	2	Valle del Cauca
760010360901	E.S.E. Hospital Departamental Psiquiatrico Universitario del Valle	2	Valle del Cauca
730010104701	Hospital Federico Lleras Acosta E.S.E.	3	Tolima
51290214601	E.S.E Hospital San Vicente de Paul de Caldas	2	Antioquia
661700027803	Puesto de Salud Frailes	2	Risaralda
50040547802	Ese Hospital San Juan de Dios de Abriaqui	2	Antioquia
661700027804	Centro de Atención Ambulatorio Japìn	2	Risaralda
51010213901	E.S.E Hospital La Merced de Ciudad Bolivar	2	Antioquia
176530064609	Centro de Salud San Felix	2	Caldas
544980054701	Empresa Social del Estado Hospital Emiro Quintero Cañizares	2	Norte de Santander

Economic exposure and disruption analysis from landslides

A retrospective analysis of historical landslide deposit heights yielded two distinct scenarios occurring within the landslide risk zones identified by the climate-sensitive integrated risk model. The landslide deposit heights for the scenarios measured 1.56 meters and 3.96 meters, respectively. Based on economic exposure models, health facilities facing exposure to the 1.56-meter scenario amounted to USD 416.4 million (2023), while those exposed to the 3.96-meter scenario totaled USD 656.4 million. Notably, structures within the 3.96-meter scenario are anticipated to experience extensive damage, ultimately leading to complete loss. The disruptions arising from both scenarios are estimated to persist for years, as all impacted facilities would necessitate reconstruction in the aftermath of such an event.

Likewise, comprehending and strategizing the distribution of health services from a non-operational facility among functioning ones could mitigate the repercussions of functional losses. These strategies can be further enhanced by implementing monitoring systems that offer advanced alerts to health facilities (Thompson et al. forthcoming).

Indirect Impacts on Accessibility: Zoom In on Bogotá

To illustrate the secondary effects of floods on people's ability to access health services in a timely manner, a Network Analysis approach (meso-simulation, methodology in Tariverdi et al. (2023)) for Bogotá, D.C was used. The nework approach models climate-induced disruptions to transport networks that cause accessibility delays and isolated communities (complete accessibility loss to care). The model considers peoples' preferences for specific health facilities based on number of beds and services offered (type of facility) as described earlier in Methodology section of this chapter. The analysis estimates *average expected travel times to seek different health services.* As shown in Figure 36, the average travel time for all citizens increases from 30 to 45 minutes as a result of moderate floods. Note while the times reported here are average travel times, some communities suffer much higher delays. Northwestern areas of Bogotá are the most affected by floods, with average travel times increasing five-fold (from 15 minutes to 80 minutes), indicating a severe delay in access to potentially life-saving services. Delayed access to healthcare services is associated with significant costs for patients due to higher risks of morbidity and mortality from treatable conditions in addition to service disruptions due to health workers access to facilities and supply chain issues. Such events in higher frequency and caused delays, potentially affect population health as to travel long distances to reach health facilities have been shown to decrease the likelihood of seeking health services (Battle et al. 2016; Alegana et al. 2017; Manongi et al. 2014). Flood exposure information for Bogotá in greater detail is available in ***digital outputs.***

Photo: © Hembo Pagi (CC BY-NC 2.0)

Northwestern areas of Bogotá are the most affected by floods, with average travel times increasing five-fold (from 15 minutes to 80 minutes), indicating a severe delay in access to potentially life-saving services.

Figure 36. Average Accessibility Time of Population to Their Preferred Health Services in Bogotá and Most Affected Communities by Indirect Impact of Floods

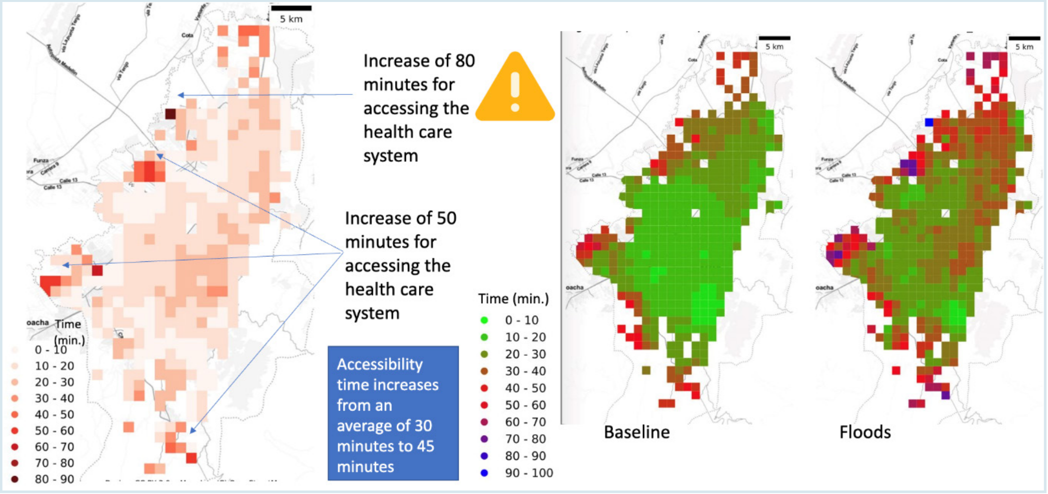


Figure 37. Critical Road Segments in Bogotá Essential to Ensure Accessibility to Health Services

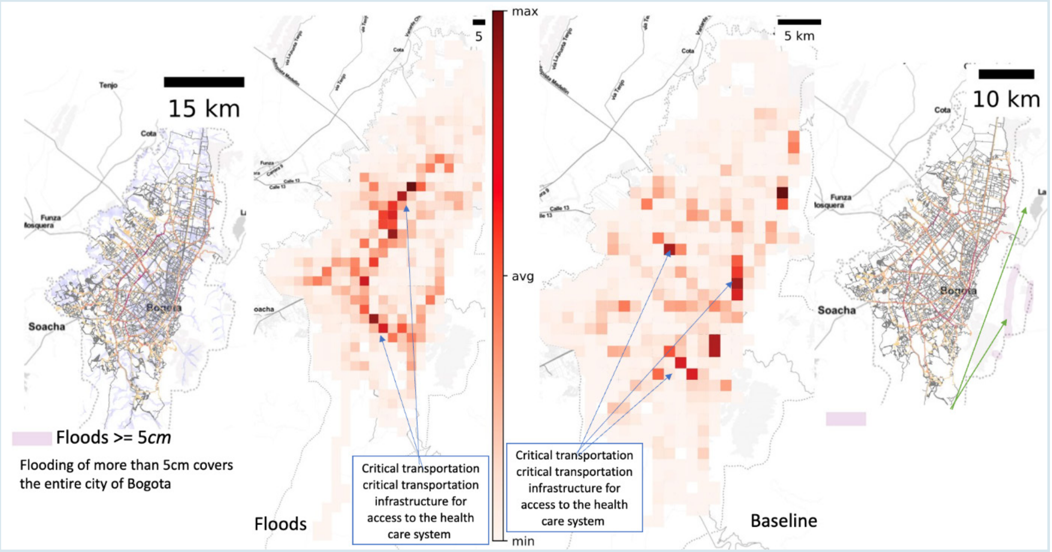


Figure 37 complements the accessibility time metric by highlighting critical routes to be maintained to ensure accessibility to the health system at times of disruption. The criticality of roads is defined based on routes that serve the largest number of people seeking access to all the health services of their choice. The higher the criticality, the more important the road and the greater the need to be prioritized by the governing agency for risk mitigation and preparedness interventions (e.g., prepositioning debris removal, flood protections). Note that these road sections are crucial for continuity of care in health. Using this metric, the analysis shows that western routes are the most essential to be maintained and kept open for floods; while for landslides, eastern routes becomes more essential for access to health services. It is important to note that exposure data may underestimate future impacts of flooding, as land use and other human development are exacerbating flooding in Colombia (Campos Garcia 2011).

Conclusion and Recommended Actions

The impact of climate change and hazards on population health is exacerbated by social inequalities, poverty, overwhelmed healthcare facilities, and a lack of evidence-based public policies (Palmeiro 2023). To better understand the situation in Colombia (including variations in different regions), this analysis identified vulnerable populations and overlayed that data with health system vulnerabilities. **The results indicate a significant and direct impact of floods and landslides on both Colombia's population and its health system, particularly where health resources are more limited and where they serve more vulnerable populations.**

In this regard, the Climate-Sensitive Risk Index can be a starting point for prioritization, as it systematically classifies risk based on a normalized and representative set of information. It considers climate-sensitive risk determinants for populations and the health system simultaneously to identify departments, communities, and facilities at the forefront of climate change-related health risks. It directly supports decision making by providing timely key performance indicators and data analysis to prioritize departments, as shown in the results, while also generating detailed lists of vulnerable communities and priority health facilities (PHCs, hospital category II, and hospital category III) for targeted interventions.

The risk assessment results highlight several potential actions. Mitigation strategies are strongly recommended, preparedness interventions, and policies to reduce risks from floods and landslides, starting in the departments with the highest risks, as identified in the results and detailed in the annex. **Mitigation and preparedness measures are critical** for the identified departments due to the extensive exposures detailed in the findings. **Prioritization is key**, given the limited resources and vast potential impacts; it impossible to immediately equip every facility to the highest standard to minimize disruption of health services to the most vulnerable parts of the population.

Enhanced communication channels, data-driven approaches for coordinated service delivery, resource allocation, and targeted deployment of mobile clinics can help to meet surge demand through a system-level and regionally coordinated response. Table 10 lists the recommendations; they are aligned with previous government of Colombia policy measures to reduce the impact of climatic and non-climatic hazards, including seismic and some volcanic activity. While government ministries in Colombia agree about the vulnerability of the healthcare system due to climate change, to date, more work is needed. To address this, it is recommended that the **emergency preparedness of the country's health systems regarding extreme climatic events should be closely coordinated with the overall emergency management and disaster response systems, to increase efficiency and leverage existing structures.** This includes further integrating the health system's disaster risk management efforts with actors such as the military, civil protection, and community groups, with clearly defined roles and mandates for crisis response, including more frequent hazards such as floods.

Concerning preparedness for floods and impact mitigation, the Climate-Sensitive Risk Index can support local agencies to determine flood risk locations in each area and develop a detailed preparedness and response plan accordingly (Wood 2018). Department-level exposure maps can be used directly. Additionally, the index can be used to prioritize the creation of the evacuation protocols and multi-purpose shelter locations needed for critical hospitals this analysis has identified as priority facilities. Tailored response plans also need to be developed for each area.

We suggest adding information on long-term care facilities and strengthening service delivery for areas with a higher proportion of seniors and for people with jobs directly exposed to weather, such as construction and agriculture. Further assessments should be conducted to identify and prioritize the concrete needs and to tailor policy interventions according to community needs and routine health service delivery specific to the region's need and disease profiles.

Lastly, **multi-sectoral investment involving the health, transport, power, water, and communication** sectors is recommended to strengthen the health system and enhance its climate resilience. As part of flood and landslide mitigation measures, transport upgrades should prioritize identified critical corridors for health service delivery. Measures could include maintaining critical routes and prepositioning response equipment. In addition, modes of alternative service delivery, such as telehealth, should be considered for highly impacted communities. However, doing so depends on the availability and strengthen of internet and cellular coverage in some areas of the country. It may also be useful to revisit land-use zoning to reduce risks to health services and populations in high-risk departments (Habitat for Humanity 2023).

In order to strengthen data-driven policy interventions and to enable more granular analyses at the municipality level (administrative level 2), **increased access to sampling and coverage for the Large Integrated Household Surveys and Measuring Monetary Poverty and Inequality survey would be useful.** Such granularity could enable efficient microtargeting. In addition, collecting data on how internally displaced population facing these hazards seek health, would greatly enhance any future analysis.

Recommendations—based on the results of this analysis and supporting research—include **specific actions for planning, disaster preparedness, staff training, capacity building, and the structural quality of buildings and infrastructure** (highlights in Table 10). Building capacity, particularly in under-resourced areas, will become increasingly important to minimize the losses to the health system and to population health due to climate change, which is contributing to increased risk from hazards. It is important to note that many recommendations require multi-level governance and multi-sectoral collaborations involving the health sector and other sectors, particularly emergency response and lifeline infrastructure. This reflects the importance of a unified approach in governance to strengthening health and other key systems from hazard impacts (Rentschler et al. 2021).

Table 10. Recommended Actions to Improve Health System Climate Resiliency in Colombia

Observation	Potential Action	Action Type	Reference(s)
According to the Climate-Sensitive Risk Index, flooding impacts approximately 20% of healthcare facilities, and landslide risks affect approximately 3.5% of healthcare facilities. Many of the most exposed facilities are in areas with high percentages of vulnerable populations.	Prioritize in-depth risk assessments of facilities focused on hazards and health services being provided through various modalities (i.e. remote consultations, telehealth) in areas with vulnerable populations (e.g., Valle del Cauca) in line with national laws and guidance, such as Decree 2157 of 2017 (2.3.1.5.2.1).	Health infrastructure; Health system planning	Campos Garcia et al. (2011); Bennett and Iossa (2006); Government of Colombia (2021); California Hospital Association. 2023
Floods and landslides disrupt lifeline infrastructure, like electricity and water supplies; this reduces or cripples health facilities' ability to function.	Invest and maintain redundancies as outlined in mandated risk assessments (e.g., Decree 2157 of 2017) or equivalent assessments (e.g., hospital safety index). Consider green solutions like solar panels that address climate and hazard mitigations together.	Health infrastructure	Rentschler et al. (2021)
The size and scope of flooding and landslide threats highlight the importance of data-driven prioritizing of healthcare investment in new building, retrofitting, and maintenance.	Conduct assessments of building, retrofitting, and maintaining health infrastructure based on the risk index to determine how to prioritize investments in these areas. To this end, Installing or improving built environment flood mitigation measures can be prioritized through a cost-benefit analysis.	Health infrastructure	Campos Garcia et al. (2011); Habitat for Humanity (2023); Edmonds et al. (2020); Thompson et al. (forthcoming)
Mitigating flooding and landslide threats to health facilities and other health infrastructure should be prioritized in alignment with available resources.	Use the Climate-Sensitive Risk Index and climate exposure and disruption analysis to help prioritize investment in flood and landslide mitigation measures for health facilities and other related infrastructure. That includes preparedness and evacuation planning for both hazards, which includes securing multi-sectoral support (e.g., enough evacuation vehicles, cross-agency training) to execute these plans. Additionally, implementing monitoring systems in hazard-prone and high-impact areas would improve preparedness.	Health system planning; Contingency planning	Rentschler et al. (2021); Thompson et al. (forthcoming)

Observation	Potential Action	Action Type	Reference(s)
Climate change, coupled with changes in the built environment, may make flood and landslide zones exceedingly dangerous to inhabitants and responders. These areas may be too expensive to rehabilitate after the hazard.	Continue to be proactive in terms of health system planning. Align plans with interventions that incentivize or mandate that people in highest risk landslides and flood zones relocate/mitigate, based on precedents adopted for volcano zones.	Health system planning; Development and built environment	World Bank (2008)
Urban and rural development can change and exacerbate flood inundation areas and landslide flows, potentially impacting people, health service delivery, and lifeline infrastructure.	Include this consideration in health system planning and health system modality optimizations. High risk areas identified here can inform such decisions as starting point Areas at high climatic risk, with currently lower accessibility to services, can benefit from mobile clinics and alternative solutions.	Health system planning; Development and built environment	Campos Garcia et al. (2011); World Bank (2012b)
Flood and landslides disrupt transportation networks, particularly in some regions (e.g., the western part of Bogotá), limiting or delaying accessibility to health services.	Promote multisectoral investment between health and transport to leverage potential synergies in investment goals. Consider increasing the health services in areas with very high baseline access times.	Multisectoral	Hallegate, Rentschler, and Rozenberg (2019); Edmonds et al. (2020)
Information from the analysis concerning the exposure of vulnerable populations, lifeline infrastructure, and health infrastructure highlights the importance of coordination across the national, departmental, and municipal levels.	Continue to increase coordination in planning and preparedness between the health and emergency response sectors, including civil protection, the military, and other designated response groups. Strengthen multi-level governance.	Multisectoral	Rentschler et al. (2021); Díaz-Tamayo (2022)
More data on vulnerable populations can help refine prioritization related to health sector and multisectoral investment, planning, drills and simulation, response, and recovery, including mitigating some of the risks outlined by the Climate-Sensitive Risk Index.	Increase or mandate geospatial data collection for (i) vulnerable populations, particularly internally displaced populations, and (ii) other vulnerability indicators at the departmental and municipal levels, in alignment with previous efforts by the Instituto Geográfico Agustín Codazzi (IGAC).	Data capabilities and planning	Wood (2018); Habitat for Humanity (2023); World Bank (2021); Sipe and Dale (2003); Díaz-Tamayo (2022)

Observation	Potential Action	Action Type	Reference(s)
One of the barriers in using data or data-driven tools, like the Climate-Sensitive Risk Index, in decision-making is an absence of integration of these data or tools in planning.	Incentivize or mandate the inclusion of geospatial and other data-driven tools in planning for health system planning and delivery—including service modality plans, shelter-in-place directives, and alternative patient care-paths through health system.	Health service delivery; Data capabilities and planning	Sipe and Dale (2003)
Climate change likely will change hydrometeorological hazards in Colombia and will impact other hazards, increasing the importance of using the most current hazard data to understand and plan for future impacts.	Update the assessments based on the latest climate modeling (e.g., rainfall predictions, wind speed) when possible. Collect data and monitor risk mitigation and preparedness interventions to adjust the risks accordingly. As shown in priority facility section above, vulnerabilities must be considered side-by-side with exposures.	Data capabilities and planning	Füssel (2007)

COMPONENT 3

Biodiversity and Climate Change: Implications for Human Health in Colombia

Key Messages

- Human health is interlinked with biodiversity and climate change.
- Colombia is the third most biodiverse country in the world, but 88 percent of its ecosystems are at risk. In a megadiverse country like Colombia, analyzing the human health impacts this raises requires a comprehensive understanding of the drivers of biodiversity loss, such as deforestation, and the interaction with climate change.
- In Colombia, mortality attributed to environmental risk factors accounted for 17,549 deaths in 2016, of which 15,681 were associated with poor air quality and 1,209 with poor water quality.
- It is critical to outline and spotlight the benefits of maintaining biodiversity to tackle human health problems caused by interaction of climate change and air pollution.

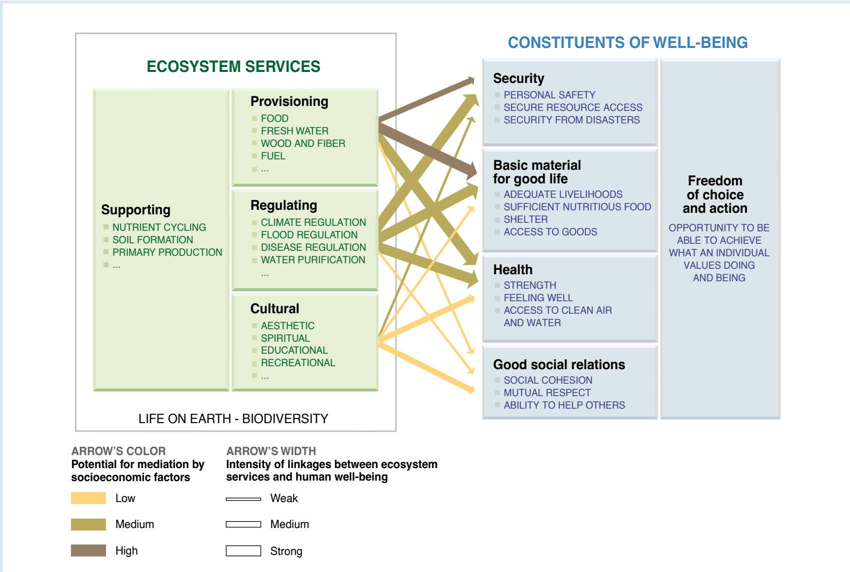
- Deepening efforts to address interactions will increase demand on governance mechanisms and require strengthened multisectoral and multilevel arrangements.
- Given the impacts of biodiversity loss and climate change on human health, the health sector in Colombia must have a more central role in developing policies and programs to prevent and respond to health risks related to biodiversity loss and climate.
- In urban planning, health risks should be integrated as key determinants for land use planning and decision-making.
- The Ministry of Health would benefit from scaling up nature-based solutions, which could have large co-benefits for health and climate.

Biodiversity, Climate Change, and Health

Climate is a factor affecting the planet's environment and ecosystems, with direct and indirect implications for human health (Bonebrake et al. 2018). Rises in greenhouse gas emissions due to anthropic (human) activities have increased the temperature on the planet, generating changes in ecosystems and their biodiversity. As the climate changes, so does the performance of ecosystems and the way they fulfill their ecosystem functions (Lindley et al. 2019).

Biodiversity operates as an underlying requirement for the optimal functioning of ecosystems, and the provision of various ecosystem services that in turn affect health and well-being. Ecosystem functions include physicochemical and biological processes that help maintain and regulate life on earth, such as air purification, climate regulation, crop pollination, and seed dispersal. These functions are vital for ecosystem services, such as producing food, maintaining environmental conditions that ensure water and air quality, and other elements supporting mental health—all of which depend on healthy natural capital (Figure 38) (Costanza 2012; Kremen 2005; Millennium Ecosystem Assessment 2005).

Figure 38. Ecosystem Services, Biodiversity, and Implications for Human Well-Being



Source: Millennium Ecosystem Assessment 2005

Changes in the use and overexploitation of natural resources degrade ecosystem services. These changes are largely due to deforestation and changes in land use for livestock and crops, as well as use of natural resources (e.g., mining and dam construction) (Loh et al. 2015). Human activities have modified an estimate 75 percent of the planet's land surface (Ellis and Ramankutty 2008; IPBES 2019), and 66 percent of its ocean area, resulting in the loss of more than 80 and 50 percent of the biomass of wild mammals and plants, respectively (Pörtner et al. 2023).

In this sense, climate change-induced temperature increases have added to biodiversity loss; these two factors are among the most complex threats to the functional integrity of ecosystems (García et al. 2018). Climate change affects biodiversity and ecosystems at different levels. At the level of populations and species, it affects the life cycles of organisms, their behavior, and their geographical ranges. At the ecosystem level, climate change impacts primary production, the interaction between species, and adaptive capacities in species such as their vulnerability to biological threats and extreme weather events that affect their resilience (Weiskopf et al. 2020).[3/4]

Just as climate change affects biodiversity, biodiversity can also exert changes in climate. The quantity and variability of vegetation can contribute to increased or decreased capture and storage of carbon dioxide (CO_2), both in vegetation and soil, consequently

3 Almost all life on Earth depends on primary producers. Primary producers use abiotic energy sources such as sunlight to produce compounds that can be used later by other organisms. These photosynthetic organisms are the basis of most food systems. They also produce most of the Earth's oxygen and regulate important components of the carbon cycle and carbon dioxide (CO_2) sequestration. In terrestrial ecoregions, primary producers are mainly plants, while in aquatic ecoregions, algae they carry out this role.
4 The resilience of a system refers to its ability to cope with change and maintain fundamental control of its structure and function.

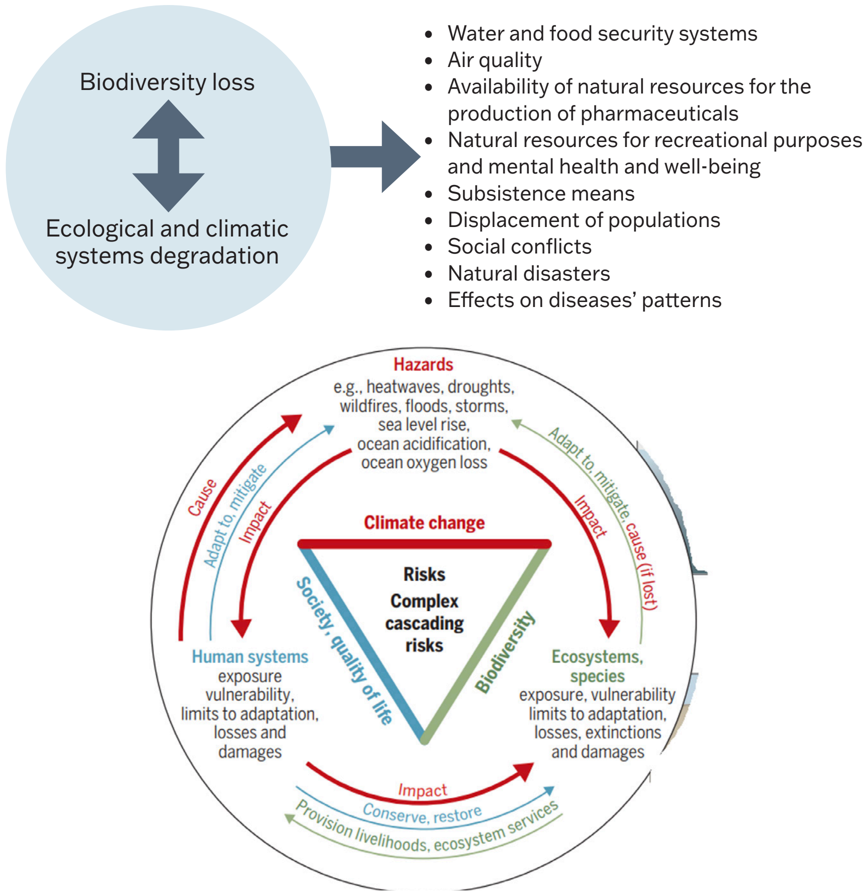
affecting temperature variability (Korn et al. 2019). In different terrestrial biomes, plant species diversity plays an important role in ecosystem productivity. This richness, in turn, acts as a bulwark against temperature variability. In other words, the greater the richness of plants, the greater the stability of temperature and ecosystems (Oliveira et al. 2022).[5] **Consequently, climate and biodiversity act as determining conditions that shape the environment, as well as the ecological and social processes that occur in them** (Lindley et al. 2019).

The loss of biodiversity increases the risks and impacts of climate change. Biodiversity loss and climate change are interrelated, as are other drivers of biodiversity loss. However, understanding of these interrelationships and their synergies is still limited. Both are increasingly influenced by human activity, resulting in increased risks to social systems. The effects of one also exacerbate the effects of the other (IPCC 2014; Korn et al. 2019). In this sense, biodiversity and climate change are both drivers and consequences, resulting in negative impacts on parts of the natural world that affect people's health and well-being, and the functioning of society (Pörtner et al. 2023; Jaureguiberry et al. 2022; Cohen-Shacham et al. 2016). These effects can be biophysical, such as the degradation of air and water quality, as well as socioeconomic and cultural (e.g., impacts on crop and food production) (Figure 39).

5 Richness reflects the number of species in a given community or ecosystem (Goteli and Colwell 2001).

Photo: © Matt Zimmerman 'Slash and burn agriculture in the Amazon' (CC BY 2.0)

Figure 39. Effects of Biodiversity Loss and Degradation on the Climatic and Ecological Balance



Source: Pörtner et al. 2023

Climate change and the degradation and use of natural resources are complex problems that directly threaten the health and well-being of communities in Colombia; they are also closely related to the drivers of biodiversity in the country.[6] In Colombia, drivers of biodiversity loss act synergistically with climate change, creating conditions for an ecological imbalance that directly or indirectly affects human health. Colombia is the third most biodiverse country in the world (Box 1). Yet only 12 percent of its ecosystems are not at risk: more than 44 percent of its ecosystems are ranked as threatened; 27 percent are in critical status; and 17 percent are in danger (Etter et al. 2017). Colombia is also vulnerable to climate change, ranked 89 of 181 countries in terms of climate risk according to the ND-GAIN INDEX (Notre Dame Global Adaptation Initiative 2021), and 47 percent of its territory is in the high and very high-risk categories (IDEAM (Institute of Hydrology, Meteorology, and Environmental Studies) et al. 2019).[7] Colombia is highly vulnerable to extreme events, in particular flooding due to the La Niña phenomenon. Critically vulnerable areas include the Caribbean and Andes regions, affecting key sectors such as housing, transport, energy, agriculture, and health (World Bank

6 The drivers of biodiversity loss are agents that act directly or indirectly on the same, generating changes in the balance of ecosystems as a result of unsustainable anthropic activities.
7 The index ND-GAIN ranks 181 countries using a score that calculates a country's vulnerability to climate change, other global challenges, and its readiness to improve resilience. Colombia's ranking is due to a combination of political, geographical, and social factors (World Bank 2021).

2021) Taken together, its high species richness, high number of degraded ecosystems, and climatic vulnerability mean that Colombia has a greater exposure risk to emerging diseases, as these factors drive more human-animal-environment interface.

The loss of ecosystem functions is rapidly influenced by drivers of biodiversity loss, which cause a chain of changes in ecological patterns and processes, with important consequences for human health. In Colombia, biodiversity loss is affected by five main drivers, which in turn impact environmental, animal, and human health: (i) changes in land use and changes in coastlines and seas; (ii) direct overexploitation of organisms; (iii) the introduction of invasive species; (iv) climate change; and (v) pollution. All these drivers acting together exacerbate negative impacts on nature and humans and are driving biodiversity and its associated ecosystem services to a point of no return (Jaureguiberry et al. 2022; IPBES 2019).

Box 1. Colombia: A Megadiverse Country

Due to its high species richness and endemism (native species found only in its territory), Colombia is listed as one of the 17 megadiverse countries on the planet, ranked as country with the third-greatest diversity (after Brazil and Indonesia). One of ten of all species that exist on the planet are found in Colombia (SIB Colombia 2022; Like Minded Megadiverse Countries 2002). Colombia has 37,290 species of plants and 31,676 registered animals and is the country with the greatest wealth of birds, butterflies, and orchids in the world.

Group	Plants	Animals	Fungi	Mammals	Birds	Reptiles	Amphibians	Fish
Total species	37,290	31,676	4,709	737	2,363	761	895	4,128
Endemic species	5,374	505	99	50	79	-	-	349
67,000 recorded species including plants, animals, fungi, and microorganisms								

Drivers of Biodiversity Loss

Land Use Changes

Land use change, through construction and the expanding use of land for agriculture, leads to deforestation, soil degradation, and loss or damage to wildlife habitats as the agricultural frontier is expanded.[8] Between 2001 and 2021, Colombia lost more than 3.2 million hectares of forest (Ministry of Environment and Sustainable Development 2022). In 2021, 174,103 hectares were deforested—a 1.5 percent increase in deforestation compared to 2020. The areas with the greatest changes in natural forest cover in 2021 were concentrated in the Amazon (64.8 percent), Andean (17.2 percent), Pacific (7.7 percent), Caribbean (5.5 percent), and Orinoquia regions (4.8 percent) (IDEAM and Ministry of Environment and Sustainable Development 2022). The average annual rate of forest loss (TMAPB) for the Colombian Amazon in 2020–2022 was 142,204 hectares (ha) per year, with the departments of Meta and Caquetá having the highest rates of loss (41,692 ha and 40,119 ha, respectively) (Amazon Institute of Scientific Research (SINCHI) 2023). During 2020–2022, habitat loss in the Amazon region of Colombia occurred at an average rate of 207,054 hectares per year due to increases in the amount of land used for raising livestock. The highest forestation loss rates were in the departments of Caquetá and Meta (59,834 ha and 58,492 ha, respectively) (SINCHI 2023).

Land-use change, such as the conversion of natural covers in agricultural or urban areas, influences the risk of emerging zoonotic diseases in humans, which can lead to global and systematic effects (Gibb et al. 2020). These transformations

8 According to Colombia's Rural Agricultural Planning Unit (UPRA), the agricultural frontier is the boundary of rural land that separates areas where agricultural activities are carried out from areas where agricultural activities are excluded by law.

Photo: © Counter Culture Coffee 'Alvarado Castillo' (CC BY-NC-ND 2.0) can generate changes in the habitat of disease-transmitting species, such as rodents, which, in turn, increase the channels of transmission and risk of humans contracting zoonotic diseases from wild populations. This is because, despite damage to their natural habitats, rodents are adaptable, able to colonize human-centered environments and even increase their populations in human-centered environments and in lands converted to agricultural use (Gibb et al. 2020; Mendoza et al. 2020). In Colombia, rodents serve as the main hosts for the zoonotic diseases of toxoplasmosis, leptospirosis, and hemorrhagic viral fevers.[9]

Land use changes made to establish planting monocultures and raise livestock homogenize the landscape abruptly reduce biodiversity and affect the ecosystem roles of different species. Population decreases amongst important species or natural predators of pests and herbs (e.g. microorganisms and insects) in crops, are caused by the increasing use of pesticides. This leads to greater exposure to pesticides for the people who handle them and in food for human consumption. This then creates risks for human health, since it has been established that direct and prolonged exposure to pesticides is associated with neuronal and reproductive problems and genotoxic effects (Sanborn et al. 2007), as well as with some types of cancer such as Hodgkin's lymphoma, leukemia, brain, and prostate cancer, among others (Bassil et al. 2007). On the other hand, the reduction or elimination of vertebrate species and vector-controlling invertebrates increases the risk of contracting communicable diseases such as dengue, malaria, and enteric diseases (Müller et al. 2019).

The use of land for intensive food production—involving the continuous use of fertilizers and pesticides, the overexploitation of aquifers, and excessive grazing predominate—increases the salinization and desertification of the soil, depleting the land of nutrients and organic material necessary for food cultivation. This renders land unusable for food production, which is particularly worrying given overpopulation and high demand for food. In addition, deforestation to clear land for agricultural use is a major source of CO_2 emissions, the greenhouse gas that contributes most to climate change (IDEAM et al. 2017).

Overexploitation of Species

Overexploitation of natural resources also drives biodiversity loss and has repercussions for human health. In Colombia, the overexploitation of fishery resources and other wildlife populations due to hunting or illegal trafficking of species, as well as illegal logging, has caused the decline of species that may well be important sources of food or raw materials for the production of medicines (e.g., bioactive compounds of plants

9 Rodents are mammals with early sexual maturity and high reproduction rates. They reproduce frequently and have several offspring per birth. Zoonotic diseases are diseases that can spread from animals to humans.

and fungi). These factors endanger the country's food security, in terms of food availability and quality, leading to potential malnutrition problems. For example, overfishing in the Colombian Amazon—including unsustainable management practices and failure to respect closures and minimum catch sizes— has led to a decline in species populations, particularly large catfish (Agudelo-Córdoba 2015). As a result, an estimated 62 percent of the fish marketed in the Amazon River are below the regulatory size, as are 47 percent of the marketed fish from the Putumayo River (Agudelo-Córdoba et al. 2012).

Photo: © Louis Vest 'Fishing, Cartagena' (CC BY-NC 2.0)

Species loss can also impact both prevention and treatment in human health care. More than half of today's synthetic medicines come from plant, fungal, and wild animal species. And components of different species are already being used or studied for use in treating various types of cancer, high blood pressure, HIV (human immunodeficiency virus), and malaria, and for use as antibacterial and antifungal treatments (MacKinnon et al. 2020; Erwin et al. 2010).

Invasive Species

Invasive species also drive biodiversity loss, to the extent that they drive out native species and degrade ecosystems. Invasive animal species may reproduce rapidly and consume a wide range of foods, which allows them to colonize more quickly in new habitats. In Colombia, there are 508 identified exotic species of fauna and flora. However, data are available for 74 percent (378 species), and within this subset, 22 species have been identified as invasive (SIB 2022; World Wildlife Foundation 2022; and Ministry of Environment, Housing, and Territorial Development Colombia 2008).[10] For example, the giant African snail threatens the agricultural production, as it quickly and effectively colonizes any habitat. Its presence has been reported in parts of Putumayo, Meta, Tolima, Vaupés, Casanare, Arauca, and Valle del Cauca.

10 There are a total of 23 officially recognized invasive species in Colombia (Minambiente 2022).

Moreover, this snail is host to the nematodes Angyostrongylus cantonensis and Angyostrongylus costaricensis, which cause abdominal meningoencephalitis and angiostrongylosis, respectively (Alburqueque et al. 2008). Meningoencephalitis can be marked by severe headache, nuchal rigidity, nausea, vomiting, and paresthesias (González-Aguilera and Arias-Ortiz 2019). For its part, the lionfish can cause injuries in humans who step on their poisonous barbs. The lionfish also threatens food security, since it feeds on native species, such as snapper, grouper, and lobster, which are important in the diets of local communities. It has been reported on beaches near Santa Marta, Taganga, and the Tayrona National Natural Park, in the department of Magdalena (Ministry of Environment and Sustainable Development 2017). Overall, there is limited information on the environmental and economic costs of the diverse invasive species in the country.

Climate Change

Climate change is both a driver and a consequence of biodiversity loss. Drastic changes in rainfall and temperatures patterns alter the habitats species, affecting how species function and develop. It can also change where a species lives, sometime forcing them out of long-established territory or facilitating their movement into new areas. This may lead to an increased risk of vector-borne diseases, such and dengue and malaria which are transmitted by Aedes and Anopheles mosquitoes (Müller et al. 2019).

Climate change-induced changes in temperatures and weather patterns alter and degrade ecosystems and their biodiversity. The impacts of associated changes and decreases in vegetation are manifest in poor air quality and temperature increases, due to the absence and/or degradation of vegetation that helps eliminate pollutants and cool the air. This conjunction of pollution with higher

Photo: © Iván Erre Jota Medellín - Tormenta (CC BY-SA 2.0) temperatures poses a risk to human health, since it increases respiratory complications, as well as morbidity and mortality from cerebrovascular and cardiac diseases, both in rural and urban areas, while the situation in cities is more complex due to the presence of heat islands (Lindley et al. 2019).[11]

The impacts of climate change together with changes in land use affect the presence and stability of strategic ecosystems, such as mangroves, riparian forests, wetlands, and moors, which buffer and regulate water cycles and availability. The deterioration or removal of these ecosystems translates into an increased risk of injuries and deaths from floods, landslides, and storms, as well as impaired access to health facilities caused by such events. The regions with the highest number of municipalities in the high and very high categories of climate risk are the Andean region (36), the Amazon region (31), and the Pacific region (25). At the departmental level, the five departments with the highest climatic risk are San Andrés, Vaupés, Amazonas, Guainía, and Atlántico. The 20 departments most at risk represented 69 percent of the national gross domestic product (GDP) in 2016 and are home to 57 percent of the country's population (IDEAM et al. 2017).

11 Urban heat islands are a phenomenon in which urban areas experience higher temperatures compared to surrounding non-urban areas. Heat islands increase temperature in cities, energy consumption, and air pollution, and, in general, they decrease in the quality of life for urban populations.

Contamination

Pollution generated by human activities is a driver of biodiversity loss, has pressing consequences for human health, and is closely related to the deterioration of natural resources. Air pollution (gaseous or particulate matter) from the combustion of fossil fuels for industrial and automotive purposes, as well as particulate matter from forest fires, represents a risk to the health of Colombians and is associated with respiratory diseases such as asthma, bronchitis, and rhinitis. This is directly related to the increase in polluting sources, the loss of tree cover, and impacts on natural ecosystems located in urban and peri-urban areas, as these ecosystems are burdened with more air pollution and have less vegetation to remove air pollutants through absorption (World Health Organization (WHO) and Secretariat of the Convention on Biodiversity (CBD) 2015). By 2016 in Colombia, the respiratory diseases with the highest incidence in mortality related to poor air quality are ischemic heart disease (IHD) and chronic obstructive pulmonary disease (COPD), with 7,230 and 3,873 attributable deaths, respectively (National Institute of Health (INS) 2018).[12] Overall, 15,681 deaths were attributed to air quality-related risks (619.78 per 100,000) in 2016, out of 17,549.

12 Gaseous pollutants such as ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) are eliminated through the stomata of tree leaves. Therefore, the less vegetation cover, the less air cleanliness.

Acting together, high temperatures and poor air quality increase exposure to respiratory diseases and affect the vascular, cardiac, and neurological systems (e.g., impacts on learning, memory, and behavior). They also cause worsening health in people with pre-existing conditions (e.g., heart disease, asthma, emphysema, and diabetes), with older adults and children the populations most at risk (WHO and CBD 2015). This is because high temperatures tend to increase the concentration of particulate matter (PM), and because the climate directs the way in which pollutant particles are transported and dispersed in the air. Notably, in Colombia the proportion of the total burden of disease attributed to PM2.5 (fine particulate matter) stands at 15.8 percent, with the greatest concentrations observed in Quindío, Córdoba, and Antioquia (INS 2018).

The contamination of natural resources by different means threatens natural ecosystems, their biodiversity, and public health. The contamination of freshwater, marine or terrestrial, due to domestic or industrial activities such as improper management of solid and liquid waste, oil spills, the use of fertilizers on agricultural land (including products with nitrogen and/or phosphorus), and products associated with illegal mining such as mercury, represents a serious risk to human health. In Colombia, an estimated 1,209 deaths are attributable to environmental risk factors associated with poor water quality, of which 593 are due to acute diarrheal disease (INS 2018).

Photo: © Mariusz Kluzniak 'smog over Bogotá' (CC BY-NC-ND 2.0)

High temperatures tend to increase the concentration of particulate matter (PM), and the climate directs the way in which pollutant particles are transported and dispersed in the air.

Soils and water bodies can be highly contaminated by pesticide use, which can cause health complications. An example is the use of herbicides such as glyphosate, which has been used in Colombia for aerial spraying to eradicate illicit crops. The use of herbicides such as glyphosate has been associated with four types of cancer: liver, kidney, lymphatic, and pancreatic (WHO and CBD 2015). It has also been associated with miscarriages and dermatological diseases. These pollutants, when applied to the land, are spread through runoff water, filtration, and leaching into groundwater and surface bodies of water, and through soil erosion—all of which affect biodiversity. Pesticides can also be transported to other areas by evaporation. In addition, fertilizer components such as nitrogen and phosphorous place too much of these elements in aquatic ecosystems and cause degradation.[13] The presence of pollutants affects the ecosystem function of filter-feeding aquatic organisms (i.e., mollusks and bivalves), which are key in carrying out a water purification role in marine, freshwater, and wastewater environments (WHO and CBD 2015).

Another pollutant of natural resources in Colombia is mercury (Hg). Mercury contamination of water bodies and fish species is worrying in Colombia and represents a public health problem that urgently needs to be addressed. Mercury is used in the illegal exploitation of gold, discharged into water bodies, and handled and inhaled directly by the people who carry out this activity. Upon contact with water bodies, mercury passes through different trophic levels, reaching fish that are consumed both by local river communities and by people in large cities. Mercury contamination is associated with fetal malformations such as polydactyly, cognitive and learning difficulties, and affectations associated with fetal neuropathies. This situation is worrisome since different studies in Colombia show levels of mercury that exceed what is permissible by the WHO in human tissue samples, with the local riverine populations being the most affected. For example, studies in indigenous communities of the Colombian Amazon reveal that of 1,875 hair samples taken, 1,525 had mercury levels above the WHO limit (2015), corresponding to 1 part per million (ppm) for hair (Foundation for Conservation and Sustainable Development 2022). Likewise, in the indigenous community of Bocas de Taraira (Yaigojé Apaporis National Natural Park), mercury values were found in hair between 2.3 and 34.9 ppm—the highest value reported for an indigenous community in Latin America, according to published research (Valdemar-Villegas and Olivero-Verbel 2019). On the other hand, medical consultations in Colombia of people who received some care associated with mercury contamination between 2015 and 2022, totaled 1,101 cases, with the largest number registered in the departments of Antioquia (321), Atlántico (114), Chocó (153), Bogotá (87), Bolívar (73), and Córdoba (72) (Information System for the Monitoring of the Quality of Water for Human Consumption (SIVICAP) 2023; Integrated Social Protection Information System (SISPRO) 2023).

13 Eutrophication is nitrogen and phosphorous overload in aquatic ecosystems, which leads to uncontrolled phytoplankton proliferation, biodiversity imbalances, and anoxia conditions.

Interaction of Environment and Human Health in Colombia

In Colombia three main factors account for the burden of environmental disease in the country and that impact the health of the Colombian people:[14]

- ✓ Poor urban air quality (air pollution in cities)
- ✓ Poor indoor air quality (burning solid fuels for cooking)
- ✓ Poor water quality (industrial, agricultural, or domestic wastes that pollute water sources, which is related to deficiencies in access to drinking water and basic sanitation)

In Colombia, exposure to poor quality air and water results in 17,549 deaths per year, which corresponds to 8 percent of the total annual mortality in the country; of that total, 15,681 deaths are attributed to poor air quality (INS 2018). The gradual increase in poor air quality in Colombia's cities began as a result of automotive growth and increased industrial activity, factors that have been exacerbated by population growth (National Planning Department (DNP) 2018). These factors are associated with seven diseases of high occurrence in Colombia: ischemic heart disease, stroke, obstructive pulmonary disease (COPD), acute respiratory infections, lung cancer, acute diarrheal disease, and chronic kidney disease (INS 2018).

Similarly, mortality related to environmental degradation translates into associated costs of COP 16.6 billion annually, corresponding to 2.08 percent of the country's GDP in 2015. Poor air quality is the greatest factor in this result, where urban air pollution represents an approximate cost of COP 12.2 billion per year (1.5 percent of GDP in 2015). About 8,000 deaths occur annually in relation to poor air quality, representing a cost of COP 10.6 billion (DNP 2018).[15]

In 2022, the national average rate in Colombia of air pollution due to PM2.5 was 15.5 μg/m³, which was higher than the 2021 average of 14.1 μg/m³. This increase is explained by the increase in forest fires in the Colombian Amazon during the dry season of 2022. Almost 30 times more forest fires were reported in January 2022 compared to January 2021. Consequently, the PM2.5 (fine particulate matter) that comes from the fires can travel suspended

14 Colombia's National Institute of Health (INS) has studied the burden of disease in the country associated with environmental risk factors; this is known as the environmental burden of disease (EBD).

15 This economic assessment of environmental degradation in Colombia was based on the effects on human health of the main environmental risk factors for the country (urban air pollution, indoor air pollution, and poor water quality related to deficiencies in access to drinking water and basic sanitation). Mortality and morbidity associated with environmental degradation were estimated, and their economic value subsequently calculated (DNP 2018).

in the air long distances and pollute the air of major cities such as Bogotá or Medellín. The cities of Bogotá, Cota (Cundinamarca), Guane (Santander) and Medellín (Antioquia), registered the highest average values in a period of 5 years, between 2018 and 2022 (Air Quality 2021).

In the municipalities of Sabaneta, Medellín, and Bogotá, the highest values of particulate matter smaller than 2.5 microns (PM2.5) were recorded for the year 2021; these rates were above the annual norm for Colombia (25 µg/m^3 (micrograms per cubic meter)) and exceed the annual WHO guideline (5 µg/m3) by several units (Table 11). Regarding particulate matter smaller than 10 microns (PM10), by 2021 seven air quality monitoring stations located in the departments of Antioquia (municipalities of Itagüí and Amaga), Cundinamarca (Bogotá and the municipality of Soacha), and Magdalena (municipality of Ciénaga) recorded values that exceed the national standard and the WHO guideline (IDEAM 2021).

Air pollution and climate change are closely interrelated. High temperatures act as a chemical catalyst and can convert existing elements in the air into tropospheric ozone (or ground-level ozone), which is a pollutant gas and key component of smog. Tropospheric ozone is a lung irritant, and chronic exposure to it is linked to premature deaths from respiratory diseases and heart attacks (United States Environmental Protection Agency 2022; IQAir 2022).

Table 11. Annual Indicated Values of Particulate Matter (PM 10 and PM2.5) to Protect Public Health, according to the WHO guideline value, intermediate goals, and national regulations of Colombia (Resolution 2244 of 2017)

Particulate Matter	WHO Guideline (2021)	WHO Intermediate Targets			Colombia's Guideline	
		Goal 2	Goal 3	Goal 4	As of 2018	From 2030
PM 10 (µg/m^3)	20	50	30	20	50	30
PM 2.5 (µg/m^3)	10	25	15	10	25	15
The levels indicated in the guideline values are evidence-based, WHO recommendations and reflect a systematic review of the evidence demonstrating adverse health effects caused by particulate matter with a diameter of 2.5 microns or less (PM2.5) and with a diameter of 10 microns or less (PM10) (WHO 2021).						
The WHO intermediate targets serve to guide reduction measures towards achieving the guideline levels. Fulfilling the intermediate goals would represent a health benefit (WHO 2021).						
Colombia's Guideline — Resolution 2444 (2017) of the Ministry of Environment and Sustainable Development is the standard that establishes the permissible values of pollutants for a healthy environment and to minimize the risk to human health in Colombia. It also establishes maximum permissible levels for 2030.						

Note: µg = microgram; m3 = cubic meter; PM = particulate matter; WHO = World Health Organization.

In Colombia, research has identified common sources of greenhouse gas emissions and air pollutants, mainly in the transport, agriculture, and residential sectors. The sources of emission of both air pollutants and greenhouse gases (GHG) come from anthropogenic (human) activities, such as industrial activities, automotive traffic, agriculture, and the production and burning of fossil fuels and biomass (Grisales Vargas 2021; World Bank 2022).

Photo: © Adam Cohn 'Bucaramanga Colombia Traffic' (CC BY-NC-ND 2.0)

A congruence has been found between GHGs and air pollutant emissions in the national and global results, which denotes the link between these substances during the development of those activities (Grisales Vargas 2021). GHGs in Colombia are mainly related to the agriculture, livestock, forestry, and other land use (AFOLU) sector.[16] This sector has historically generated the largest percentage of total emissions, with 71 percent of the average historical total, followed by the energy sector with a historical average of 23 percent (IDEAM 2017). Reducing overall GHG emissions in the country would bring co-benefits for health. Different national and international actors have highlighted that Nationally Determined Contributions (NDCs) commitments under the Paris Agreement would save many lives. For example, one of the NDC mitigation scenarios would result in 896,000 morbidity episodes averted by 2030—a 10 percent reduction relative to the usual scenario, without additional climate mitigation effort beyond current legislation (Ministry of Health and Social Protection (MSPS) 2022a).

16 Short-lived climate pollutants (SLCP) are referred to as such because they remain in the atmosphere less time than carbon dioxide (CO_2). SLCPs include black carbon (soot), methane gas (CH_4), tropospheric ozone (O_3), and hydrofluorocarbons (HFCs).

Nature as an Ally for Public Health

The relationship between climate change, air pollution, and public health invites us to address these problems in a comprehensive manner. The health sector has begun to incorporate mechanisms to adapt to climate change (Watts et al. 2015), but it is also necessary to integrate measures that reflect the influence and contributions of biodiversity (Marselle et al., 2019). In this sense, it is essential to think about joint climate change and air pollution mitigation actions, since the co-benefits would be represented in lower GHG emissions, better air quality, and related positive repercussions for human health and ecosystems (Grisales Vargas 2021).

Climate policies for air pollutant emissions could reduce global warming by 0.5°C and save the lives of 2.4 million people per year (Clean Air Fund 2022). However, as of 2021, only 7 percent of countries included short-lived climate pollutants (SLCP) in their national climate action plans. In addition, it is estimated that between 2015 and 2021, only about 2.2 percent of global public resources—coming from international development efforts aimed at Paris Agreement efforts—go directly to air quality globally; and only 0.3 percent of those resources are designated to Latin America and the Caribbean (Clean Air Fund 2022).

The health sector should consider and integrate the benefits that nature brings both to health and to climate change mitigation and air quality improvement. Trees perform important

Photo: © Jorge Láscar 'Tayrona Walk - Calabazo to Pueblito' (CC BY 2.0) services of temperature cooling, air cleaning, absorbing CO_2, and maintaining biodiversity, which also contributes to ecosystem health (WHO and CBD 2015). Better understanding and management of biodiversity also allows better management of vectors that can trigger zoonotic diseases, which has important implications for preparedness for future pandemics.

Forests have the potential to serve as robust thermal buffers, effectively minimizing the occurrence of strong and extreme heat stress days. In a global review of 714 paired temperature data points, De Frenne et al. (2019) discovered that tree canopies provide a buffering effect to the forest floors, effectively regulating both high and low temperatures for the macroclimate (the overall climate in a large geographical area). On average, the understory temperatures were cooler than the macroclimate temperatures by approximately 1.7±0.3°C, with a maximum temperature difference of 4.1±0.5°C. These findings underscore the value of increasing forest coverage as a nature-based solution, not only in regulating temperatures but also in providing additional health benefits such as improved air quality, reduced stress, and enhanced physical activity (Gillerot 2022). However, the effects of forest coverage on temperature extremes are influenced by the forest structure, tree species composition, and geographical location. On the other hand, in 2010, trees and forests in the U.S. were also estimated to have removed 17.4 million tons of air pollution, with an estimated human health cost savings of USD 6.8 billion, as well as 850 deaths averted, 670,000 fewer incidences of acute respiratory symptoms, 430,000 fewer asthma exacerbation events, and 200,000 fewer school days lost (Nowak et al. 2014).

Large cities in Colombia such as Bogotá have poorer ratios of trees per person than WHO-recommended rate of half a tree per inhabitant (Botanical Garden of Bogotá 2019). The rates for other cities in Colombia vary considerably. The localities with the best values are Santa fé, Chapinero (1.71 trees per three inhabitants) and Teusaquillo (1.20 trees per three inhabitants), while localities with high poverty rates and high population densities such as Bosa and Ciudad Bolívar, have values of 0.15 and 0.21 trees per three inhabitants respectively (Chamber of Commerce of Bogotá 2020). This highlights inequities in human health, environment, and quality of life. In the Aburrá Valley (Medellín, Caldas, Estrella, Sabaneta, Envigado, Itagui, Bello, Copacabana, Giradota, and Barbosa) in the department of Antioquia, it is estimated that there is only one tree for every seven inhabitants (Metropolitan Area of the Aburrá Valley 2019).

While the WHO recommends that cities and towns have a minimum green area of nine square meters (m^2) of green area per inhabitant, in Latin America, the proportion is 3.5 m^2 per inhabitant. Deficits are also seen in cities in Colombia such as Bogotá, where 80 percent of the population lives with a deficit of green areas (Greenpeace 2020).

Deficits of green spaces in cities due to their omission in urban planning lead people to reduce their physical activity. This, in turn, causes, among other things, increased stress and obesity, as well as physical, emotional, and behavioral instability (e.g., nature deficit disorder).[17] On the other hand, including green and natural and manmade waterbodies in and between cities and maintaining them as part of a network with larger surrounding protected areas helps with disease prevention and treatment by generating important benefits for both physical and mental health (Box 2). These spaces do not necessarily have to be large. Small green spaces can contribute and be sufficient to sustain biodiversity (e.g., microbial diversity), contribute to efforts to build networks with larger rural green areas, and provide benefits associated with health.

Studies of green spaces and the biodiversity associated with them report optimal relationships with respect to the increase and promotion of physical activity (Kaczynski and Henderson 2007; Coutts and Hahn 2015). This aspect is particularly important with regard to noncommunicable diseases such as diabetes and cardiovascular diseases, for which physical activity is a tool for both prevention and treatment (Cook et al. 2019). In this sense, green spaces are regulators of physiological functions, removing

17 The term "nature deficit disorder" was coined by Richard Louv (2005), to describe different behavioral problems, such as decreased use of the senses, attention difficulties, and higher rates of physical and emotional illness resulting from less time outdoors.

Box 2. Health Naturally in Parks Initiative

The Health Naturally in Parks initiative of National Natural Parks of Colombia has its origins in the Healthy Parks Healthy People initiative in the Australian province of Victoria, which has been very well received by the community and has provided additional benefits for protected areas.

The National Natural Parks of Colombia has 23 protected areas with ecotourism packages that offer services and activities to visitors.

The Health Naturally in Parks Program aims to consolidate the Colombian National Natural Parks as environments that provide health benefits by promoting healthy lifestyles and well-being for children, youth, and adults who visit them (National Natural Parks of Colombia (PNN) 2017).

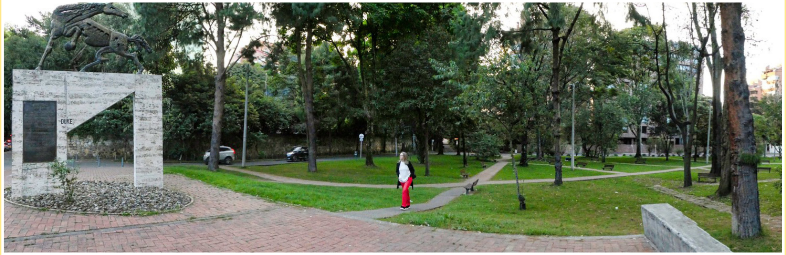


Photo: © F Delventhal 'Parque Del Japon' (CC BY 2.0) or reducing the impact of possible stressors, especially in large and overcrowded cities (Hartig et al. 2014; Coutts and Hahn 2015). In addition, performing physical activity in urban green spaces is potentially healthier, since the healthier green environment avoids greater exposure to harmful levels of air pollution and the consequent effects on respiratory and cardiovascular systems (Lindley et al. 2019).

With this in mind, different "Biodiver-cities" initiatives are being developed in Colombia, to counteract the effects of air pollution and other factors and to improve the quality of life and health of its inhabitants. Examples include the cities of Barranquilla (Atlántico department) and Leticia (Amazonas), as well as the RAMSAR-designated Urban Wetlands Complex of the Capital District of Bogotá (Box 3).

Box 3. Biodiver-cities Initiatives in Colombia: Improving Environmental and Human Health

Barranquilla Biodiver-city

The city of Barranquilla is part of the Cities4Forest program, a reforestation initiative to increase green spaces and better prepare for flooding and coastal erosion (Cities4Forest 2023). Following the Guide for the Ecological Restoration of Mangroves for Colombia and the recommendations of the local community, 22,100 red mangrove seedlings were planted, with a survival rate of 87 percent at the beginning of 2023. Likewise, for 10 years the city has been executing the *Todos al parque* initiative, which has created more than 1.5 million green areas, improving the local economy, safety, and outdoor physical activity (Mayor's Office of Barranquilla 2023). For of all these achievements, Barranquilla was recognized by the World Resources Institute in February 2023 as the city with the most innovative sustainable urban transformation project in the world. It has also been recognized on four occasions by the Tree Cities of the World program of the Arbor Day Foundation and the United Nations Food and Agriculture Organization—recognition that highlights the cities that best manage their urban forest systems (Tree Cities of the World 2023).


Photo: © Juanerre 'Barranquilla' (CC BY-NC-ND 2.0)

Leticia Biodiver-city.

The city of Leticia in the Colombian Amazon is also on its way to becoming a Biodiver-city. In 2020, within the framework of the Leticia Pact for the Amazon, the memorandum of understanding Leticia Biodiverciudad was signed between different entities (the Ministry of Environment and Sustainable Development, the Amazon Institute of Scientific Research (SINCHI), Corpoamazonia, the Government of the Amazon, and the Mayor's Office of Leticia), with the purpose of jointly guiding the city towards the sustainable management and use of its natural, cultural, and ethnic wealth.

Important initiatives led by SINCHI such as the Bioempaques Amazonas and the Bioabonos project, as well as activities to characterize urban wetlands, educate the population in sustainable consumption habits, and fish farming with native species, guide efforts to consolidate Leticia as a Biodiver-city, involving citizens in the development of a more sustainable city. Leticia is part of a group of 14 cities in the country, which, together with the Ministry of Environment and Sustainable Development, began projects aimed at recovering urban biodiversity and improving the human-nature relationship (Ministry of Environment and Sustainable Development 2020; SINCHI 2023).


Photo: © Eli Duke 'Colombia: Boat from Leticia' (CC BY-SA 2.0)

Urban Wetlands Complex of the Capital District of Bogotá

The city of Bogotá has a complex of wetlands that have received the RAMSAR* designation. RAMSAR wetlands are ecosystems that, due to their biological, hydrological, and ecological characteristics, are considered of high importance for their conservation at the international level. The city's RAMSAR wetland complex is made up of 11 of the capital's 17 wetlands. These ecosystems are permanent bodies of fresh water that are home to different species, some of them endemic to the high Andean zone of the country. This wetland complex is an important water regulator of the rivers of the Bogotá savannah; in the rainy season it helps regulate and cushion floods. It also helps with building a green network in the city, since it constitutes the main ecological connector of the urban and rural territory of the Bogotá River basin and crosses the city from east to west, also providing recreation for inhabitants. The Bogotá RAMSAR wetland complex has a management plan that was consolidated in March 2023, to map actions that help with its conservation and contribute to the environmental health of the capital (Ministry of Environment and Sustainable Development 2023; Environmental Observatory of Bogotá 2023).

**RAMSAR refers to the Convention on Wetlands which was signed in Ramsar, India.*

Governance in Environmental and Human Health

The governance of countries and territories plays a central role in addressing the relationships between human health and environmental health. These mechanisms allow for the generation and implementation of relevant public policies and direct decision-making. Therefore, a dynamic, effective, and intersectoral governance approach is imperative for the management of environmental and human health in Colombia.

Although in the decades prior to the year 2000 Colombia had instruments touching on the integrated management of human and environmental health (e.g., Decree-Law 2811 of 1974 and the National Sanitary Code 1979), these aspects were developed in a disjointed manner. However, with the emergence of two important laws in the Colombian health system in 2007 and 2011, the first real steps are beginning to be taken to integrate environmental health as an important governance issue. The first of these was Law 1122 which formulates the National Public Health Plan (PNSP) for 2007–2010. It incorporates environmental factors as part of the approach to the social determinants of health (Balladelli et al. 2007). The second is Law 1438 of 2011, mapping out the implementation plan for the Ten-Year Public Health Plan 2012–2021 (PDSP), which prioritizes environmental health, establishing specific objectives, goals, and strategies. One of the environmental health goals is the

Photo: © 2019 European Union (Photographer N. Mazars) (CC BY-NC-ND 2.0)

creation of national and territorial mechanisms for the formulation, approval, and dissemination of a comprehensive environmental health policy (Ministry of Health and Social Protection 2013).

Resolution 1035 of 2022 created the Ten-Year Public Health Plan for 2022–2031, which outlines environmental health as the basis of public health, recognizing the right to a healthy environment, stable climate, and the availability of food. It also proposes the implementation of policies, plans, and programs to reduce outdoor and indoor air pollution. Notably, the resolution proposes special considerations for vulnerable populations such as the indigenous peoples and communities of Colombia, victims of the armed conflict, the Roma people, and the black, Afro-Colombian, Raizal, and Palenquera populations (Ministry of Health and Social Protection 2022b).

Colombia actively participates in efforts to address challenges at the intersection of health and environment. This work is led by the Ministry of Health's Department of Environmental Health, which is also leading strategies to address health risks related to climate change. The country emphasizes the importance of environmental health as a determinant of general well-being, coordinating efforts through the National Intersectoral Technical Commission on Environmental Health (CONASA), which promotes the efforts of the National Committee on Economic and Social Policy (CONPES) 3550 and the creation of the Comprehensive

Environmental Health Policy. These initiatives recognize that environmental factors, including climate change, biodiversity loss, and deforestation, have direct and indirect impacts on individual and collective quality of life. Colombia's commitment to promoting environmental health reflects its dedication to sustainable development and improved public health outcomes.[18]

The Government of Colombia has demonstrated its awareness of the possible negative impacts of climate change on health and the environment and has acted by establishing strategic guidelines policies, as well as laws to address the impacts of climate change and lay the groundwork for collaboration and developing concrete actions. Since Colombia signed the Paris Agreement in 2016 and ratified it 2018, the government has demonstrated its political commitment and acted to address the challenges of climate change by implementing related legislative frameworks and strategies, programs, and activities. In Colombia, environmental policies and related legislative frameworks and their implementation, including climate change, are the responsibility of the Ministry of Environment and Sustainable Development (Minambiente). The Ministry of Environment, together with the National Planning Department (DNP), has been at the forefront of coordinating efforts to address climate-related challenges.

Colombia has also been energetic and timely in developing documents that highlight key areas in different sectors that need to be addressed to reduce the country's carbon footprint reduction and adaptation to climate-related risks. The country has developed a National Climate Change Policy (2017), the Climate Action Law (Law 2169 of 2021), a National Climate Change Adaptation Plan (2012), and several tools to monitor and track the progress of programs and policies to address climate change, including the National Climate Change Information System (SNICC); the Integrated Vulnerability, Risk and Adaptation System (SIIVRA); the Forest and Carbon Monitoring System (SNByC); the Climate Action Toolbox (HaC); and the National Climate Change System (SISCLIMA). In addition, the Intersectoral Commission on Climate Change (CICC) plays a crucial role in establishing policies and actions to achieve Colombia's climate change objectives, serving as the main intersectoral mechanism to promote mitigation and adaptation strategies.

18 The Intersectoral Commission on Environmental Health (CONASA) is composed of the following institutions: Ministry of Environment and Sustainable Development, Housing, and Territorial Development; Ministry of Health and Social Protection; Ministry of Agriculture and Rural Development; Ministry of Trade, Industry, and Tourism; Ministry of National Education; Ministry of Mines and Energy; Ministry of Transport; National Planning Department (DNP); Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM); National Institute for Drug and Food Surveillance (INVIMA); National Institute of Health (INS); Colombian Agricultural Institute (ICA); and Administrative Department of Science, Technology, and Innovation (Colciencias).

Colombia also has developed the National Policy for the Integrated Management of Biodiversity and its Ecosystem Services (PNGIBSE) (2012) and a related action plan for 2016–2030. Both documents use a socio-ecological approach, recognizing the direct relationship between biodiversity and human health. The PNGIBSE policy (Ministry of Environment and Sustainable Development 2012) includes targets to restore the benefits that ecosystems bring to human health (see, e.g., Target 14, Strategic Objective D. "Improve Benefits for All from Biodiversity and Its Ecosystem Services").

Photo: © Alianza por la Solidaridad, 2020. (CC BY-ND 2.0)

Addressing the interaction of biodiversity, health, and climate change poses a challenge that goes beyond technical and scientific analysis, and that translates into a need for effective for multisectoral and multilevel governance mechanisms in Colombia. This includes: (i) multisectoral and multilevel coordination; (ii) capacity strengthening for local governments to implement public policy and execute resources; and (iii) integration of surveillance systems. These are key areas in developing strategies and interventions that address the interactions of environment, climate change, and health.

Multisectoral and Multilevel Coordination

The National Climate Change System (SISCLIMA) is an intersectoral commission that coordinates policies, instruments, and tools for climate change. SISCLIMA, in turn, is made up of nine regional climate change nodes that allow the articulation of efforts under collaborative governance models involving the national government, departmental governments, and the different nongovernmental actors in each region. Each node works to coordinate with actors from different subnational governments, public utilities, regional autonomous corporations, civil society, the private sector, and academia. SISCLIMA has four committees:

(i) a technical committee to advise the CICC; (ii) a technical and scientific information committee on climate change, focused on the production and management of technical information; (iii) a financial management committee; and (iv) an international affairs committee.

In the field of environmental health, CONASA (the National Intersectoral Technical Commission on Environmental Health) has the Territorial Councils for Environmental Health (COTSAs). The territorial councils are designed to support the decision-making process on environmental health, intersectoral management for the management of social and environmental determinants that affect quality of life, and to act as implementers of the Comprehensive Environmental Health Policy (PISA). There are currently 41 COTSAs that were established by administrative act. Of these COTSAs, 32 are at the departmental and district levels, and six are at the municipal level.

Despite having mechanisms that promote a collaborative governance model bringing together the central government and the territories, in both climate change and environmental health, there is no information on the actual interaction between the two government levels. It is also not clear what roles each actor assumes and what plans or strategies are being implemented under these collaborative arrangements at the territory level. Similarly, it is unknown how the interaction between COTSAs and regional nodes is working and if there are redundant efforts to achieve common goals, taking into account the risks and variables at the intersection between biodiversity, health, and climate change.

Local Government Capacity

Local governments capacities are critical for the effective implementation of programs and interventions at the intersection of climate change, health, and biodiversity. As of 2021, local budget sources for this work remained inadequate. Approximately 19 percent of the departments exhibited poor budget execution, indicating that they used less than 50 percent of the revenues they generated. This implies that a significant portion of their own income remained unspent or unallocated, hindering their ability to effectively implement interventions and policies. Departments such as Vaupés, Vichada, Amazonas, and Sucre depended on transfers from the central government to support more than 80 percent of their relevant activities. Similarly, in 2021, most departments showed an average performance rate of 50 percent for disaster risk management, indicating that they completed only half of the tasks or strategies outlined within their annual plan. On the other hand, technical capabilities and implementation for climate-related threat preparedness intervention are limited and not prioritized. In 2022, progress in implementing environmental and sustainable development plans remained an issue. The four departments with lowest implementation rates were La Guajira (11.11 percent), Amazonas (12.63 percent), Arauca (17.65 percent), and Magdalena (18.18 percent) (DNP 2021). (See Annex 1 for details.)

Nongovernmental actors in Colombia with extensive experience in collaborative mechanisms with local governments and indigenous leaders are essential in addressing environmental challenges. This includes organizations such as Doctors Without Borders, Aida, De Justicia, Sinergias, and others. Importantly, these organizations have a higher level of trust among the community and better knowledge of the context and the relevant actors. They are also able to channel funds from international organizations directly to vulnerable regions and can partner with local governments on joint implementation. As a result, coordination involving the national government, local governments, and nongovernmental actors can result in greater technical capacities or financing mechanisms for local governments.

Information and Surveillance Systems

In Colombia, environmental health is framed in light of determinants of health, such as social, economic, and environmental aspects that affect the health system and population health. These factors interact with the health system and can generate poor living conditions, environmental risks, and changes in lifestyles. For example, factors such as water

Photo: © Alliance of Bioversity International and CIAT 'Colombia Floods8' (CC BY-SA 2.0) access and quality, as well as air pollutants, are key determinants of health in Colombia. The result is observable changes in life expectancy and the appearance of diseases, disabilities, and deaths, impacting the well-being of the population. In this sense, monitoring and surveillance of the determinants of health are critical for decision-making, intervention prioritization, and resource allocation to improve health outcomes for Colombians.

Since 2001, public health in Colombia has adopted the health situation analysis (ASIS) model. This model incorporates health indicators, health system performance, and social determinants, especially demographic, socioeconomic, and environmental determinants. Although research centers and the Ministry of Health have done analytical studies on social and environmental determinants, the different databases that address the different determinants are fragmented and there is no integration of different sources of information that would enable the creation of predictive analytical models, showing results in real time; nor is it possible to estimate compound risks related to environmental, climatic, health, and health system variables.

Colombia has been developing a unified environmental health information system (SUISA) since 2010 through the National Technical Commission for Environmental Health (CONASA). SUISA integrates various information systems on health and environmental determinants, such as water, air, public services, living conditions, food, medicines, and substances that are a risk to humans. Initially conceived from the perspective of the natural environment, SUISA has evolved towards a broader vision of the environment, considering the natural, physical, economic, and social environment. In this sense, there are about 35 fragmented information systems managed by different ministries, which address different social, economic, or environmental determinants. The fragmentation of information hinders the surveillance of diseases affected by social determinants, as well as the capacity of national and local governments to develop programs and interventions that could reduce health risks.

Conclusions and Recommendations

In the context of Colombia's abundant biodiversity, understanding the drivers of biodiversity loss becomes a pressing concern for assessing associated health risks. Ranking as the third most biodiverse country globally, Colombia faces significant risks, with 88 percent of its ecosystems being threatened. It is essential to acknowledge that climate change acts as both a driver and a consequence of biodiversity loss, as outlined in this component. To address the challenges at hand, it is crucial to delve deeper into understanding the drivers of biodiversity loss and their implications for health. This includes acknowledging the dual role of climate change as both a driver and consequence of biodiversity loss, particularly in relation to deforestation. Further scientific investigation is necessary to examine the intricate interaction between biodiversity loss and health, guiding the formulation of effective public policies, decision-making processes, and resource allocation at the subnational level.

It is essential to highlight the benefits of preserving biodiversity to combat health issues stemming from the combined impact of climate change and air pollution. This requires intensified efforts to address these interactions, which will necessitate stronger governance mechanisms and enhanced cross-sectoral and cross-level arrangements. Notably, the health sector in Colombia should play a more central role in developing policies and programs to

Photo: © Alliance of Bioversity International and CIAT 'NP_Rice Emissions10' (CC BY-SA 2.0) prevent and respond to health risks associated with biodiversity loss and climate change.

In the light of the interaction of health, climate change, and biodiversity, Colombia can benefit from strengthening collaborative arrangements in order to harness policies and programs that would bring health co-benefits. Important steps could include the following:

a. **Develop models** that estimate the benefits and economic costs of inaction and action on biodiversity to tackle health problems caused by interaction of climate change and air pollution

b. **Deepen efforts to address those interactions**; this will increase demand on governance mechanisms and require strengthened multisectoral and multilevel arrangements

c. **Integrate health risks as key determinants in urban planning and land use decision-making processes**, ensuring that health considerations are central to land use planning and development

d. **Strengthen the role of the health sector in Colombia** as central actor in the development of policies and programs to prevent and respond to health risks associated with biodiversity loss and climate change

e. **Scale up nature-based solutions** within the health ministry's initiatives to capitalize on their potential for delivering significant co-benefits for both health and climate

COMPONENT 4

Towards a Roadmap of Interventions to Address Climate Change in Colombia's Health Sector

Background

In recent decades, climate change has gained increasing attention due to mounting evidence of its negative impacts on ecosystems and society. This has resulted in a series of calls for action on climate change, reflecting a growing understanding of the threat it poses to our planet and the urgent need to address it. These calls from scientists, social movements, and international organizations already have a long history with some significant milestones.

The Intergovernmental Panel on Climate Change (IPCC), established in 1988, has played a critical role in raising awareness and calls for action. The IPCC periodic reports have provided a solid scientific foundation on climate change and its consequences, leading to greater understanding and awareness of the need for urgent action (IPCC 2014b). In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was created, establishing the framework for global cooperation in the fight against climate change (UNFCCC 1992). Since then, various conferences of the parties have been held to discuss and negotiate international agreements, with the aim of reducing greenhouse gas emissions and limiting global warming. One of the most important milestones in the calls for action was the adoption of the Paris Agreement in 2015. This agreement, ratified by the vast majority of countries, established the commitment to limit the increase in global temperature to below 2 degrees Celsius, and strove for a limit of 1.5 degrees Celsius (UNFCCC 2015). In addition, the Paris Agreement urged countries to submit Nationally Determined Contributions (NDCs) with specific measures to reduce emissions and adapt to the effects of climate change. These calls to action have generated increased awareness and mobilization around the world. Civil society, scientists, and nongovernmental organizations have played a key role in pushing for more ambitious action (IPCC 2018).

Health is a central issue in the debate on climate change, and climate change has been characterized by some as the greatest threat to global health in the 21st century (WHO 2015). The effects of global warming have significant direct and indirect consequences on people's health, and all of the evidence supports the need to take urgent action to address climate change from a health perspective. Numerous studies and organizations recognize the close interconnection between climate change and health, which has led to increased concern and calls for action. According to the World Health Organization (WHO), climate change represents a significant threat to health worldwide, as it directly affects health systems, food security, access to drinking water, and disease patterns (WHO 2018). The effects include increased risk of vector-borne diseases such as malaria and dengue fever, as well as respiratory and cardiovascular diseases linked to air pollution. Health impacts also include heat stress, malnutrition, foodborne illness, and increased natural disasters such as floods and droughts. In addition, the IPCC has highlighted that climate change can exacerbate health inequalities, disproportionately affecting the most vulnerable populations, such as children, the elderly, the poor, and those living in remote regions (IPCC 2014a).

These calls to action around the strong links between health and climate change have been echoed and expressed in international commitments such as those established in the Paris Agreement and in the development of commitments for NDCs. However, despite the advances and commitments of nations, the pace at which these actions are being taken may not be fast enough. In the health sector in particular, it has been noted that while progress has been made and the new iterations of several NDCs include healthcare, action is "too slow if any" (Hartinger et al. 2023).

This component seeks to integrate the results of the first three components of this study into an analysis that can inform and facilitate decision-making in the face of the challenges of climate change in the health sector.

Methods

The methodological approach is guided by elements developed in frameworks for the analysis of costs and consequences of climate change in the health sector (WHO 2013; WHO 2023), which propose a comparative analysis between the costs of inaction in the face of climate change and the potential costs and benefits of intervening to mitigate or adapt to the (partially unavoidable) consequences of climate change.

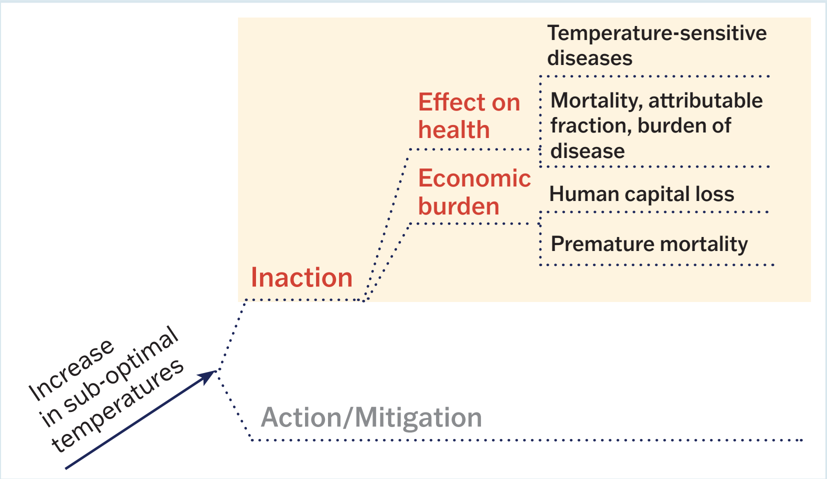
To do this, on the one hand, this analysis identifies and estimates the impact of climate change on health. On the other hand, it identifies actions to face these challenges, and for each of these elements, it defines the indicators to be quantified. In this sense, the conceptual framework emphasizes the need to integrate knowledge from different disciplines into the analysis and highlights that it is essential to spotlight the role of assessing the cost of inaction in raising awareness of current and future health-related challenges that deserve attention from public policy. This becomes a critical element of the process, since it is expected to stimulate political intervention (WHO 2023).

> This component integrates the findings of other components of this study that point to the costs of inaction and incorporates them in a comparative analysis alongside the costs of interventions.

Thus, this component integrates the findings of other components of this study that point to the costs of inaction and incorporates them in a comparative analysis alongside the costs of interventions. For this reason, the dimensions of the analysis start with the components of the study—in particular, the economic burden associated with non-optimal temperature—and complements them with an estimate of the associated costs to mortality and morbidity, using a tool to assess the effects of climate on health (the Climate Change and Health Economic Valuation Tool discussed below).

In terms of the conceptual framework, the disease and economic burden due to non-optimal temperature evidences the costs of inaction and assesses the economic cost of premature mortality associated with non-optimal temperature (Figure 40; see also methodological details in Component 1).

Figure 40. Quantifying the Costs of Inaction: Sub-Optimal Temperature



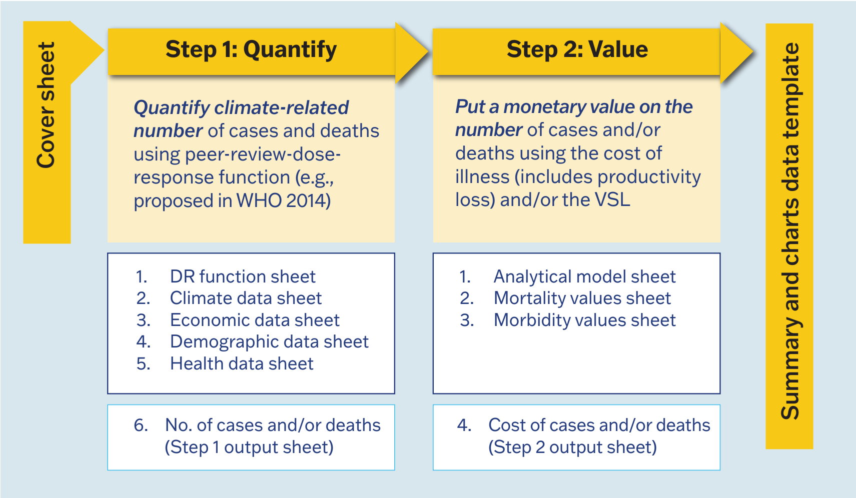
Additionally, as noted above, the effects of climate change on health are not limited to temperature. There are also important effects through changes in ecosystems that have, for example, substantial implications for diseases transmitted by vectors or for diseases related to the quality and availability of water. Therefore, to complement the analysis with a vision of the costs of inaction in other dimensions, the tool developed by Metroeconomica and the World Bank for the economic valuation of the effects of climate change on health is used (Metroeconomica-World Bank 2022). The methodology of the tool is described below.

Climate Change and Health Economic Valuation Tool

The Climate Change and Health Economic Valuation Tool (CHEVT) helps to quantify the economic cost of inaction and is articulated with the framework described above, applying the steps of quantifying the impact of climate change on health and subsequently valuing that impact in economic terms.

To estimate the impact, the tool uses models proposed in the literature (Aström et al. 2012; WHO 2014) that describe the climate-health relationship for the following outcomes: dengue, malaria, malnutrition, diarrheal disease, health outcomes associated with temperature extremes, and health outcomes associated with extreme weather events. The models associate climate information, along with other demographic, economic, and health indicators, to quantify the number of cases and the number of deaths associated with each of the selected events, thus producing a quantitative measure of the impact of climate change on morbidity and mortality. Subsequently, it combines this information with cost data and uses the cost of illness method to value morbidity and the value of a statistical life method to value mortality in order to estimate the economic value of that effect (Figure 41). For the climate data (temperature and precipitation) the tool uses the SSP3–RCP7.0 scenario from Coupled Model Intercomparison Project Phase 6 (CMIP6). The tool quantifies and values deaths and cases attributable to climate change under two different scenarios—with and without climate change.[19]

Figure 41. CHEVT: The Tool in Brief



Source: adapted from Metroeconomica-World Bank (2022).
Note: CHEVT = Climate and Health Economic Valuation Tool.

To use the tool, it is then necessary to calculate the indicators with the data for Colombia. The list of indicators and the related sources of information used for the present analysis presented below (Table 12).

19 RCPs are scenarios developed by the research community "to provide information on possible development trajectories for the main forcing agents of climate change" (see van Vuuren et al. 2011).

Table 12. Indicators and Information Sources, Colombia Analysis

Indicator	Source
National GDP per capita at market prices	SSP Database
National GDP per capita in terms of purchasing power parity	SSP Database
National population (2020)	SSP Database
Dengue cases (2020)	SIVIGILA
Direct cost per dengue episode	Literature and own calculations
Indirect cost per dengue episode	Literature and own calculations
Total cost per dengue episode	Literature and own calculations
Malaria case fatality rate per 1,000 cases	IHME
Number of malaria cases nationwide (2020)	IHME
Direct cost per malaria episode (2014–2016, indexed to 2020)	Literature and own calculations
Indirect cost per malaria episode (2014–2016, indexed to 2020)	Literature and own calculations
Total cost per malaria episode (2014–2016, indexed to 2020)	Literature and own calculations
Direct cost per episode of diarrhea (2014–2016, indexed to 2020)	Literature and own calculations
Indirect cost per episode of diarrhea (2014–2016, indexed to 2020)	Literature and own calculations
Total cost per episode of diarrhea (2014–2016, indexed to 2020)	Literature and own calculations

Note: IMHE = Institute for Health Metrics and Evaluation; GDP = gross domestic product.

Estimation of cost indicators are a combination of literature sources and authors' calculations. For each cost indicator, a literature search for sources reporting data on these outcomes was conducted in English and Spanish. Regarding the items identified, the cost information per case was extracted and updated at 2020 prices, using the growth in the legal minimum wage (considering that several of the calculations are based on prices of the rates used in Colombia, several of which are indexed to the growth of the minimum wage).

We also did our own calculations of the cost for each of the cases, using individual health records (claims data) to characterize all the health care services provided to patients that meet the selected diagnoses. The analysis includes all services related to the episode, including those provided during the first identified point of contact, as well as additional services for patients transferring to other healthcare settings (e.g., hospital care or intensive care units). The analysis used data on the monetary value paid by health insurance companies for these services to estimate the financial cost to the health system and out-of-pocket payments were used for the same services to estimate the direct cost borne by patients. The analysis also estimated the number of days (using admission date and discharge date) that patients have limited ability to work and valued those days using different wage scenarios (minimum wage, median earnings) to estimate indirect cost.

The cost of each of the cases was estimated using individual health records (claims data) to characterize all the health care services provided to patients that meet the selected diagnoses.

To estimate the financial cost, generalized linear models (gamma with log link) and nonparametric models (XGBoost and Random Forests) were used. First, the data was split into a training set and a test set. Then, the estimation worked with the training set using resampling techniques (10-fold cross-validation) to choose between alternative model specifications and to fit hyperparameters. After having a small number of candidate models in the training set, the analysis used the test set to evaluate competing models and choose the best model using predictive performance indicators. The best selected model was used to estimate the cost per episode. In the case of out-of-pocket payments, a generalized linear models with a Tweedie distribution and a log link function was used. To estimate the number of days with limited ability to work per episode, a negative binomial model was used and followed the same procedure explained above. Then, each day was valued using different using different scenarios for the reference salary.

Identifying Interventions

To identify interventions that have the potential to address the challenges of climate change in the health sector, a two-step approach was used. First, a literature review was conducted to identify interventions that have been proposed and/or implemented internationally, and a review was conducted of regulatory developments and other initiatives that have been proposed in Colombia as strategies to deal with climate change.

For the literature review, a scoping review was conducted with the aim of systematically mapping the available literature on interventions related to climate change and the health sector. An exhaustive bibliographic search was carried out in electronic databases (PubMed, Scopus, and Web of Science), using search terms related to climate change, the health sector, and interventions. Studies published in English and Spanish were included. Inclusion criteria were initially applied by reviewing titles and abstracts, and then relevant studies were selected for full review. Key data was extracted from the selected studies, such as author, year of publication, country of origin, interventions evaluated, and whether data on the effectiveness of the intervention and its costs are reported. The findings are presented in a descriptive manner, highlighting the identified interventions and grouping them thematically.

Results

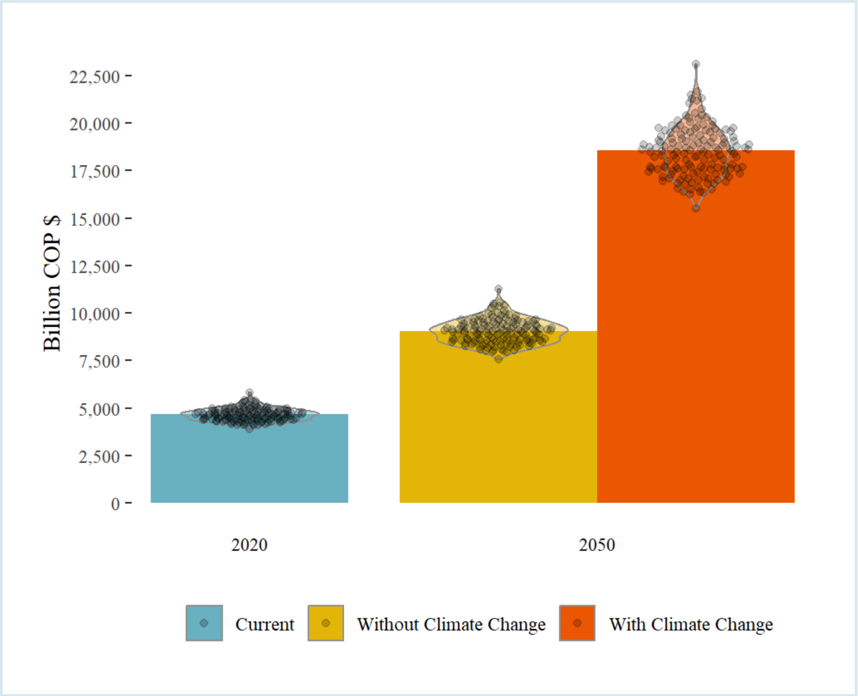
The Cost of Climate Change Impacts

The CHEVT results indicate that the economic (social) cost of mortality and morbidity arising from malaria, dengue, diarrhea, stunting and extreme heat is estimated to increase from COP 7.1 trillion in 2020 to COP 31.5 trillion in 2050. This economic cost represents 0.7 percent of GDP in 2020 and is estimated to increase to 1.6 percent of GDP in 2050. Not all of this increase in the economic cost is attributed to climate change. Changes in total population, changes in the structure of the age pyramid, and changes in gross domestic product also explain the significant increase in health costs. In Colombia, CHEVT estimates indicate that 46 percent of the health costs in 2050 are directly attributed to climate change. Thus, climate change will contribute 0.8 percent of GDP to health costs in 2050.

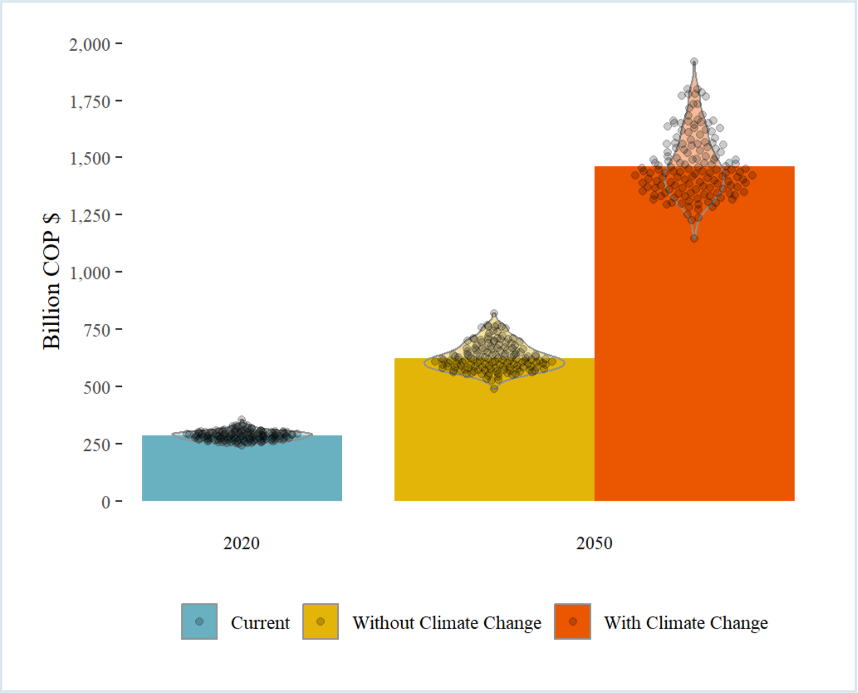
The CHEVT results indicate that among selected outcomes, dengue represents the greatest burden, with an estimated cost of COP 4.7 trillion in 2020. This is followed by stunting, with a cost of COP 580 billion and extreme heat with COP 122.9 billion. Climate change does not uniformly affect all outcomes. The increase in cost due to climate change is primarily explained by heat and vector-borne diseases (dengue, malaria), but less so by diarrhea or stunting, where the cost difference between scenarios with and without climate change is relatively small.

Figure 42. CHEVT Results, Colombia

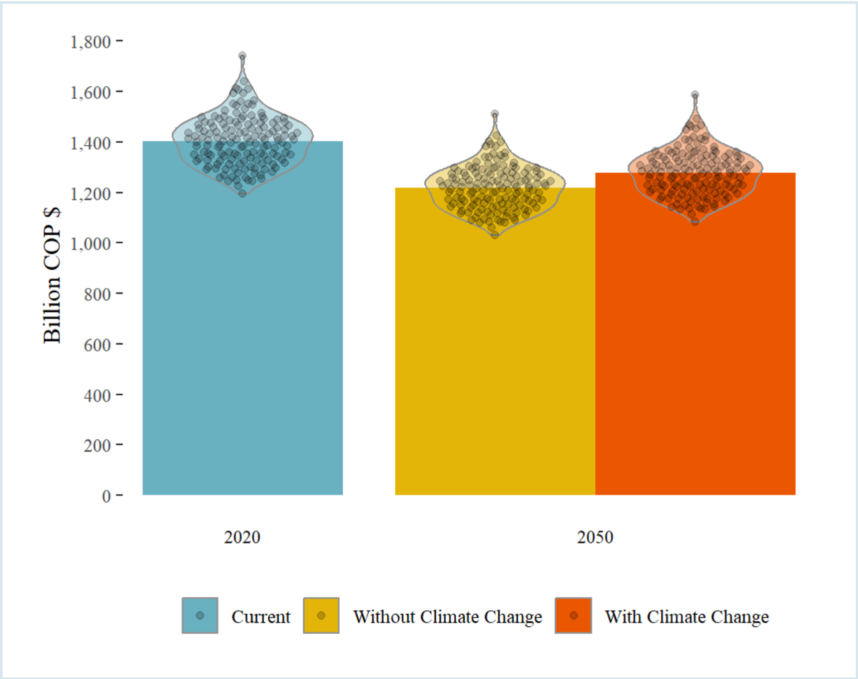
(A) Dengue



(B) Malaria



(C) Diarrhea



(D) Stunting

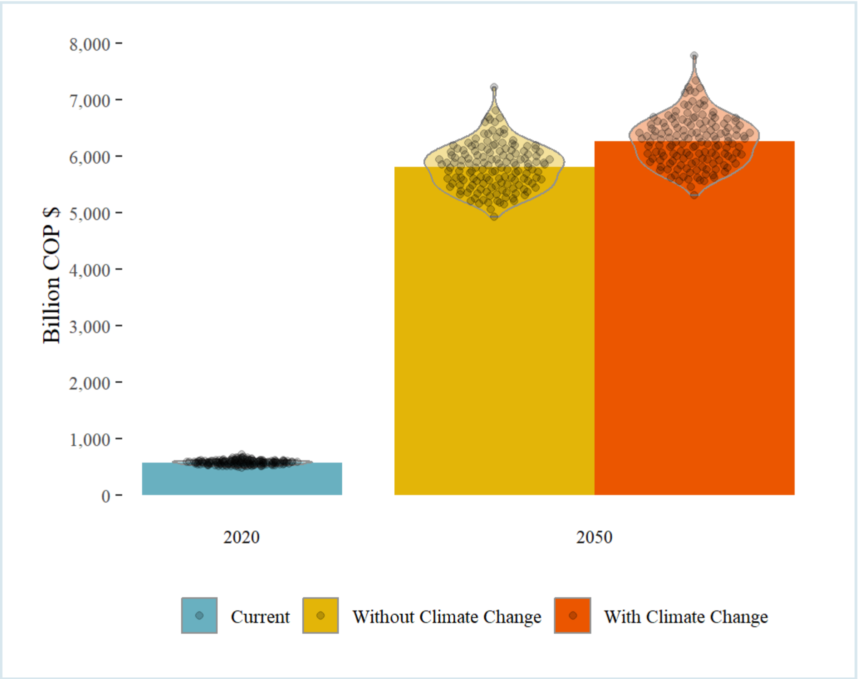


Photo: © James Gathany

Interventions Identified Through the Literature Review

An important group of interventions are those based on improving knowledge of the health climate relationship, where three key interventions play a leading role in the literature: climate-aware health surveillance systems, early warning systems, and efforts to assess vulnerability and risks. Surveillance systems help identify and understand the specific health impacts of climate change. This information is essential for guiding targeted interventions and resource allocation, as well as for evaluating the effectiveness of interventions over time. Without accurate and up-to-date surveillance data, it would be challenging to identify emerging health risks, allocate resources effectively, and develop evidence-based strategies to protect public health. Early warning systems play a crucial role in forecasting and alerting communities and healthcare providers about these events, allowing for timely preparedness and response. By providing advance notice, early warning systems help mitigate the adverse health impacts of climate-related disasters, such as injuries, waterborne diseases, and mental health effects. They enable the implementation of preventive measures, evacuation plans, and the allocation of resources to ensure a swift and effective response. Assessing vulnerability and risks associated with climate change is essential for understanding which populations and regions are most at risk and need targeted interventions. Vulnerability assessments evaluate the susceptibility of individuals, communities, and healthcare systems to climate-related health hazards based on factors such as socioeconomic status, geographic location, and existing health conditions. Risk assessments, on the other hand, identify and evaluate the potential health hazards and consequences of climate change, enabling proactive planning and preparedness. These assessments help prioritize interventions, allocate resources appropriately, and ensure that the most vulnerable populations receive the necessary support and protection.

Another important group of interventions comprise preparedness and response plans. By establishing protocols, guidelines, and resources in advance, these plans ensure timely and coordinated actions during emergencies, leading to the efficient allocation of resources, effective response efforts, and the protection of individuals and communities. Moreover, they promote awareness, knowledge, and readiness—empowering communities to cope with crises, adapt to changing circumstances, and recover more swiftly, and ultimately contributing to the overall safety and well-being of populations. In the literature, preparedness and response plans are usually associated with specific risks, hazards, or diseases.

There seems to be a growing consensus that holistic strategies, plans, and policy frameworks are important in addressing the complex and far-reaching challenges posed by climate change in the health sector. They aim to provide a structured and comprehensive approach to guide actions and initiatives to safeguard public health in the face of changing climatic conditions. They establish a clear vision and direction for addressing climate change impacts on health. They also outline overarching goals and objectives, highlighting the specific areas of focus and priority actions. By setting a strategic direction, these frameworks enable policymakers and stakeholders to align their efforts and allocate resources effectively. Policy frameworks establish the regulatory and governance mechanisms necessary to support the implementation of strategies and plans. They provide a legal and institutional framework for decision-making, resource allocation, and coordination among various stakeholders. Policy frameworks also enable the integration of climate change considerations into existing health policies, ensuring that climate-related risks and vulnerabilities are adequately addressed.

The literature frequently studies interventions individually considered. For example, in the context of heat-related diseases, interventions such as the increase in the use of air conditioning, public awareness campaigns on personal protection measures, and cooling centers, among others, are discussed. One salient characteristic of this set of interventions is the diversity. This is the result of the multi-faceted complexity of the problem and the multiple pathways of risk exposure and impact. It is also a consequence of the fact that, ultimately, many actions should be taken at the local level, tackling the locally relevant issues with the resources available.

The interventions discussed above can contribute to creating a roadmap of interventions to cope with the consequences of climate change in the health sector. The review also pinpointed two key messages from the literature: (i) there is no silver bullet intervention to deal with climate change in the health sector, instead, countries should embrace comprehensive and integrated approaches to deal in the short and long term with climate change; and (ii) action at the local level is key, and although national strategies are indispensable, if they do not translate into action at the local level, they can hardly be effective.

Even though many studies focus on a single intervention, there seems to be consensus that single interventions fall short in dealing with the complexities of climate change. It is crucial to adopt a comprehensive strategy rather than focusing solely on individual interventions. **A comprehensive approach considers the complex and interconnected nature of climate change and its effects on health.** By implementing a broader strategy, policymakers and stakeholders can effectively address the multiple dimensions of climate change, mitigate risks, and build resilience within healthcare systems. For instance, a study by Watts et al. (2018) emphasized the need for integrated approaches that combine adaptation measures, health system strengthening, and mitigation efforts to achieve sustainable health outcomes in a changing climate. Furthermore, a review by Frumkin et al. (2019) highlighted the significance of adopting a systems-thinking approach that considers the interdependencies between the environment, human health, and social factors. A comprehensive strategy is essential for effectively addressing climate change in the health sector. Academic research emphasizes the need to adopt integrated approaches and systems-thinking to effectively mitigate risks, strengthen health systems, and safeguard public health in the face of climate change challenges. By taking a holistic approach, policymakers can ensure sustainable and resilient health outcomes for present and future generations.

Action at the local level plays a pivotal role in addressing the consequences of climate change in the health sector. Local governments and communities are at the forefront of responding to the immediate and long-term health impacts of climate change, as they possess a deep understanding of local contexts, vulnerabilities, and resources. Schramm et al. (2020), for example, using a number of case studies, shows how local data and expertise can drive effective programs tailored to specific needs and illustrates how one-size-fits-all models would not work for climate and health adaptation. It also highlights some barriers to developing local climate-health solutions, including a lack of needed data and capacity or expertise.

Additionally, a study by Patz et al. (2015) underscores the role of local-level interventions in reducing the health risks posed by climate change. The authors argue that targeted local initiatives, such as improving access to healthcare, enhancing emergency response systems, and promoting community resilience, can significantly enhance health outcomes and reduce the burden of climate-related health impacts.

Moreover, a review by Vardoulakis et al. (2017) highlights that local action can effectively address the localized health effects of climate change, including heat-related illnesses, vector-borne diseases, and air pollution. The review emphasizes the need for tailored local strategies that account for geographical, socioeconomic, and demographic factors to protect vulnerable populations effectively.

Evidence on the effectiveness is relatively scarce. In particular, hard evidence in the form of randomized trials is not commonly available for the majority of interventions, evaluating specifically how they address the impact of climate change. Such evidence sometimes may not be ethical to produce and sometimes it may not be feasible (Smith et al. 2023).

Interventions in the Colombian Context

In Colombia, significant efforts have been made to address climate change. A central milestone was Colombia's signing of the Paris Agreement and the presentation of Colombia's first commitments in the Nationally Determined Contributions (NDCs) in 2015. In 2020, the country presented its NDC update. In the update, it commits to more ambitious measures to reduce emissions; and in the health sector, the update explicitly includes two objectives in terms of (i) adaptation in prevention of climate-sensitive diseases and (ii) adaptation actions by healthcare providers for possible events associated with climate variability and change. The strategies defined in the NDC commitments have become a cornerstone of the fight against climate change in Colombia—so much so that they were raised to legal status with the issuance of Law 2169 of 2022, which promotes the country's low-carbon development by establishing goals and minimum measures in terms of carbon neutrality and climate resilience.

A previous law (Law 1931 of 2018) defines the Comprehensive Territorial Climate Change Management Plans (PIGCCT) as the instruments through which local governments evaluate, prioritize, and define measures and actions for adaptation and mitigation of greenhouse gas emissions. As a result, PIGCCTs are a key vehicle to realize the NDC commitments by taking action at the local level. To date, 24 of the 32 departments in Colombia have already formulated PIGCCTs (Minambiente 2022). In health, the governing body has articulated in these efforts and the Ministry of Health has developed guidelines for the formulation of locally-tailored PIGCCTs specific for the health sector, in terms of both adaptation (Minsalud 2021b; Minsalud 2021c) and mitigation (Minsalud 2021a).

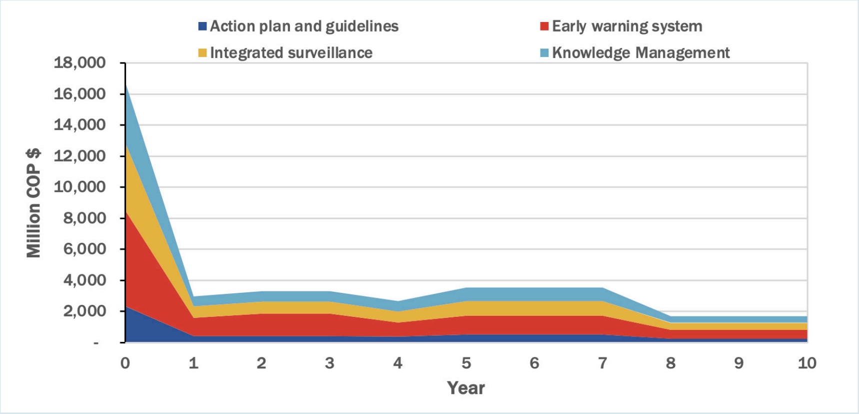
Thus, Colombia has a clear framework for actions against climate change in general, and particularly in the health sector. Additionally, it is noteworthy that this framework generally responds to the main recommendations of the literature in terms of creating national strategies and plans that are developed and implemented locally so that they are tailored to local needs and capacities.

In this sense, the country seems to be on the right track. However, as various international studies have pointed out, the pace of reform implementation should accelerate. An illustrative example of this is the PIGCCTS formulation process. Only 15 percent of the published PIGCCTS include a fully developed component of adaptation actions in health. Thus, accelerating the speed at which these specific plans for the health sector are formulated throughout the territory would seem to be a priority need.

Costs of Intervention

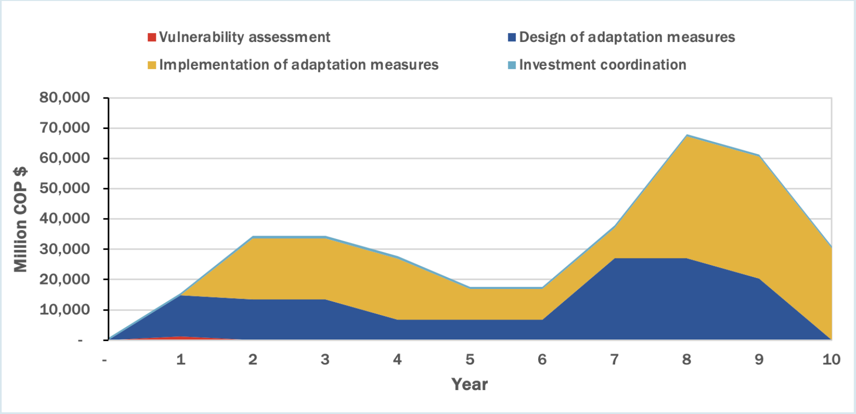
To illustrate the magnitude of the intervention costs, the costing of the specific health targets set forth in the NDC were taken as a starting point. Costing exercises to support the development and implementation of a health surveillance system that integrates climatic data and meteorological models were reviewed. The costing exercise also supports the development of an early warning system for climatic events, as well as knowledge management and the production of guides and action plans. Figure 43 illustrates the costs of implementing these actions over a 10-year horizon, with an estimated value of COP 39 billion in net present value (Ricardo Energy-Ecoversa 2020).

Figure 43. Climate-Aware Integrated Health Surveillance Implementation Costs (10-year horizon)



To address the second goal of Colombia's NDC, the costing exercise included a vulnerability assessment to identify the healthcare providers subject to mitigable and non-mitigable risks, and the design and implementation of adaptation measures. Figure 5 shows the estimated costs for implementation over 10 years; the total cost in net present value amounts to COP 184 billion (Ricardo Energy-Ecoversa 2021).

Figure 44. Health Care Providers' Adaptation Implementation Costs (10-year horizon)



Discussion

The results from this analysis show that implementation costs are dwarfed by the costs associated with the consequences of climate change on people's health and the health system. For example, while the economic burden attributable to sub-optimal temperature ranges between COP 0.6–3.3 trillion over a 10-year period, enhancing climate-sensitive disease prevention efforts through strengthening integrated, conscious early warning and surveillance systems of the weather, would cost around COP 43 billion. Although the evidence on the effectiveness of these types of interventions in addressing the consequences of climate change is still accumulating, the potential benefits are large enough to suggest that it is likely to be a good investment.

Colombia has set a clear path with the NDC goals specific for the health sector and the PIGCCTs as a key vehicle to assess, prioritize and define measures and actions for adaptation and mitigation of climate change, to be implemented in the local contexts. Yet, it is important to accelerate the pace of its implementation. In particular, the development of a climate-aware integrated surveillance system is one of the measures in line with NDC's goals that is yet to be a reality. The national government should lead the development and implementation of such a system, to strengthen the current surveillance system that, despite its many strengths, still does not comprehensively and systematically include climatic information. Such a system should include early warning systems for climate-relevant hazards, implemented at scale, building on some of the pilot experiences already tried out in Colombia. Recognizing that many of the measures that can ultimately reduce the health effects of climate change must be implemented at the local level and tailored to the local context, the development of fully-fledged PIGCCT for the health sector should be a priority. The national government should lead the strategy to spur the formulations of such plans throughout the country and accompany the subnational governments in charge of the development of the plans through technical assistance and the creation of spaces to share the experiences with other sub-national governments and the civil society in general.

ANNEXES

ANNEX 1. COMPONENT 1

A. Methodological Annex

Systematic Literature Review

Systematic Review of Epidemiological Studies of Disease Burden by Temperature Variation

Objective: to review the different methodological options for calculating the burden of disease by temperature.

Three procedures were carried out to search for relevant information in the study of this methodology

1. Studies published in indexed journals that evaluated the burden of disease by chronic diseases, communicable diseases and injuries of external cause in Latin America, through 3 different search engines.

2. Studies published in indexed journals that evaluated the association of risk factors, emphasizing temperature on the burden of disease in Latin America, through 3 different search engines.

3. Gray literature published on the internet in the last 30 years, using Google Scholar as a search tool, selecting the most relevant publications and carrying out a secondary search for information through the snowball method.

The following section describes each of these procedures.

Burden of disease in Latin America

- **Search engines:** PubMed, Embase, EBSCO Host
- **Inclusion criteria:** Indexed articles published in English, Spanish and Portuguese between 1990 and 2022 in Latin America using keywords for burden of disease included within health science descriptors (DeCS) in the 3 languages https://decs.bvsalud.org/E/homepagee.htm
- **Search syntax:** The search syntax is presented in the following box

Box A1.1. Search syntax disease burden Latin America

Embase

('disability-adjusted life year'/de OR daly:ab,ti,kw OR dalys:ab,ti,kw OR ((disabil* NEAR/4 adjust* NEAR/4 life* NEAR/4 year*):ab,ti,kw) OR yll:ab,ti,kw OR ylls:ab,ti,kw OR ((year* NEXT/2 life* NEXT/1 lost*):ab,ti,kw) OR yld:ab,ti,kw OR ylds: ab,ti,kw OR ((year* NEAR/3 lived NEAR/3 disabil*):ab,ti,kw)) AND ('latin america'/exp OR latam OR 'hispanic america/de' OR iberoamerica OR colombia*:ab,ti,kw OR peru*:ab,ti,kw OR chile*:ab,ti,kw OR argentina*:ab,ti,kw OR bolivia*:ab,ti,kw OR mexico*:ab,ti,kw OR uruguay*: ab,ti,kw OR brazil*:ab,ti,kw OR venezuela*:ab,ti,kw OR ecuador*:ab,ti,kw OR paraguay*:ab,ti,kw OR panama*:ab,ti,kw OR 'costa rica*':ab,ti,kw OR nicaragua*:ab,ti,kw OR honduras*:ab,ti,kw OR guatemala*:ab,ti,kw OR salvador*:ab,ti,kw OR cuba*: ab,ti,kw OR haiti*:ab,ti,kw OR dominican*:ab,ti,kw OR 'puerto rico*':ab,ti,kw) AND [1990-2030]/py

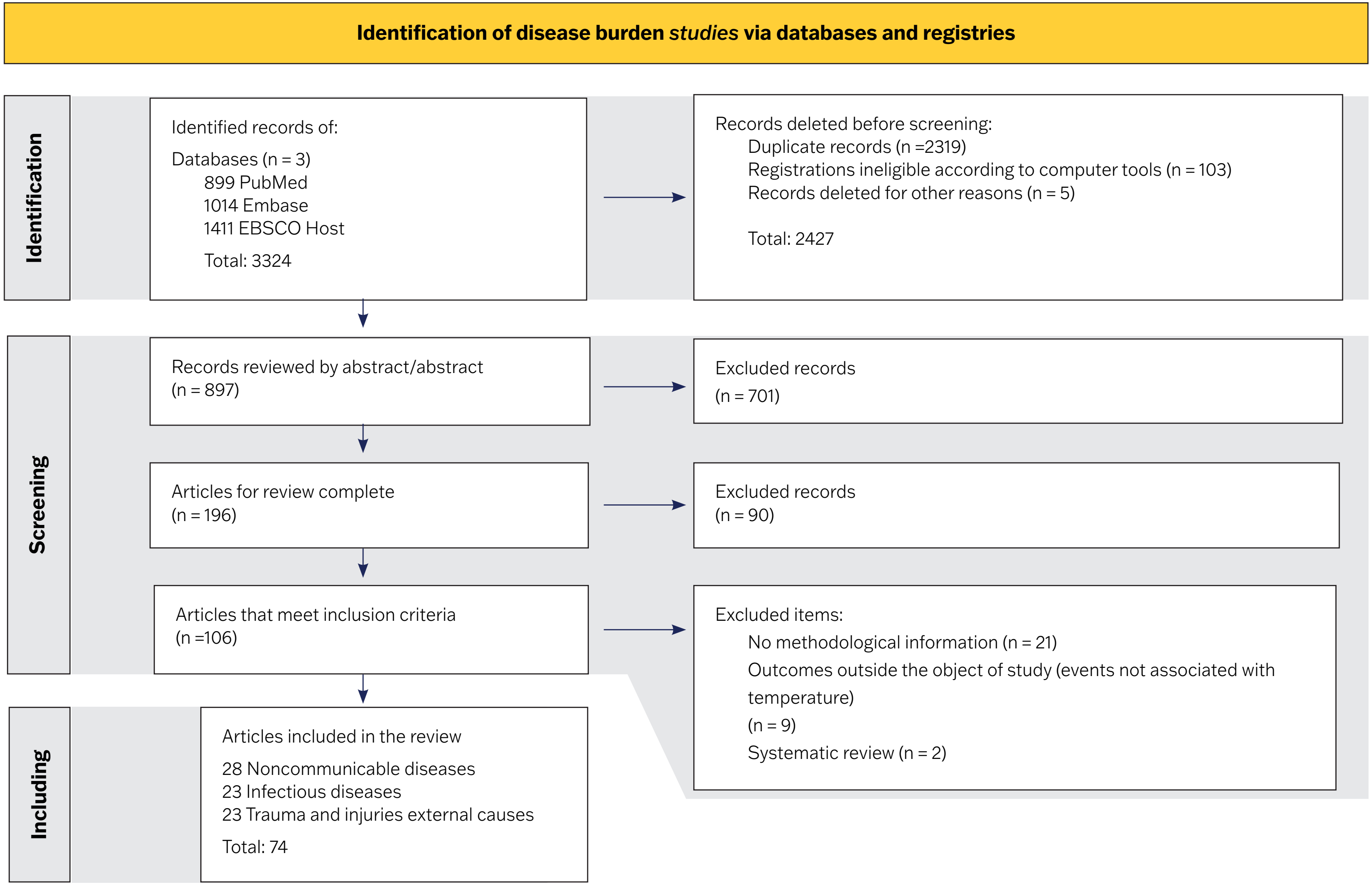
EBSCO Host

("DALY" OR "Disability" OR "adjust" OR "life" OR "year" OR "YLD" OR "YLL" OR "lost") AND ("Latinamerica" OR "Colombia" OR "Venezuela" OR "Ecuador" OR "Peru" OR "Bolivia" OR "Paraguay" OR "Chile" OR "Argentina" OR "Uruguay" OR "Brazil" OR "Panama" OR "Costa Rica" OR "Nicaragua" OR "Honduras" OR "Guatemala" OR "Salvador" OR "Mexico" OR "Cuba" OR "Haiti" OR "Puerto Rico" OR "Dominicana")

PubMed

("DALY" OR "DALYs" OR "disability adjusted life year" OR "YLL" OR "YLLs" OR "Year of life lost" OR "YLD" OR "YLDs" OR "years lived with disability") AND ("Brazil"[All Fields] OR "Colombia"[All Fields] OR "Venezuela"[All Fields] OR "Ecuador"[All Fields] OR "Peru"[All Fields] OR "Bolivia"[All Fields] OR "Paraguay"[All Fields] OR "Chile"[All Fields] OR "Argentina"[All Fields] OR "Uruguay"[All Fields] OR "Brazil"[All Fields] OR "Panama"[All Fields] OR " Costa Rica"[All Fields] OR "Nicaragua"[All Fields] OR "Honduras"[All Fields] OR "Guatemala"[All Fields] OR "Salvador"[All Fields] OR "Mexico"[All Fields] OR "Cuba"[All Fields] OR "Haiti"[All Fields] OR "Puerto Rico"[All Fields] OR "Dominicana"[All Fields])

Figure A1.1. Flowchart Search Result Burden of Disease



Data extraction: the data was extracted to an Excel matrix, using the following categories to synthesize the information

Table A1.1. Categories of Analysis of Data Extracted from the Review

Category	Description
Overview	General aspects study (journal, title, author, year of publication, objectives, language)
Study characteristics	Type and group of cause/event, geographical distribution, reference period, stratification
Data adjustment	Use of sources of mortality or incidence, data management (adjustment, integration), internal consistency of the study, type of software used
DALY (disability-adjusted life year) calculation method	Perspective of YLD (year lived with disability) estimates (incidence/prevalence), Type of method calculation of life expectancy-YLL, reported disease model, calculation of disability weight, methods used in the calculation of disability weight (elicitation method, jury panel, severity distribution), comorbidity and adjustment methods, weighting process
Injury classification (only for trauma and externally caused injuries)	Cause of injury, nature of injury, injury type matrix and % incident cases by cause and injury.
Uncertainty	Use of uncertainty analysis, sensitivity analysis or scenario analysis

Risk factors in Latin America

- **Search engines:** PubMed, Embase, EBSCO Host
- **Inclusion criteria:** Indexed articles published in English, Spanish, and Portuguese between 1990 and 2022 in Latin America using keywords for risk factors included within health science descriptors (DeCS) in the 3 languages https://decs.bvsalud.org/E/homepagee.htm
- **Search syntax:** The search syntax is presented in the following box

Box A1.2. Search Syntax Risk Factors Latin America

Embase

('temperature'/de OR 'weather'/de OR 'heatwave'/de OR coldspell OR (attributable AND 'risk'/de) OR ((attribut* NEAR/3 (risk* OR fraction* OR burden* OR mortalit* OR death*)):ab,ti,kw) OR ((comparat* NEAR/3 risk* NEAR/3 assessment*):ab,ti,kw)) AND ('latin america'/exp OR latam OR 'hispanic america/de' OR iberoamerica OR colombia*: ab,ti,kw OR peru*:ab,ti,kw OR chile*:ab,ti,kw OR argentina*:ab,ti,kw OR bolivia*:ab,ti,kw OR mexico*:ab,ti,kw OR uruguay*:ab,ti,kw OR brazil*:ab,ti,kw OR venezuela*:ab,ti,kw OR ecuador*:ab,ti,kw OR paraguay*:ab,ti,kw OR panama*:ab, ti,kw OR 'costa rica*':ab,ti,kw OR nicaragua*:ab,ti,kw OR honduras*:ab,ti,kw OR guatemala*:ab,ti,kw OR salvador*:ab,ti,kw OR cuba*:ab,ti,kw OR haiti*:ab,ti,kw OR dominican*:ab,ti,kw OR 'puerto rico*':ab,ti,kw) AND [1990-2030]/py

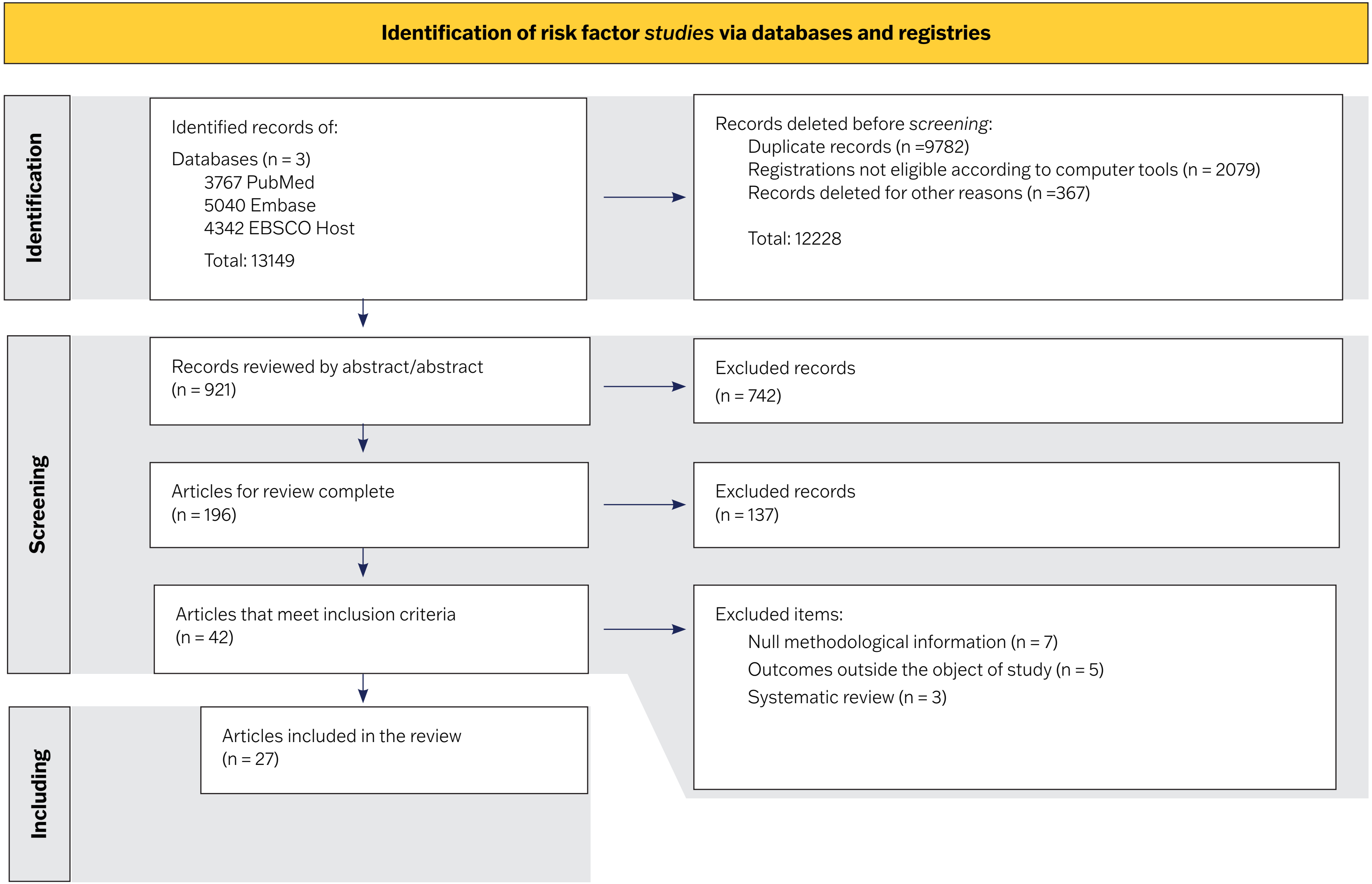
EBSCO Host

("temperature" OR "weather" OR "heatwave" OR "coldspell") OR ("attributable" OR "risk" OR "fraction" OR "mortality" OR "comparative" OR "assessment") AND ("Latinamerica" OR "Colombia" OR "Venezuela" OR "Ecuador" OR "Peru" OR "Bolivia" OR "Paraguay" OR "Chile" OR "Argentina" OR "Uruguay" OR "Brazil" OR "Panama" OR "Costa Rica" OR "Nicaragua" OR "Honduras" OR "Guatemala" OR "Salvador" OR "Mexico" OR "Cuba" OR "Haiti" OR "Puerto Rico" OR "Dominicana") AND [1990-2030]

PubMed

(("temperature"[All Fields] OR "weather"[All Fields] OR "heatwave"[All Fields] OR "coldspell"[All Fields]) AND ("attributable"[All Fields] OR "risk"[All Fields] OR "mortality"[All Fields] OR "death"[All Fields] OR "fraction"[All Fields] OR "burden"[All Fields]) AND ("Brazil"[All Fields] OR "Colombia"[All Fields] OR "Venezuela"[All Fields] OR "Ecuador"[All Fields] OR "Peru"[All Fields] OR "Bolivia"[All Fields] OR "Paraguay"[All Fields] OR "Chile"[All Fields] OR "Argentina"[All Fields] OR "Uruguay"[All Fields] OR "Brazil"[All Fields] OR "Panama"[All Fields] OR "Costa Rica"[All Fields] OR "Nicaragua"[All Fields] OR "Honduras"[All Fields] OR "Guatemala"[All Fields] OR "Salvador"[All Fields] OR "Mexico"[All Fields] OR "Cuba"[All Fields] OR "Haiti"[All Fields] OR "Puerto Rico"[All Fields] OR "Dominicana"[All Fields])) AND (1990:2023[pdat])

Figure A1.2. Flowchart Search Results Risk Factors



Data extraction: the data was extracted to an Excel matrix, using the following categories to synthesize the information

Table A1.2. Categories of Analysis of Data Extracted from the Review

Category	Description
Overview	General aspects study (journal, title, author, year of publication, objectives, language)
Study characteristics	Type and group of cause/event, geographical distribution, reference period, stratification
Data adjustment	Use of sources of mortality or incidence, data management (adjustment, integration), internal consistency of the study, type of software used
DALY calculation method	Perspective of YLD estimates (incidence/prevalence), Type of method calculation of life expectancy-YLL, disease model, calculation of disability weight, methods used in the calculation of disability weight (elicitation method, jury panel, severity distribution), comorbidity and adjustment methods, weighting process
Risk benchmarking	Clarity of risk factor definition, sources of exposure, risk-outcome combinations, definition of exposure-response function, data source exposure-response curve, definition of minimum exposure risk threshold (MRREL), method of calculating attributable risk, use of stratified analysis
Uncertainty	Use of uncertainty analysis, sensitivity analysis or scenario analysis

Gray literature burden of disease from suboptimal temperature exposure

- **Inclusion criteria:** All types of grey literature published in Spanish and Portuguese in Latin America between 1990 and 2022 with keywords included within health science descriptors (DeCS) and terms of free use https://decs.bvsalud.org/E/homepagee.htm
- **Search strategy:** the search was performed in Google Scholar, using the search syntax shown in Box A1.3

Box A1.3. Search Syntax Gray Literature

Spanish

"temperature|climate|heatwaves|extreme cold"|"attributable risk|fraction|burden|mortality"|"Comparative Risk Assessment"|Latin America|Colombia| Peru|Chile| Argentina|Brazil |Bolivia | Ecuador|Uruguay| Paraguay| Venezuela |Panama|" Costa Rica"|Nicaragua| Honduras |Guatemala |Salvador| Cuba | Haiti| Dominican|" Puerto Rico"

Portuguese

"temperature | climate | heatwave | extreme tempofrio" |" Riscoatribuivel |Fraçao|Cargo |Mortality| "mediçaocomparativaderisco"| latinamerica | colombia | peru |chile | argentina | brazil| bolivia|ecuador|uruguay|paraguay|venezuela| panama|" Costa Rica"|Nicaragua| Honduras | Guatemala| Salvador|Cuba |Haiti|Dominican |" Puerto Rico"

Subsequently, the most relevant documents were selected and a search was performed using the snowball procedure to complete the search process.

Results: 75,400 documents were obtained in Spanish and 64,900 in Portuguese. After a review of the documents, 139,801 documents were discarded and 499 were reviewed. After an initial screening, seven documents were selected, which through the snowball procedure allowed to identify four more documents for a total of 11.

Data extraction: data were extracted to an Excel matrix and classified according to the following categories (Table A1.3):

Table A1.3. Categories of Analysis of Data Extracted from the Review

Category	Description
Overview	General aspects study (journal, title, author, year of publication, objectives, language)
Study characteristics	• Document Type: Thesis, Report, White Paper, Book Chapter, Article • Article type: review, research, mixed, white paper • Risk factor studied • Outcome studied • Burden of disease study (Yes/No) • Environmental data sources • Health Data Source • Study design: Analysis type

As a result of the literature review, it was obtained that:

Mapping of information sources: define the most suitable sources after the bibliographic review and the piloting of the quality and completeness of these sources.

Among the most used sources of environmental information for temperature are records of the monitoring networks (studies n = 9), followed by satellite temperature records such as ERA5 (studies n = 7) and not defined (studies n = 2). Some covariates used, part of humidity, atmospheric pressure, and precipitation were some indices such as the Caldas Lang, the Koppen Geiger index, and the environmental probability index.

With regard to health sources, the most used to assess mortality were vital statistics (in most countries) and surveys or verbal autopsies in Haiti and in some very isolated places in Latin America. For the calculation of the years of life lost (YLLs), the predominant method was the use of the standard GBD life tables.

Literature Review of Economic Studies of Temperature Variation

A narrative review of the literature was conducted to identify parameters and methodological approaches that guide the calculation of the economic burden of premature mortality associated with changes in temperature. For this, PuMed-Medline was used as a search engine, with the terms *"economic burden"*, *"climate change"*, *"temperature"*. We reviewed articles published in indexed journals published in English, Spanish and Portuguese, between 1995 and 2023. We included studies with estimates of economic parameters on temperature change, studies of economic burden of disease that calculated direct or indirect costs, and studies that detailed methodological approaches to estimation of economic burden of disease, carried out in any country in the world. Apart from original research, literature reviews were also considered. Conference abstracts and letters to the editor were excluded.

Reference screening and study selection

References were screened by two reviewers independently, analyzing titles and abstracts against predefined selection criteria. When there was any doubt about compliance with the established eligibility criteria, the full document was read to determine whether it provided useful information for the analysis developed in the present study. From the group of preselected references, studies were chosen through reading the full text, in order to confirm that they met the specific eligibility criteria (inclusion and exclusion).

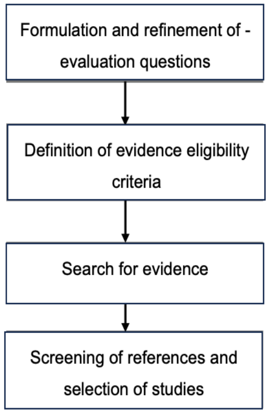
Data extraction and synthesis of evidence

The characteristics of the selected studies were summarized narratively from what was reported in the original publications. The whole process was in charge of two researchers, comparing the results included in the evaluation report with the results presented in the original publications.

Article review

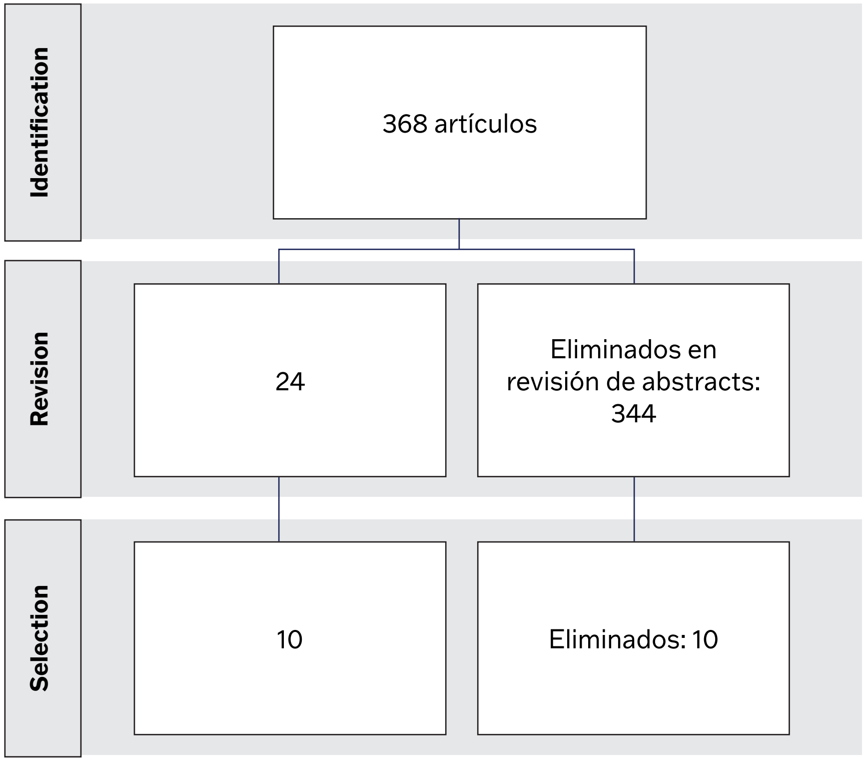
We identified 368 references from the PubMed-Medline search. We excluded 344 references after reading titles and abstracts, because they did not correspond to the established criteria of population, outcomes of interest, or type of publication. After analyzing the remaining 24 full-text references, 10 articles were excluded.

Figure A1.3. Steps Review Economic Literature



Source: IETS 2022

Figure A1.4. PRISMA from the Literature Review of Studies of Economic Burden Due to Temperature Changes



The main findings of the selected articles are described in the following table:

Table A1.4. Characteristics of the Articles Included in the Review of Studies of Economic Burden of Temperature Variation in the World

Author (year)	Country	Period	Studio design	Health Outcome	Type of cost	Main results
Martinez-Solanas et al. (2018)	Spain	1994–2013	Descriptive study	Occupational diseases	• Costs associated with maintaining production (including overtime payments and replacement and training costs), • Lost earnings (total income lost when a worker suffers an injury and is unable to return to work), • Associated health costs with treatment and rehabilitation costs, and • Pain costs and suffering (level of disability).	The study included 15,992,310 occupational injuries. Overall, 2.72% [95% confidence interval (CI): 2.44–2.97] of all lesions were attributed to non-optimal ambient temperatures, with moderate heat representing the highest fraction. This finding corresponds to an estimated 0.67 million (95% CI: 0.60–0.73) person-days of work lost each year in Spain due to temperature, or an annual average of 42 days per 1,000 workers. The estimated annual economic burden is trillions of euros, or 0.03% of Spain's GDP (EUR 2,015).
Adélaïde. et al. (2022)	French	2015–2019	Descriptive study	Heat stress illness	• *Direct costs:* cost-of-illness • *Indirect costs:* production losses with average daily wage • *Intangible costs:* willingness-to-pay (WTP) • *Costs of mortality:* value of a statistical life • (VSL) and value of a life year (VoLY)	Between 2015 and 2019, the economic impact of certain health effects of heatwaves amounts to EUR 25.5 billion, mainly in mortality (EUR 23,200 million), days of less restricted activity (EUR 2,300 million) and morbidity (EUR 0,031 million). The total economic valuation of excess mortality was estimated at €23 billion using VSL and EUR 8.3 billion using the VoLY approach. Under the VSL Approach, the estimated economic impact of mortality during heatwaves ranged from EUR 68 per capita in 2017 to EUR 170 per capita in 2015.

Author (year)	Country	Period	Studio design	Health Outcome	Type of cost	Main results
Wondmagegn et al. (2019)	USA, Australia, Germany, Spain	2017	Systematic review	All causes of heat-related illness and death	Direct, indirect, and economic costs	Studies showed that exposure to extreme heat was causing significant economic loss and burden on health systems. Women, the elderly, low-income families, and ethnic minorities had the largest share of Health care costs in a variety of health service utilization. Although some studies have estimated the costs of medical care by heat, none of them quantified the temperature-cost relationship in health.
Chen et al. (2022)	China	2013–2019	Meta-analysis	Heat stress illness	Costs of mortality: value of a statistical life (VSL)	Economic losses of RMB 156.1 billion (95% CI: RMB 92.28–211.40 billion), accounting for 1.81% (95% CI: 1.14–2.45%) of Wuhan's annual GDP over the seven-year period.
Jagai et al. (2017)	USA, Illinois	1987–2014	Ecological study	Heat stress illness	Total and average hospital charge per person	A 1°C increase in monthly Tmax was associated with a 0.34 and 0.02 increase in rural and urban heat stress illness (HSI) hospitalization per 100,000 population, respectively. The total hospital charge for HSI cases was COP 167.7 million with a median charge of COP 20,500 per person per year.
Knowlton et al. (2011)	USA, California	2000–2009	Case Study	All causes of disease	Cost overrun	An estimated total of 169,881 health care visits were observed. The cost of excess hospitalization, emergency department visits, and outpatient visits in the 2006 heat wave was estimated at COP 28.435 million; COP 14.110 million, and COP 136.380 million, respectively.

Author (year)	Country	Period	Studio design	Health Outcome	Type of cost	Main results
Lin et al. (2012)	USA, New York State	1991–2004	Ecological study	Respiratory disease	Cost overrun	An estimate of 100 excess annual hospital admissions during the base year with associated costs of COP 0.64 million. Projected heat-attributable hospitalization costs for the periods 2046–2065 and 2080–2099 range from COP 5.5 to COP 7.5 million and from COP 26 million to COP 76 million, respectively.
Merrill et al. (2008)	USA	2005	Descriptive study	Heat-related illness	By heat-related hospital stay	A total of approximately 6,200 heat-related hospitalizations were observed in 2005 at a cost of COP 6,200 per hospitalization. The poor and rural residents were the most vulnerable groups.
Noe et al. (2012)	USA	2004–2005	Descriptive study	Heat-related illness	Total cost	The number of medical consultations for hyperthermia was 10,007 with a mortality rate of 0.06 per 100,000. The average hospital stay was two days and the total estimated total cost was COP 36 million.
Schmeltz et al. (2016)	USA	2001–2010	Descriptive study	Heat-related illness	Average cost per hospitalization	A higher mean cost of hospitalization associated with high ambient temperature was evidenced among ethnic minorities: Asians/Pacific Islanders COP 1,208 (COP 793–COP 1,624) followed by Blacks COP 319 (COP 197–COP 440). Women and seniors share the highest cost, accounting for COP 5922 (COP 5,858–COP 5,985) and COP 1,586 (COP 1,466–COP 1,707), respectively.

Author (year)	Country	Period	Studio design	Health Outcome	Type of cost	Main results
Toloo et al. (2015)	Australia, Brisbane	2000–2012	Ecological study	All causes of disease	Cost overrun	During the reference year, older people (≥65) had an increased risk of 1.09 (95% CI: 1.06–1.13) of visiting the emergency department (ED) on hot days (≥35 °C). The number of excess visits was projected to be 98 to 336 (2030) and 229 to 2,300 (2060) for younger groups and 42 to 127 (2030) and 145 to 1188 (2060) for older people. Based on 2012–13 prices, the additional cost attributable to heat was anticipated to range from COP 59,232 to COP 195,693 in 2030 and from COP 162,587 to COP 1,496,221 in 2060.
Hübler et al. (2008)	Germany	1971–2000	Ecological study	All causes of disease	Total annual cost	The initial hospitalization cost (1971–2000) was COP 98 million. The total projected annual cost of hospitalization for the period 2071 to 2100 was estimated at about COP 592 million.
Roldán et al. (2015)	Spain, Zaragoza	2002–2006	Ecological study	All causes of death	Total and overall annual cost	The risk of mortality increased by 1.28 (95% CI: 1.08–1.57) above a temperature threshold of 38°C. A total of 107 (95% CI: 42–173) deaths and an associated cost of COP 509,978 (95% CI: COP 200,178–COP 824,544) were observed.

Methodology of Descriptive Analysis of Temperature and Demographic Structure

We used the temperature estimates of ERA5 for Colombia, a satellite database of the ECMWF (European Centre for Medium Range Weather Forecasts) with a spatial resolution of 0.25º x 0.25º and an hourly time scale, which has temporo-spatial uncertainty parameters (European Centre for Medium-Range Weather Forecasts n.d.). These values were interpolated on a daily and annual basis to calculate the zonal temperature by departments of Colombia. Measurements of central tendency and variability of temperatures were obtained and the vector of average temperature change in each department during the decade was calculated.

For the validation of the temperature data, a sensitivity analysis was carried out with the departmental data of fixed monitoring stations of 10 cities in Colombia belonging to the network of hydro-meteorological stations of the Institute of Hydrology, Meteorology and Environmental Affairs of Colombia (IDEAM). This sensitivity analysis was performed using two statistical tests: the intra-class correlation coefficient (cci) and the Bland Altman graphs. For mortality data by department of residence, vital statistics of the National Administrative Department of Statistics of Colombia (DANE) were used, with the ICD-10 (ICD refers to the International Classification of Diseases) codes of the following 17 events: lower respiratory infections, coronary ischemic disease, cerebrovascular vento-stroke (CVA), hypertensive heart disease, cardiomyopathy/myocarditis, chronic obstructive pulmonary disease, diabetes mellitus, chronic kidney disease, traffic accidents, other transportation accidents, drowning, exposure to mechanical forces, contact with animals, exposure to forces of nature (natural disaster), suicide, interpersonal violence, and other unintentional injuries.

For the registered mortality that presented missing data in the variables of department of residence (1.2 percent), age and sex (<0.3 percent), and an imputation of data was made with the machine learning methodology with non-parametric models of random forest classification with the missForest package (Stekhoven and Buhlmann 2012) of the programming language R version 4.2.3 (Rstudio Team 2020). Regarding mortality projections, given that the information provided by DANE is in specific rates for simple ages, with the population projections of the same entity for each year and simple age, the number of deaths was calculated, multiplying the specific rate by the projected population for each year, department, and age. Subsequently, deaths were grouped by five-year period and by sex.

Population data by department were also obtained from the projections of the 2018 DANE Population and Housing Census (National Administrative Department of Statistics (DANE) 2022).

Estimation of Disease Burden Attributable to Suboptimal Temperatures

It builds on GBD's approach to the other approaches reviewed without dismissing the criticisms made in this regard by other research groups in environmental epidemiology. Some critics suggest underestimation of the effects because the analysis does not take into account: (i) temperature delays, (ii) seasonality, and (iii) mortality displacement (Vicedo-Cabrera et al. 2022). However, the authors mention that, although this may be a limitation, the study has the strength of examining the relationship of temperature with different causes of death, including injuries from external causes, something that had not previously been evaluated in other studies (Burkart et al. 2022).

The relative risks (RR) and their uncertainty intervals were estimated by means of a derivation of the exposure-response curves provided by the GBD, which used a Bayesian regression model that allows for the reproduction the patterns of the nonlinear curves. For the calculation of the burden of disease attributable to suboptimal temperature, the comparative risk assessment approach was used. In this way, the Theoretical Thresholds of Minimum Exposure to the Risk Factor (UTEMFR or TMREL) specific for Colombia were set, which are the counterfactual level of exposure associated with the lower burden of disease of the events included in the analysis, which were extrapolated from the exposure response curves previously calculated by the GBD for suboptimal temperature.

Each of the days was classified as an effect of heat or cold according to whether the average daily temperature for the pixel exceeded the TMREL of the specific climate zone.

From the daily temperature of each of the pixels of 0.25 degrees (30 km) they were assigned an RR according to the climatic zone of each pixel (average annual temperature) using the response exposure curves. Subsequently, the Population Attributable Fraction (PAF) was estimated for each pixel and day of the time series following Burkhart's methodology (Burkart et al. 2021).

$$PAF_{cztd} = \frac{RR_{czt} - 1}{RR_{czt}}$$

Where *c* is the cause of death, *z* is the climatic zone (mean annual temperature), *t* is the average daily temperature for a specific pixel, and day *d*. Population-weighted means were then calculated for each day in department *l*.

$$PAF_{cld} = \sum_{p=1}^{n} pop_{ply}/pop_{ly} \cdot PAF_{cztd}$$

Subsequently, the summary exposure values (SEVs) were established as a measure of the weighted prevalence of risk, being 0 percent the situation in which there is no risk and 100 percent the situation where the entire population is exposed to the maximum level of the risk factor (RR_{max}).

$$SEV_{czly} = \frac{\sum_{t=t_{min_{zly}}}^{t_{max_{zly}}} pop_{ztly}/pop_{zly} \bullet (RR_{czt} - 1)}{RR_{max_{cz}}}$$

Where t is the average daily temperature, $t_{min_{zly}}$ and $t_{max_{zly}}$ are the minimum and maximum daily temperatures observed in department l, zone z, and year y. Subsequently, the values of SEV by department, cause of death, and year were obtained as the average of the specific SEVs of zone weighted by population.

Finally, the number of daily deaths was computed as follows:

$$N\,l\,d\,c = PAF_{cld} * Muertes_{cld}$$

Where l is the department, d is the specific day, c is the cause of death.

Finally, the years of life potentially lost due to premature death (YLL) were obtained from life expectancy using as a reference the standardized life tables of DANE by department, grouped by five-year groups. People whose permanent places of residence were abroad were not considered within the estimate. To avoid overestimating the loss, a mid-period correction was made: that is, in any age range it is assumed that death occurred on average in the middle of the period, except in people over 80, for whom the assumption is assumed that they lose 10 years, given the wider range than in the other groups. The calculation of YLL with the mid-cycle correction is explained as follows:

$$YLL = \sum_{j=1}^{n} d_j \times (evr_j - Cm)$$

Where:

d_j = deaths

evr_j = difference between the age at which death occurred and life expectancy for each age group

Cm = mid-period correction (to avoid overestimating the loss, assuming that in any age range death occurred in the middle of the period).

This analysis plan was discussed and validated with a panel of experts from the National Health Observatory of the National Institute of Health of Colombia, and with the Global Burden of Disease by Temperature group of the University of Washington-Seattle.

From this analysis, mortality, and YLL rates attributable to suboptimal temperature were obtained by cause of death, department, sex, age group, and year, with their respective 95 percent confidence intervals taking into account a Poisson probability distribution.

Since only mortality was used, the years of life potentially lost due to premature death (YPLL) were the same as the YLLs. We used only the term YLL, and not YPLL for clarity.

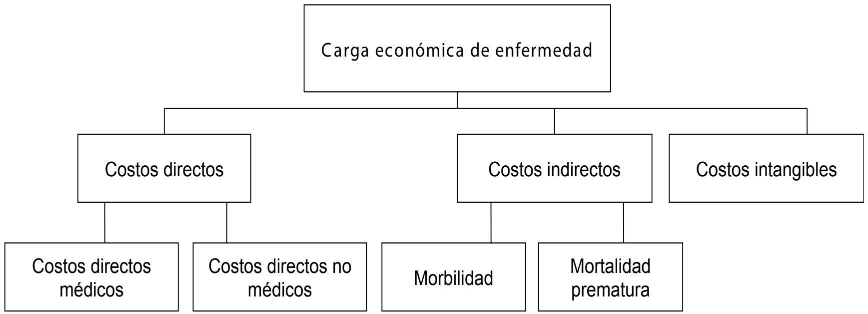
Economic Burden Attributable to Suboptimal Temperatures

Conceptual Framework

The economic burden of any disease is measured in three cost domains: direct costs, indirect costs, and psychosocial costs, also called intangible costs (Alvis-Zakzuk et al. 2022; Pisu et al. 2010). Description studies and cost analysis basically estimate direct and indirect costs. The former are divided into direct medical costs and direct non-medical costs. Direct medical costs assess the use of health care resources due to the disease, in outpatients or hospitalized, analyzing items such as hospital stay, medications, and consultations, among other items that generate costs (Alvis-Zakzuk et al. 2022; Pisu et al. 2010).

On the other hand, direct non-medical costs support the disease care process, but are not “directly” related to it. Among these types of costs are out-of-pocket expenses triggered by the disease and borne by the patient or their family members (Alvis-Zakzuk et al. 2022; Pisu et al. 2010). Indirect costs are associated with productivity losses due to illness or premature death; from the economic point of view, it can be assumed that employment is a resource of great value for the individual and society, so that illness causes a loss of working time, temporary or permanent (Alvis-Zakzuk et al. 2022; Pisu et al. 2010). Psychosocial costs refer to the loss of quality of life linked to having an illness; these types of costs are difficult to quantify and the methods for estimating them are not clearly standardized (Alvis-Zakzuk et al. 2022; Pisu et al. 2010).

Figure A1.5. Cost Taxonomy for Estimating the Economic Burden of Disease



Rational and Analysis

Current studies on the monetization of health risks caused by environmental problems consist of the estimation of indirect costs due to morbidity and mortality or the valuation of the intangible costs of disease.

As for the calculation of indirect costs, these can be estimated by means of two main methods:

1. The human capital method, which estimates the loss of productivity due to morbidity and mortality taking into account the valuation of the reduction of working hours (level of production) as an effect of the disease (future earnings potentially lost) (Drummond 1992); and

2. The friction costs method: This approximation values the time invested by companies in the search and training (called friction time) of a worker who performs the activities of the sick employee, whenever such replacement is necessary (cost of replacing the absent worker) (Koopmanschap et al. 1995), the indirect cost of the disease would then be the multiplication of the frequency and duration of the friction period by the market value of the production (Ripari et al. 2012).

On the other hand, intangible costs have been estimated mainly by means of the declared preference method, which estimates preferences based on the *individual's willingness-to-pay* under different scenarios, through contingent valuation or overall analysis (Ripari et al. 2012).

This study based the calculation of indirect costs on the modified human capital method, which then refers to the capital embodied in workers, considering GDP per capita as a statistical contribution of the year of life to society, which differs from the traditional human capital approach, which considers the contribution of the labor force to the socio-economy from the perspective of society as a whole (Chen et al. 2022).

The human capital approach estimates the loss due to premature mortality from YLL onwards. This method measures the number of years between the event of death and the years the individual would have lived taking into account the specific life expectancy. In addition, YLL can be converted into potential years of working life lost or productive years of potentially lost life (PYPLL), calculated from the difference between the age of death of the individual and the age at which he or she would cease to be part of the labor force (retirement age). These years are adjusted according to the unemployment rate of the labor market being valued with the average gross market wage or average per capita productivity.

In this sense, the calculations of indirect mortality costs involve the application of average earnings to lost work years for people who were employed, the assignment of a value to domestic services for those who cannot perform these services due to illness, and the application of labor force participation rates (Rice et al. 1985).

Finally, the indirect costs of premature mortality (ICPM) were calculated as follows:

$$ICPM = \textit{Annual minimun wage or GDPpc} * PYPLL$$

The PYPLL was valued taking into account the productive time period of people in Colombia, ranging from 15 to 57 years for women and up to 62 for men. The age of onset was defined as that age from which it can be defined as economically active population (EAP) that also had an employment rate reported in the register of employment evolution in the DANE.

The calculation of the PYPLL and the cost thereof shall be estimated taking into account the following formula:

$$PYPLL = \sum (Ep - iEl) * m$$

Where:

PYPLL = productive years of life potentially lost by age group

Ep = pension age (according to sex of the individual)

MS = age of death (adjusted for half a period)

iEI = Working age of onset of the age group of death that will depend on the age of death of the individual (MS) and the start of participation in the labour market in this way:

If ≤ 15 (minimum age for entry into the labour market) then iEI = 15,

Si em>15 entonces iEI = *iEgm*

iEgm = Age of onset of the mid-cycle adjusted age group of death (added for age groups 2.5)

m = number of deaths observed in each age group i

In the age groups with initial age below the age of initiation of participation in the labor market, the age of onset for loss of productivity was attributed to the working age of initiation (15 years) and its loss was calculated until the corresponding pension age.

In the valuation of the economic burden associated with suboptimal temperatures, the average wage or productivity was estimated in two ways, as follows:

1. Annual minimum wage (AMW), which was calculated taking as reference the legal minimum wage in force in Colombia for 2021 estimated at COP 12,179,760 (Ministry of Labor 2021).

2. Average productivity of the country evaluated as the gross domestic product per capita (GDPpc) of 2021, valued at COP 22,952,795 (Banco de la República – Colombia 2021).

These two scenarios of analysis allowed to obtain a range where the valuation of the loss of productivity due to premature deaths due to suboptimal temperatures would move. Additionally, costs were adjusted to an average annual growth rate (*g*) and a discount rate (*r*) of 5 percent according to the following formula:

$$ICPM_t^{death} = \sum_{i=15}^{Ep-t} \frac{\frac{GDPpc}{AMW} * (1+g)^i}{(1+r)^i}$$

The estimates were discriminated by age groups, departments, and causes. The capital district was included as a departmental unit because of the relative weight of its population. Thus, costs were reported with and without discount for each economic valuation scenario.

Methodology of Descriptive Analysis of Temperature and Demographic Structure

The temperature projections used by the CCKP (Climate Change Knowledge Portal) of the World Bank were used, which has temperature data with annual averages by department according to five different scenarios of greenhouse gas emissions contemplated in the Shared Socioeconomic Trajectories (SSP) prepared by the IPCC (Table 2). The change of these temperatures was estimated for 2050 and 2100, according to these different emission scenarios. Additionally, DANE post-COVID population projections by department with data to 2050, by age groups and sex, were used.

Different types of models were tested for mortality rates attributable to heat and cold by department and year, finally defining the following linear model:

$$TM_{yl} = \alpha + \beta_1 * \mathrm{t} + \beta_2 * l + \beta_3 * y$$

Where *TM* is the annual attributable mortality rate for heat or cold, is the αintersect, the coefficient, βt the average annual temperature, *l* the department, and the year.

These models were used to project mortality rates with annual temperatures from different climate change scenarios from 2020 to 2050, later adding to have national rates. They were then computed with population projections to obtain the number of deaths attributable to heat or cold, and then the respective attributable YLL.

To calculate the health co-benefits from greenhouse gas mitigation, the different disease burden indicators between climate change scenarios were compared, especially between SSP1–1.9 and SSP5-8.5, as well as the differences between 2020 and 2050. Additionally, the trends in rates attributable to heat and cold between 2020 and 2050 were analyzed, as well as the magnitudes of the rates in the different scenarios.

B. Results Attachments

Description of Temperatures and Demographic Structure in Colombia

Table A1.5. Descriptive Statistics Temperature by Department in Colombia 2010–2019

Department	Pixel*day (n)	Minimum value	Maximum value	Average (SD)	Mediana (IQR)
Amazon	519,436	19.39	31.87	25.31 (±1.02)	25.29 (1.33)
Antioquia	307,272	14.37	37.49	23.34 (±3.73)	23.84 (6.82)
Arauca	113,398	10.43	33.79	25.46 (±3.53)	26.24 (2.36)
San Andrés, Providencia and Santa Catalina Archipelago	3,652	24.12	28.91	25.85 (±0.69)	26.88 (0.95)
Atlantic	18,290	23.88	35.57	27.99 (±1.02)	27.95 (1.39)
Bogotá D.C.	10,974	7.24	23.08	13.08 (±2.52)	13.46 (4.44)
Bolívar	135,346	19.87	36.38	27.16 (±2.12)	27.40 (2.75)
Boyacá	117,056	7.08	38.62	15.39 (±4.55)	14.00 (4.46)
Caldas	36,580	12.65	37.10	19.98 (±4.47)	18.50 (6.35)

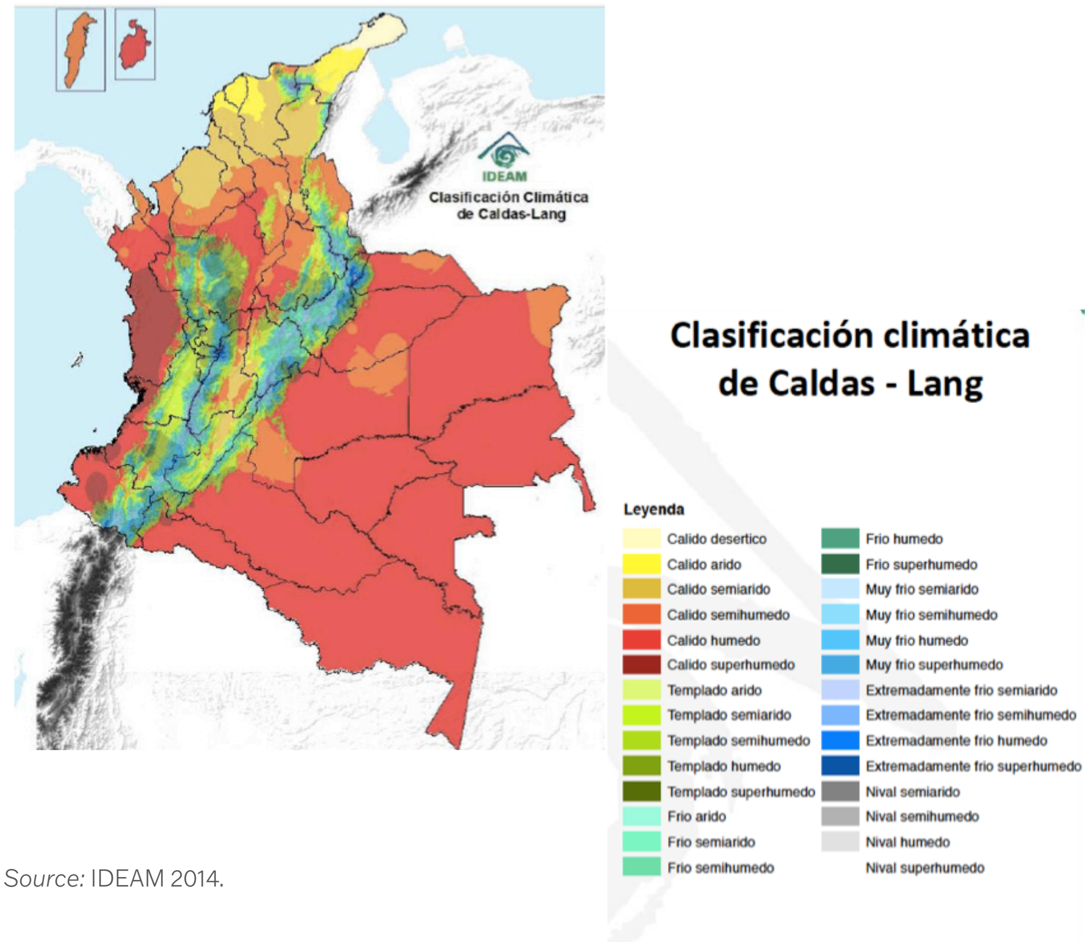
Department	Pixel*day (n)	Minimum value	Maximum value	Average (SD)	Mediana (IQR)
Caquetá	446,276	14.66	34.23	24.56 (±1.98)	24.81 (1.79)
Casanare	219,480	15.13	34.87	26.08 (±2.31)	26.29 (2.19)
Cauca	149,978	9.27	29.34	18.99 (±4.06)	18.95 (5.84)
Cesar	120,714	12.65	38.39	26.02 (±3.23)	26.27 (3.90)
Chocó	237,770	16.89	32.07	25.77 (±1.98)	26.15 (1.75)
Córdoba	120,714	19.59	33.90	27.36 (1.71)	27.48 (1.78)
Cundinamarca	102,424	8.47	36.20	18.26 (±4.94)	17.56 (8.03)
Guainía	325,562	20.41	32.02	25.35 (±1.03)	25.29 (1.33)
Guaviare	263,376	20.23	34.07	24.86 (±1.12)	24.81 (1.39)
Huila	87,792	8.76	33.19	19.32 (±3.67)	19.21 (4.19)
La Guajira	106,082	13.96	34.78	26.52 (±2.75)	27.01 (3.18)
Magdalena	113,398	10.66	38.10	26.29 (±4.21)	27.52 (4.19)
Meta	384,090	8.02	35.36	24.81 (±2.91)	25.31 (2.11)
Nariño	142,662	7.69	28.60	21.06 (±4.96)	22.26 (8.56)

Department	Pixel*day (n)	Minimum value	Maximum value	Average (SD)	Mediana (IQR)
Norte de Santander	106,082	8.67	35.51	21.81 (±4.75)	22.56 (6.80)
Putumayo	117,056	10.26	31.93	24.02 (±3.29)	24.92 (2.09)
Quindío	7,316	12.84	23.42	16.87 (±1.48)	16.79 (2.49)
Risaralda	21,948	12.41	24.83	18.88 (±2.15)	19.47 (1.56)
Santander	139,004	10.04	37.90	22.19 (±4.98)	22.12 (8.93)
Sugar	43,896	24.40	34.66	28.18 (±1.26)	28.03 (1.63)
Tolima	117,056	11.26	35.35	20.89 (±4.83)	21.56 (8.95)
Valle del Cauca	95,108	10.93	28.51	21.08 (±3.05)	20.99 (3.77)
Vaupés	256,060	20.01	32.08	24.94 (±0.99)	24.92 (1.28)
Vichada	479,198	20.75	33.99	26.15 (±1.44)	26.00 (1.76)

Source: European Centre for Medium-Range Weather Forecasts n.d.

Note: ICR = XXX; n = XX; SD = XX

Figure A1.6. Caldas-Lang Colombia Index (IDEAM)



Source: IDEAM 2014.

Figure A1.7. Monthly Temperature Behavior by Regions in Colombia

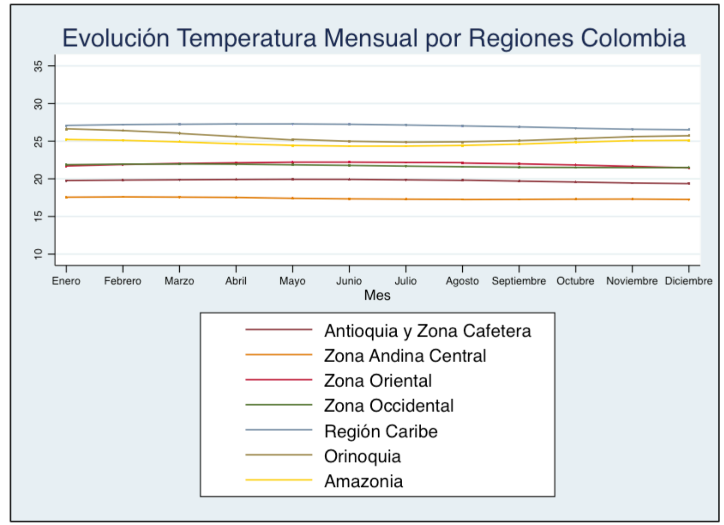


Table A1.6. Linear Regression Temperature Evolution by Year and Department, Colombia 2010–2019

Department	r^2	Beta coefficient	IC 95%	Temperature variation ºC/ decade
Amazon	0.0002	-0.004	(-0.014;0.006)	-0.04 ºC
Antioquia	0.0809	0.088*	(0.079;0.098)	+0.88ºC
Arauca	0.0008	0.012	(-0.001;0.026)	+0.12ºC
San Andrés, P. and ST.	0.0150	0.029*	(0.022;0.037)	+0.29ºC
Atlantic	0.0452	0.065*	(0.055;0.075)	+0.65ºC
Bogotá D.C.	0.0034	0.013*	(0.006;0.021)	+0.13ºC
Bolívar	0.0663	0.105*	(0.092–0.118)	+1.05ºC
Boyacá	0.0038	0.013*	(0.006;0.021)	+0.13ºC
Caldas	0.0860	0.088*	(0.079;0.097)	+0.88ºC
Caquetá	0.0003	0.006	(-0.005;0.019)	+0.06ºC
Casanare	0.0072	0.040*	(0.025;0.056)	+0.40ºC
Cauca	0.0798	0.058*	(0.051;0.064)	+0.58ºC
Cesar	0.0455	0.090*	(0.077;0.104)	+0.9ºC
Chocó	0.0599	0.069*	(0.060;0.078)	+0.69ºC
Córdoba	0.0645	0.088*	(0.077;0.098)	+0.88ºC
Cundinamarca	0.0298	0.040*	(0.033;0.048)	+0.40ºC
Guainía	0.0021	0.015*	(0.004;0.025)	+0.15ºC
Guaviare	0.0019	0.015*	(0.004;0.027)	+0.15ºC
Huila	0.0302	0.048*	(0.039;0.057)	+0.48ºC

Department	r^2	Beta coefficient	IC 95%	Temperature variation ºC/ decade
La Guajira	0.0033	0.021*	(0.009;0.033)	+0.21ºC
Magdalena	0.0848	0.112*	(0.100;0.124)	+1.12ºC
Meta	0.0016	0.017*	(0.003;0.031)	+0.17ºC
Nariño	0.1026	0.064*	(0.058;0.071)	+0.64ºC
Norte de Santander	0.0047	0.023*	(0.012;0.035)	+0.23ºC
Putumayo	0.0013	0.013*	(0.001;0.026)	+0.13ºC
Quindío	0.0367	0.052*	(0.043;0.061)	+0.52ºC
Risaralda	0.0406	0.047*	(0.039;0.054)	+0.47ºC
Santander	0.0855	0.092*	(0.082;0.102)	+0.92ºC
Sugar	0.0498	0.089*	(0.076;0.101)	+0.89ºC
Tolima	0.0966	0.102*	(0.092;0.113)	+1.02ºC
Valle del Cauca	0.0734	0.061*	(0.054;0.068)	+0.61ºC
Vaupés	0.0006	0.007	(-0.002;0.018)	+0.07ºC
Vichada	0.0056	0.030*	(0.017;0.044)	+0.30ºC

*Statistically significant values

A Temperature Sensitivity Analysis with Fixed Monitoring Data

The analysis included stations that brought together different environmental characteristics of Colombia: four stations in the Andean region (Bogotá, Soacha, Medellín and Bucaramanga), two in the Pacific region (Quibdó and Cali), two in the Caribbean region (Barranquilla and Cartagena) and two in the Orinoco-Amazonas region (Villavicencio and Leticia).

Table A1.7. Overview of Monitoring Stations 10 Cities in Colombia

Station	City	Geographical coordinates (latitude, longitude)	Altitude (masl)
Botanical garden	Bogotá	(4.66933333 -74.10266667)	2.552
Olaya Herrera Airport	Medellin	(6.22000000 -75.59000000)	1.490
Marco Fidel Suarez Air Base	Cali	(3.45450000 -76.49972222)	975
Ernesto Cortissoz	Solitude/ Barranquilla	(10.91777778 -74.77972222	14
Rafael Núñez Airport	Cartagena	(10.44725 -75.51602778)	2
San Jorge Granja	Soacha	(4.50575 -74.18927778	2.900
El Carano	Quibdo	(5.69055556 -76.64377778)	75
Leticia	Leticia	(-4.22252778 -69.94272222)	120
Palonegro Airport	Bucaramanga	(7.12147222 -73.18452778)	1.189
Vanguard	Villavicencio	(4.16191944 -73.61757778)	422

Only in six of the 10 selected monitoring stations, the representativeness of the daily temperature data is less than 75 percent (Medellín, Cali, Barranquilla, Cartagena, Quibdó, and Leticia). Likewise, the table presents the extreme values identified by the interquartile range method (IQR method).

Table A1.8. Data Representativeness Monitoring Stations 10 Cities Colombia 2010–2019

City	Representativity	Lower extreme values (Q1–1,5*IQR)	Higher extreme values (Q3+1,5*IQR)
Bogotá	32% (1,199/3,652)	1	2
Medellin	99% (3,640/3,652)	0	0
Cali	85% (3,123/3,652)	1	28
Solitude/ Barranquilla	77% (2,839/3,652)	45	3
Cartagena	95% (3,463/3,652)	7	0
Soacha	60% (2,205/3,652)	13	25
Quibdo	99% (3,603/3,652)	2	11
Leticia	84% (3,071/3,652)	62	3
Bucaramanga	42% (1,552/3,652)	13	21
Villavicencio	21% (764/3,652)	0	7

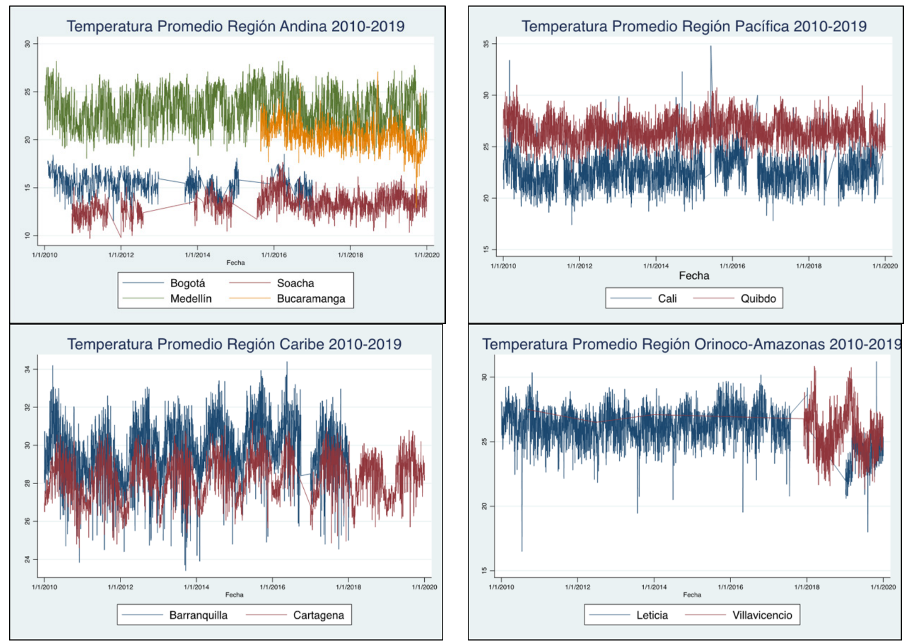
The average temperature during the period analyzed is relatively consistent with the geographical characteristics of each city, being lower in the city of higher altitude (Soacha) and higher in the lower-altitude city (Barranquilla). It should be noted that the average temperature in Cali is somewhat low, which is atypical in relation to cities at the same altitude and may be due to a greater impact on the temperature of the El Niño Southern Oscillation phenomenon, due to its location near the Pacific coast, but this is an event that needs to be evaluated in more detail. The following table presents the summary statistics for each station.

Table A1.9. Measures of Central Tendency and Variability Monthly Average Temperature Monitoring Stations 10 Cities in Colombia 2010–2019

City	Minimum value	Maximum value	Average (SD)	Mediana (IQR)
Bogotá	11.53	18.5	15.33 (±1.06)	15.4 (1.46)
Medellin	18.05	28.22	23.3 (±1.88)	23.3 (3.01)
Cali	17.4	34.8	22.5 (±1.56)	22.5 (2.1)
Solitude/ Barranquilla	23.4	34.4	29.7 (±1.56)	29.8 (2.03)
Cartagena	24.6	31.35	28.3 (±1.09)	28.4 (1.65)
Soacha	9.7	17.65	13.3 (±1.10)	13.3 (1.4)
Quibdo	22.5	31	26.6 (±1.25)	26.6 (1.75)
Leticia	16.5	31.2	26.08 (±1.50)	26.2 (1.85)
Bucaramanga	12.9	27.1	20.4 (±1.27)	20.5 (1.5)
Villavicencio	21.3	30.8	25.7 (±1.74)	25.8 (2.25)

The following figures show the time series according to the four characteristic regions of the country (Figure A1.8). For the Andean region, the city of Medellín is the only one that has a wide representation of the series during the period analyzed. The other three cities have important time jumps and do not allow to determine the trends of the series (Figure A1.8).

Figure A1.8. Average Temperature by Colombian Regions, 2010–2019



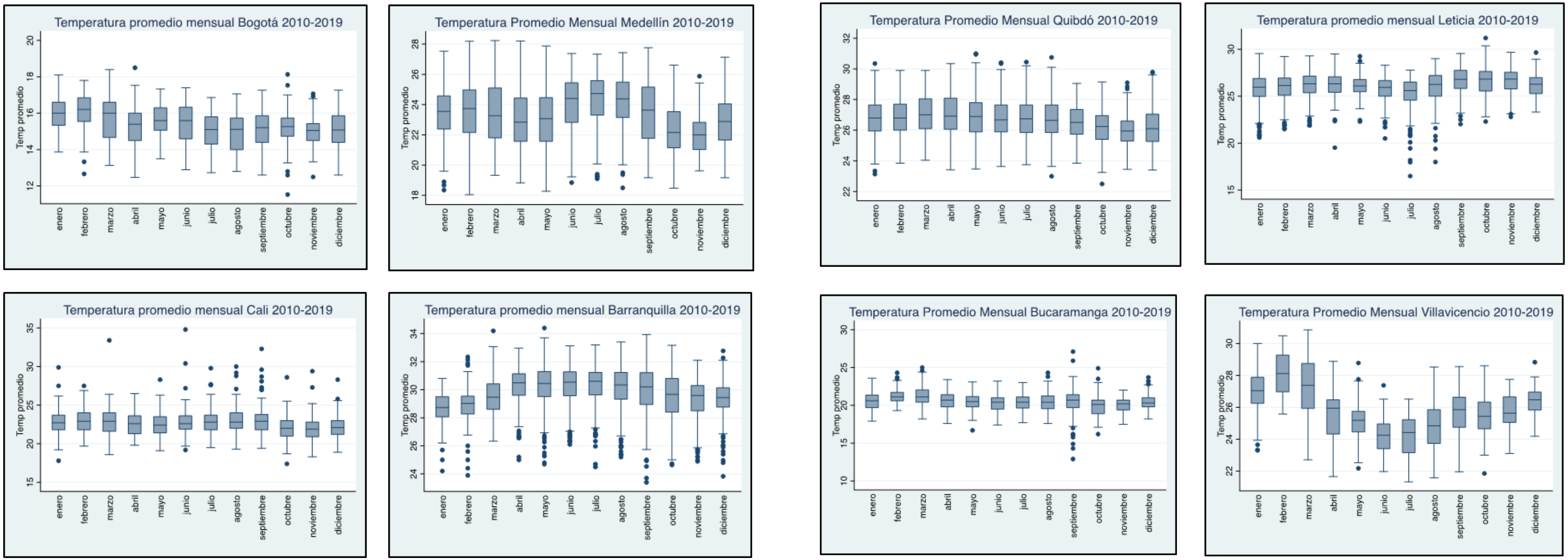
In the Pacific region, there are two cities that have adequate representation. In analyzing the series, several outliers were observed in Cali throughout the period (Figure A1.8).

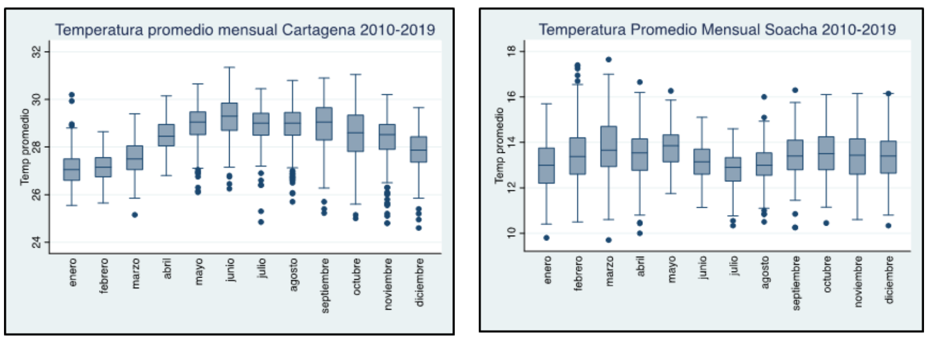
For the Caribbean region, Cartagena has greater representativeness with respect to Barranquilla, although both have sufficient daily data for subsequent studies (>70 percent). Barranquilla has no data for 2019.

With respect to the Orinoco-Amazonas region, Villavicencio has the least data of all the cities analyzed, unlike Leticia, which has a relatively constant series throughout the analyzed period (Figure A1.8). Likewise, it shows several low temperature peaks during the analyzed period that seem to coincide with the winter of the southern cone of the continent and sometimes with the phenomenon known as the "frosts of Brazil" which affects the climate of the southern Colombian Amazon.

By representing monthly average temperature trends, patterns are identified at the regional level. In the case of the Caribbean region, the temperature is lower in the first quarter of the year, as observed in Barranquilla and Cartagena. In the Andean region, there are some trends associated with the effect of the Intertropical Confluence Zone. In Medellín there is a lower temperature in the last quarter of the year and higher temperatures for the period from June to August. On the other hand, Soacha has the lowest temperatures during that period (June–August) and in Bogotá, D.C. and Bucaramanga there are no marked differences throughout the year, although this may also be due to the low representativeness of the series. In the Pacific region, there are no significant differences throughout the year, while in the Orinoco-Amazon region, Leticia has the lowest temperatures during the year in the months of June, July, and August, and a high number of extreme values during those months (Figure A1.9).

Figure A1.9. Average Monthly Temperature by Colombian Cities, 2010–2019





For the analysis of annual temperature trends, stations with at least 60 percent of the data and at least 90 percent of the years represented were taken into account. An increase was observed in almost all cities during the last 10 years, except in Leticia, where the temperature dropped by an average of 1.6ºC. Likewise, Soacha had a more pronounced increase of 1.3ºC, followed by Barranquilla (+1ºC) and Cali (+0.6ºC). The results of the analysis are presented in Table A1.10.

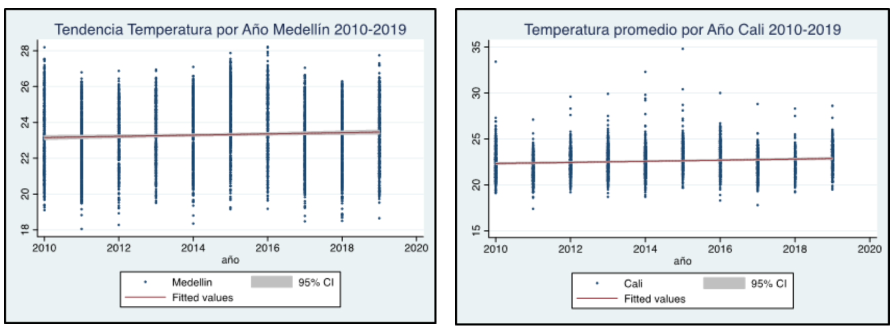
Table A1.10. Linear Regression Temperature Evolution by Year Colombia 2010–2019

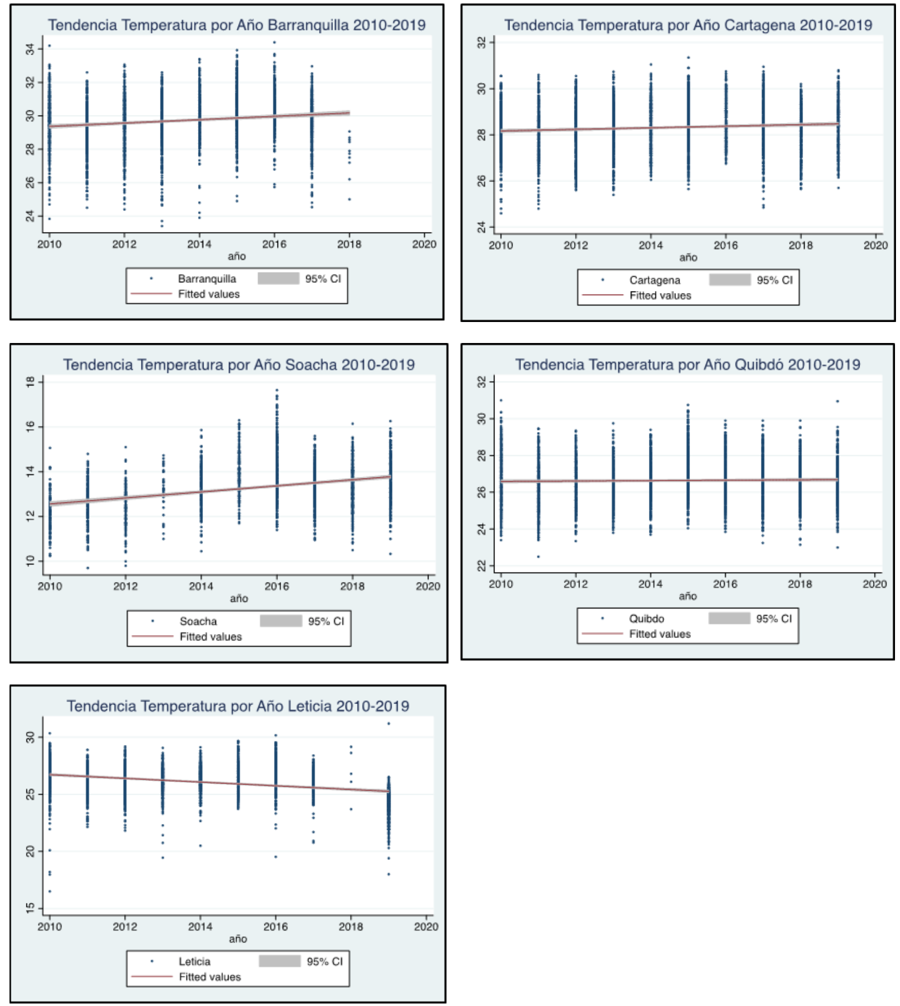
City	Obs (n)	r^2	Beta Coefficient	IC9s5%	Variation T (ºC)/ decade
Medellin	3640	0,0026	0,0033	(0,012; 0,054)*	+0.03ºC
Cali	3123	0,0119	0,0601	(0,040; 0,079)*	+0.6ºC
Barranquilla	2839	0,0217	0,1004	(0,075; 0,125)*	+1.0ºC
Cartagena	3463	0,0082	0,0339	(0,021; 0,046)*	+0.33ºC
Soacha	2205	0,1126	0,1351	(0,119; 0,151)*	+1.3ºC
Quibdo	3603	0,0006	0,0106	(-0,003; 0,025)	ON
Leticia	3071	0,0888	-0,1624	(-0,180; -0,143)*	-1.6ºC

* Statistically significant values

The above results are indicative, since complete series are not required and the time series includes exclusively the years 2010 to 2019. Figure A1.10 shows the trends.

Figure A1.10. Temperature Trends by Cities of Colombia for 2010–2019

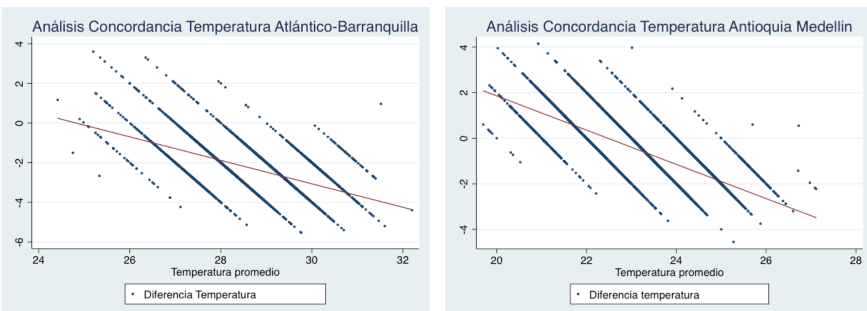


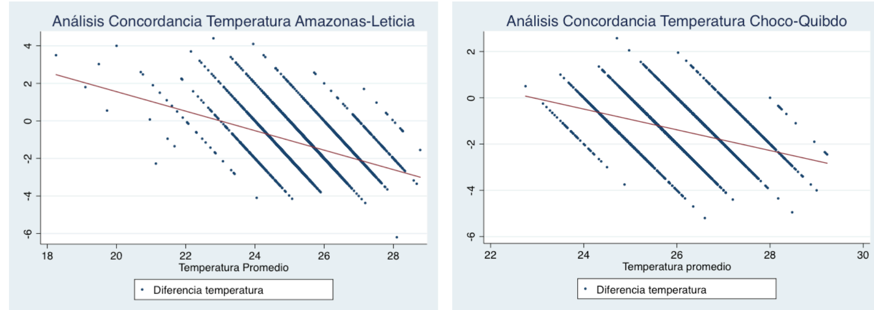


Analysis of agreement between satellite and monitoring station temperatures

In relation to the evaluation of the agreement between satellite temperatures and urban temperatures of the monitoring networks, initially cities that had a representativeness greater than 60 percent (n = 7) were included. These were matched with the departments to which they belong and the intraclass correlation coefficient (cci) was calculated; the only ones that had some degree of agreement were the Atlántico-Barranquilla pairs (cci=0.86; CI95%: 0.47–0.99), Antioquia-Medellín (cci=0.55; CI95%: 0.53–0.58), Amazonas-Leticia (cci=0.21; CI95%:0.17–0.24) and (ICC=0.11; CI95%:0.08–0.15). Figure A1.11 shows these correlations using Bland-Altman graphs.

Figure A1.11. Bland-Altman Graphs of Temperature by Department and Cities





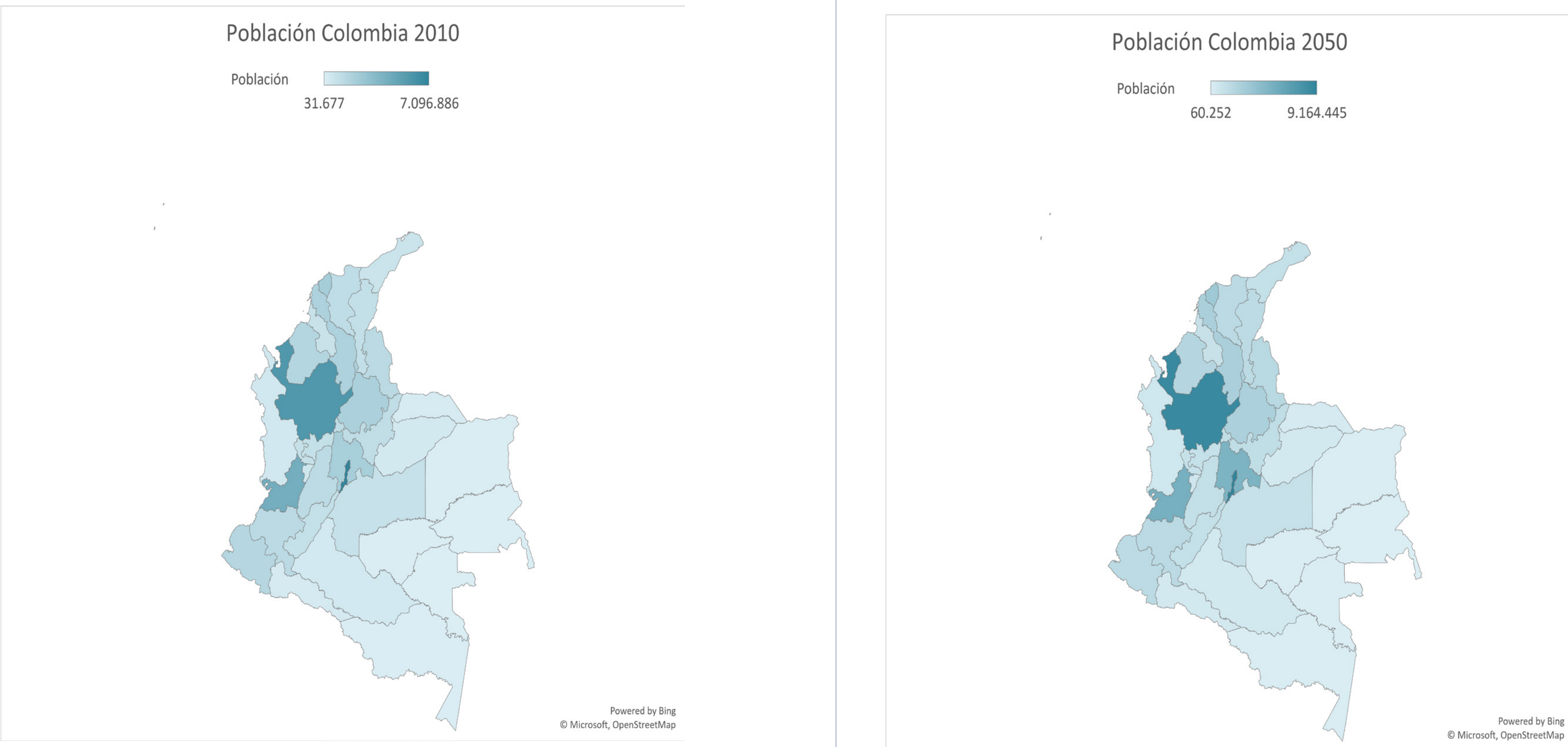
The main implication of this finding is the low reproducibility of the temperatures of the urban monitoring networks to be extrapolated to the entire department. Only the temperature of the urban station of Barranquilla could be extrapolated to the temperature of the Atlantic, although with high uncertainty. As a consequence of the low reproducibility, the use of satellite temperatures was recommended for the calculation of the burden of disease attributable to suboptimal temperatures in the departments of Colombia.

Annex to the description of the demographic structure

Table A1.11. Description of Mortality by the 17 Causes Covered by the Study

Variable	Category	N = 884,628
Year	2010	82,795 (9.36%)
	2011	79,920 (9.03%)
	2012	82,004 (9.27%)
	2013	83,669 (9.46%)
	2014	85,836 (9.7%)
	2015	89,931 (10.17%)
	2016	91,128 (10.3%)
	2017	92,908 (10.5%)
	2018	97,821 (11.06%)
	2019	98,616 (11.15%)
Sex	F	336,637 (38.05%)
	M	547,991 (61.95%)
Age	<5	5,164 (0.58%)
	5–14	6,638 (0.75%)
	15–49	210,512 (23.8%)
	50–69	179,673 (20.31%)
	70+	482,641 (54.56%)
Department	Antioquia	131,618 (14.88%)
	Bogotá, D. C.	116,664 (13.19%)
	Valle Del Cauca	111,383 (12.59%)
	Cundinamarca	51,390 (5.81%)
	Atlantic	40,655 (4.6%)
	Santander	39,691 (4.49%)
	Tolima	38,426 (4.34%)
Department	Norte De Santander	28,484 (3.22%)
	Nariño	28,352 (3.2%)
	Boyacá	26,570 (3%)
	Córdoba	25,679 (2.9%)
	Bolívar	25,553 (2.89%)
	Caldas	24,915 (2.82%)
	Cauca	23,563 (2.66%)
	Risaralda	23,120 (2.61%)
	Huila	22,466 (2.54%)
	Magdalena	19,991 (2.26%)
	Meta	19,781 (2.24%)
	Quindío	15,843 (1.79%)
	Cesar	15,481 (1.75%)
	Sugar	14,454 (1.3%)
	Caquetá	7,399 (0.84%)
	La Guajira	6,797 (0.77%)
	Putumayo	5,322 (0.6%)
	Arauca	5,034 (0.57%)
	Casanare	4,943 (0.56%)
	Chocó	4,725 (0.53%)
	Foreigner	2,083 (0.24%)
	San Andres	1,287 (0.15%)
	Guaviare	1.192 (0.13%)
Department	Vichada	632 (0.07%)
	Amazon	517 (0.06%)
	Vaupés	322 (0.04%)
	Guainía	296 (0.03%)
Cause of death	Ischemic heart disease	348,530 (39.4%)
	Homicide	138,266 (15.63%)
	EPOC	126,978 (14.35%)
	ACV	69,491 (7.86%)
	ERC	52,925 (5.98%)
	Traffic accidents	52,372 (5.92%)
	Hypertensive heart disease	33,753 (3.82%)
	Suicide	23,632 (2.67%)
	DM	15,432 (1.74%)
	Drowning	8,214 (0.93%)
	Mechanical injuries	3,526 (0.4%)
	IVRI	3,139 (0.35%)
	Unintentional	2,857 (0.32%)
	Disasters	2,178 (0.25%)
	Related animals	1,247 (0.14%)
	Cardiomyopathy myocarditis	1,226 (0.14%)
	Transport relationship	862 (0.1%)

Figure A1.12. Departmental Concentration of the Colombian Population 2010–2050



Source: DANE post-Covid population projections 2022.

Burden of Disease by Suboptimal Temperatures

In relation to the abolition frequency of YLL associated with suboptimal temperature by department, the predominant causes in the departments with greater exposure to heat are homicide, traffic accidents, and drowning. COPD and stroke are mainly seen in the departments most exposed to cold. Ischemic heart disease occurs from double exposure, but has a greater impact on departments exposed to cold. Some departments have events that do not follow the regional/national pattern. In that regard, it is worth highlighting the impact of suicide in Vaupés and diabetes mellitus in the archipelago of San Andrés, Providencia, and Santa Catalina. The following table presents the relevant data (Table A1.12).

Table A1.12. Main Suboptimal Temperature Events, Exposure by Department

Department	Total YLL (n)	Outcome 1 YLL (n)	Outcome 2 YLL (n)	Outcome 3 YLL (n)
Amazonas	77.24	Homicide 22.33	Suicide 21.86	Drowning 14.57
Antioquia	25,562.88	IHD 9,056.64	Homicide 5,165.78	COPD 3,853.99
Arauca	1,567.58	Homicide 680.35	Road traffic accident 331.70	IHD 181.42

Department	Total YLL (n)	Outcome 1 AVPP (n)	Outcome 2 AVPP (n)	Outcome 3 AVPP (n)
Archipiélago San Andres Providencia y Sta Catalina	112.69	Homicide 61.13	Road traffic accident 35.83	Diabetes mellitus 4.42
Atlántico	9843.30	Homicide 4,849.98	IHD 2,017.96	Road traffic accident 1,094.91
Bogotá DC	20,173.93	IHD 9,039,35	COPD 4,394.34	Stroke 2,719.45
Bolívar	8,107,54	Homicide 3,897. 90	IHD 1,419.12	Road traffic accident 1074.73
Boyacá	4,892.53	IHD 1,812.41	COPD 1,229.96	Stroke 577.31
Caldas	4,570.78	IHD 2,264.47	COPD 779.52	Homicide 382.50
Caquetá	1,489.30	Homicide 440.41	IHD 331.29	Drowning 232.97
Casanare	1,454.99	Road traffic accident 453.84	Homicide 294.94	IHD 231.25
Cauca	3,939.95	IHD 1,581.46	COPD 499.27	Homicide 436.83
Cesar	5,166.23	Homicide 1,656.39	Road traffic accident 1,230.99	IHD 1,030.81

Department	Total YLL (n)	Outcome 1 AVPP (n)	Outcome 2 AVPP (n)	Outcome 3 AVPP (n)
Chocó	888.74	Homicide 543.27	Drowning 89.25	IHD 72.52
Córdoba	7,695.41	Homicide 3,722.56	IHD 1,299.18	Road traffic accident 1,228.20
Cundinamarca	9,131.69	IHD 4,343.24	COPD 2,003.92	Stroke 926.66
Guainía	44.26	Drowning 15.30	Homicide 6.64	IHD 5.83
Guaviare	269.04	Homicide 106.17	Drowning 70.80	IHD 30.98
Huila	3,971.59	IHD 1,510.95	Homicide 486.31	Drowning 430.60
La Guajira	3,391.90	Homicide 1,910.95	Road traffic accident 553.29	IHD 371.32
Magdalena	4,181.07	Homicide 1,896.14	IHD 760.33	Road traffic accident 707.10
Meta	3,694.04	IHD 1,002.78	Homicide 790.47	Road traffic accident 495.69
Nariño	3,855.70	IHD 1,262.86	COPD 681.90	Stroke 470.89
Norte de Santander	6,570.85	Homicide 2,389.20	IHD 1,565.85	Road traffic accident 718.45

Department	Total YLL (n)	Outcome 1 AVPP (n)	Outcome 2 AVPP (n)	Outcome 3 AVPP (n)
Putumayo	1,050.56	Homicide 329.71	IHD 174.30	Drowning 148.29
Quindío	2,805.62	IHD 1,412.30	COPD 580.64	Stroke 242.22
Risaralda	3,882.69	IHD 1,882.39	COPD 672.99	Homicide 305.67
Santander	7,474.42	IHD 3,070.49	COPD 783.33	Homicide 770.35
Sucre	4,431.72	Homicide 1,514.45	IHD 1,097.19	Road traffic accident 838.65
Tolima	6,998.75	IHD 3,302.55	COPD 796,06	Homicide 772,26
Valle	15,329.05	IHD 6,150.11	Homicide 3,178.91	COPD 1,487.26
Vaupés	75.16	Drowning 35.16	Suicide 20.62	Homicide 5.48
Vichada	168.37	Homicide 59.58	Road traffic accident 47.31	IHD 19.92

Table A1.13. Burden of Disease Attributable to Heat, by Department Colombia 2010–2019

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Amazonas	0.41 (0.33–0.49)	2	2.91 (2.20–3.74)	72.48	9.85 (8.52–11.32)
Antioquia	0.12 (0.12–0.13)	172	2,82 (2.11–3.63)	5070,46	8,41 (7.17–9.77)
Arauca	0.023 (0.021–0.024)	41	16.47 (14.72–18.32)	1,370.42	55.40 (52.18–58.76)
Archipiélago San Andres Providencia y Sta Catalina	0.24 (0.20–0.27)	3	5.42 (4.47–6.57)	111.13	18.40 (16.56–20.37)
Atlántico	1.03 (1.00–1.05)	388	16.09 (14.38–17.95)	9,732.86	40.70 (37.95–43.59)
Bogotá DC	0	0	0	0	0
Bolívar	1.16 (1.13–1.19)	295	14.64 (13.02–16.42)	7,926.31	39.48 (36.79–42,35)
Boyacá	0.13 (0.13–0.14)	36	3.03 (2.33–3.91)	663.02	5.55 (4.56–6.68)
Caldas	0.12 (0.11–0.12)	28	2.82 (2.15–3.69)	643.68	6.60 (5.52–7.82)
Caquetá	0.23 (0.21–0.24)	18	4.40 (3.52–5.42)	626.56	15.59 (13.91–17.43)
Casanare	0.56 (0.53–0.59)	28	7.13 (6.02–8.42)	994.67	24.93 (22.80–27.23)
Cauca	0.006 (0.005–0.006)	1	0.09 (0.01–0.36)	46.42	0.32 (0.14–0.72)

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Cesar	0.96 (0.93–0.98)	149	13.25 (11.70–14.94)	4,108.46	36.64 (34.04–39.40)
Chocó	0.39 (0.36–0.41)	20	3.93 (3.12–4.92)	749.77	15.03 (13.39–16.84)
Córdoba	1.12 (1.09–1.16)	288	16.69 (14.95–18.59)	7,607.20	44.18 (41.33–47.21)
Cundinamarca	0.013 (0.013–0.014)	6	0.21 (0.05–0.51)	149.74	0.59 (0.31–1.04)
Guainía	0.31 (0.21–0.41)	1	2.03 (1.47–2.78)	37.55	8.51 (7.27–9.87)
Guaviare	0.42 (0.35–0.49)	5	6.55 (5.47–7.77)	212.72	26.09 (23.90–28.43)
Huila	0.12 (0.12–0.13)	24	2.30 (1.68–3.06)	808.75	7.65 (6.48–8.96)
La Guajira	1.44 (1.39–1.49)	102	12.75 (11.23–14.41)	3,211.30	40.57 (37.85–43.49)
Magdalena	0.79 (0.77–0.81)	151	11.86 (10.38–13.45)	4,003.60	31.47 (29.08–34.05)
Meta	0.26 (0.25–0.27)	48	4.90 (3.97–5.97)	1,530.59	15.63 (13.96–17.48)
Nariño	0.047 (0.046–0.049)	13	0.81 (0.45–1.29)	414.33	2.60 (1.94–3.40)
Norte de Santander	0.50 (0.48–0.51)	132	9.36 (8.05–10.79)	3,966.58	28.15 (25.87–30.57)

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Putumayo	0.24 (0.22–0.26)	13	3.94 (3.12–4.92)	501.70	15.38 (13.72–17.21)
Quindío	0	0	0	0	0
Risaralda	0.0003 (-0.0001;0.0008)	1	0.005 (0–0.18)	1.95	0.02 (0–0.18)
Santander	0.21 (0.21–0.22)	82	3.86 (3.03–4.81)	1,873.45	8.90 (7.64–10.30)
Sucre	1.31 (1.27–1.36)	186	21.17 (19.18–23.26)	4,374.51	49.80 (46.75–52.99)
Tolima	0.21 (0.20–0.22)	67	5.08 (4.15–6.19)	1,675.31	12.71 (11.18–14.36)
Valle	0.023 (0.023–0.024)	26	0.59 (0.31–1.04)	849.20	1.99 (1.42–2.72)
Vaupés	0.46 (0.31–0.60)	2	4.27 (3.43–5.31)	63.13	17.00 (15.24–18.90)
Vichada	0.85 (0.72–0.98)	5	5.23 (4.29–6.35)	158,67	15.52 (13.86–17.37)
Amazonas	0.41 (0.33–0.49)	2	2.91 (2.20–3.74)	72.48	9.85 (8.52–11.32)
Antioquia	0.12 (0.12–0.13)	172	2.82 (2.11–3.63)	5,070.46	8.41 (7.17–9.77)
Arauca	0.023 (0.021–0.024)	41	16.47 (14.72–18.32)	1,370.42	55.40 (52.18–58.76)
Archipiélago San Andres Providencia y Sta Catalina	0.24 (0.20–0.27)	3	5.42 (4.47–6.57)	111.13	18.40 (16.56–20.37)

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Atlántico	1.03 (1.00–1.05)	388	16.09 (14.38–17.95)	9,732.86	40.70 (37.95–43.59)
Bogotá DC	0	0	0	0	0
Bolívar	1.16 (1.13–1.19)	295	14.64 (13.02–16.42)	7,926.31	39.48 (36.79–42.35)
Boyacá	0.13 (0.13–0.14)	36	3.03 (2.33–3.91)	663.02	5.55 (4.56–6.68)
Caldas	0.12 (0.11–0.12)	28	2.82 (2.15–3.69)	643.68	6.60 (5.52–7.82)
Caquetá	0.23 (0.21–0.24)	18	4.40 (3.52–5.42)	626.56	15.59 (13.91–17.43)
Casanare	0.56 (0.53–0.59)	28	7.13 (6.02–8.42)	994.67	24.93 (22.80–27.23)
Cauca	0.006 (0.005–0.006)	1	0.09 (0.01–0.36)	46.42	0.32 (0.14–0.72)
Cesar	0.96 (0.93–0.98)	149	13.25 (11.70–14.94)	4,108.46	36.64 (34.04–39.40)
Chocó	0,39 (0,36–0,41)	20	3,93 (3,12–4,92)	749,77	15,03 (13.39–16.84)
Córdoba	1.12 (1.09–1.16)	288	16.69 (14.95–18.59)	7,607,20	44.18 (41.33–47.21)
Cundinamarca	0.013 (0.013–0.014)	6	0.21 (0.05–0.51)	149.74	0.59 (0.31–1.04)
Guainía	0.31 (0.21–0.41)	1	2.03 (1.47–2.78)	37.55	8.51 (7.27–9.87)
Guaviare	0,42 (0,35–0,49)	5	6,55 (5,47–7,77)	212,72	26,09 (23,90–28,43)

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Huila	0.12 (0.12–0.13)	24	2.30 (1.68–3.06)	808,75	7,65 (6,48–8,96)
La Guajira	1.44 (1.39–1.49)	102	12.75 (11.23–14.41)	3,211.30	40.57 (37.85–43.49)
Magdalena	0.79 (0.77–0.81)	151	11.86 (10.38–13.45)	4,003.60	31.47 (29.08–34.05)
Meta	0.26 (0.25–0.27)	48	4.90 (3.97–5.97)	1,530.59	15.63 (13.96–17.48)
Nariño	0.047 (0.046–0.049)	13	0.81 (0.45–1.29)	414.33	2.s60 (1.94–3.40)
Norte de Santander	0.50 (0.48–0.51)	132	9.36 (8.05–10.79)	3,966.58	28.15 (25.87–30.57)
Putumayo	0.24 (0.22–0.26)	13	3.94 (3.12–4.92)	501.70	15.38 (13.72–17.21)
Quindío	0	0	0	0	0
Risaralda	0.0003 (-0.0001;0.0008)	1	0.005 (0–0.18)	1.95	0.02 (0–0.18)
Santander	0.21 (0.21–0.22)	82	3.86 (3.03–4.81)	1,873.45	8.90 (7.64–10.30)
Sucre	1.31 (1.27–1.36)	186	21.17 (19.18–23.26)	4,374.51	49.80 (46.75–52.99)
Tolima	0.21 (0.20–0.22)	67	5.08 (4.15–6.19)	1,675.31	12.71 (11.18–14.36)
Valle	0.023 (0.023–0.024)	26	0.59 (0.31–1.04)	849.20	1.99 (1.42–2.72)
Vaupés	0.46 (0.31–0.60)	2	4.27 (3.43–5.31)	63.13	17.00 (15.24–18.90)

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Vichada	0.85 (0.72–0.98)	5	5.23 (4.29–6.35)	158.67	15.52 (13.86–17.37)

Table A1.14. Burden of Disease Attributable to Cold, by Department Colombia 2010–2019

Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Amazonas	0.06 (0.02–0.09)	1	0.43 (0.20–0.85)	4.76	0.65 (0.57–1.48)
Antioquia	0.87 (0.86–0.89)	1278	20.96 (18.99–23.05)	20,492.42	33.75 (31.25–36.39)
Arauca	0.23 (0.22–0.25)	12	4.75 (3.84–5.80)	197.15	8.08 (6.90–9.44)
Archipiélago San Andres Providencia and Sta Catalina	0.008 (0.0009–0.015)	1	0.16 (0.03–0.43)	1.56	0.25 (0.08–0.58)
Atlántico	0.011 (0.009–0.014)	8	0.33 (0.14–0.72)	110.43	0.46 (0.20–0.85)
Bogotá DC	1.00 (0.98–1.01)	1,407	19.34 (17.46–21.37)	20,173.93	27.80 (25.53–30.20)
Bolívar	0.036 (0.0033–0.039)	11	0.56 (0.27–0.98)	181.22	0.90 (0.53–1.42)
Boyacá	1.07 (1.06–1.09)	313	26.28 (24.10–28.64)	4,229.51	35.50 (32.93–38.21)
Caldas	0.98 (0.96–1.00)	275	27.89 (25.63–30.31)	3,927.09	39.94 (37.22–42.81)
Caquetá	0.66 (0.64–0.69)	49	12.17 (10.71–13.83)	862.74	21.58 (19.61–23.73)
Casanare	0.47 (0.45–0.49)	24	5.93 (4.92–7.12)	460.31	11.58 (10.15–13.19)
Cauca	0.99 (0.97–1.00)	233	16.46 (14.72–18.32)	3,893.52	26.36 (24.14–28.6)
Cesar	0.36 (0.35–0.37)	60	5.36 (4.38–6.46)	1,057.77	9.47 (8.19–10.95)
Chocó	0.12 (0.11–0.13)	6	1.15 (0.72–1.72)	138.96	2.77 (2.11–3.63)
Córdoba	0.016 (0.013–0.018)	5	0.31 (0.11–0.65)	88.20	0.51 (0.23–0.91)
Cundinamarca	1.07 (1.05–1.08)	641	25.44 (23.28–27.76)	8,981.94	35.72 (33.12–38.41)
Guainía	0.14 (0.08–0.19)	1	0.93 (0.57–1.48)	6.70	1.50 (1.01–2.14)
Guaviare	0.29 (0.25–0.33)	3	4.18 (3.35–5.19)	56.31	7.01 (5.88–8.26)
Huila	0.87 (0.85–0.88)	213	20.13 (18.23–22.21)	3,162.84	29.98 (27.64–32.49)
La Guajira	0.13 (0.12–0.14)	9	1.16 (0.72–1.72)	180.60	2.27 (1.68–3.06)

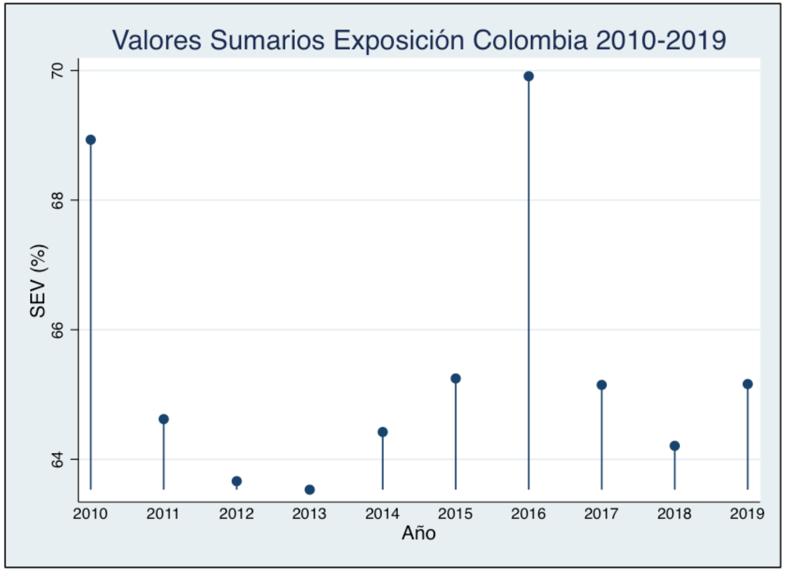
Department	PAF % (CI 95%)	Attributable deaths (n)	Attributable Rate per 1,000,000 n (CI 95%)	YLL (n)	YLL per 100.000 n (CI 95%)
Magdalena	0.046 (0.043–0.049)	11	0.84 (0.49–1.36)	177.47	1.38 (0.93–2.02)
Meta	0.59 (0.58–0.61)	127	12.94 (11.42–14.62)	2,163.44	22.01 (19.99–24.15)
Nariño	0.78 (0.77–0.80)	230	14.32 (12.69–16.05)	3,441.36	21.47 (19.46–23.57)
Norte de Santander	0.53 (0.52–0.59)	170	11.96 (10.48–13.56)	2,604.27	18.31 (16.47–20.27)
Putumayo	0.57 (0.54–0.60)	28	8.52 (7.31–9.93)	548.85	16.70 (14.95–18.59)
Quindío	1.15 (1.12–1.17)	196	37.45 (34.81–40.23)	2,805.62	53.60 (50.43–56.90)
Risaralda	0.99 (0.97–1.01)	255	27.70 (25.44–30.10)	3,880.73	42.28 (39.49–45.24)
Santander	0.81 (0.79–0.82)	364	17.38 (15.61–19.32)	5,600.96	26.77 (24.53–29.11)
Sucre	0.023 (0.018–0.027)	4	0.48 (0.23–0.91)	57.21	0.66 (0.34–1.11)
Tolima	0.82 (0.81–0.83)	375	28.39 (26.11–30.83)	5,323.44	40.34 (37.61–43.23)
Valle	0.76 (0.75–0.77)	830	19.00 (17.13–21.00)	14,479.85	33.33 (30.86–35.97)
Vaupés	0.19 (0.13–0.25)	1	1.58 (1.09–2.25)	12.03	3.21 (2.46–4.08)
Vichada	0.10 (0.06–0.14)	1	0.67 (0.38–1.17)	9.69	0.96 (0.57–1.48)

Summary Exposure Values (SEV)

Summary exposure values (SEVs) are used to capture the prevalence of risk-weighted exposure. This indicator is interpreted as the percentage of the population that is exposed to a maximum risk and goes from a range of 0–100 percent, where 0 percent implies that there is no exposure to the risk factor and 100 percent is when the entire population is completely exposed to this same factor.

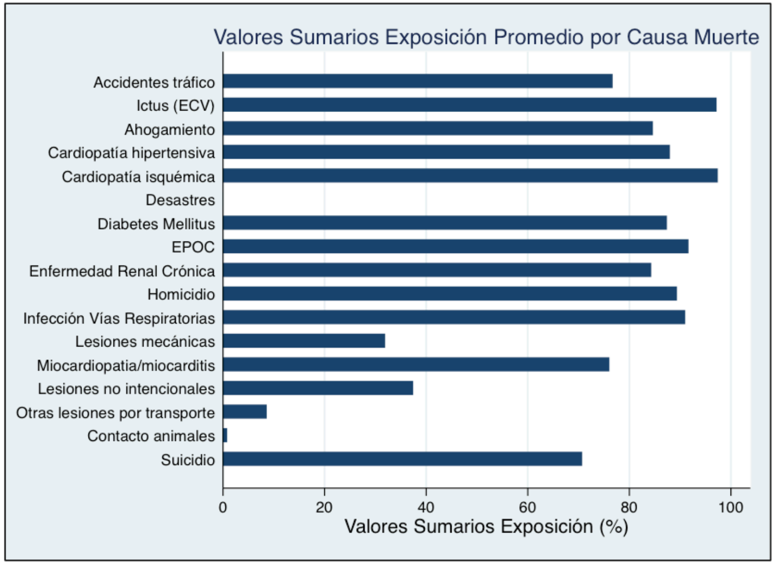
The average value of the SEV for all causes in Colombia is 65.4 percent (CI95: 63.9–57.0 percent), with the years 2010 and 2016 being where the highest values were presented. The following figure shows the evolution of SEVs during the period 2010–2019.

Figure A1.13. Evolution of Summary Exposure Values (SEV) in Colombia 2010–2019



The five main causes of SVS in Colombia are ischemic heart disease (97 percent), stroke-cerebrovascular disease (97 percent), chronic obstructive pulmonary disease (COPD) (92 percent), homicides (89 percent) and hypertensive heart disease (88 percent). The complete distribution of SEVs is shown in the following figure.

Figure A1.14. Average SEV by Cause of Death



With regard to the distribution by regions, in the region of Antioquia and the Coffee Axis, the department of Antioquia has the highest percentage of SEV (66 percent) followed by Risaralda (65 percent). The predominant causes are ischemic heart disease (99.9 percent), stroke (99.8 percent), and COPD (99.7 percent).

The department with the highest percentage of SEV in the Central Andean Zone is Tolima (64 percent), followed by Huila (63 percent) and Cundinamarca (57 percent). The causes with a higher proportion of SEVs are ischemic heart disease (99.6 percent), stroke (99.1 percent) and drowning (98.8 percent) (Table A1.15).

Table A1.15. Summary Exposure Values Antioquia Exhibition and Coffee Axis 2010–2019

Cause of death	Antioquia	Caldas	Quindío	Risaralda
Traffic accident	49%	36%	12%	98%
Stroke (cerebrovascular disease)	100%	100%	100%	100%
Drowning	96%	95%	100%	100%
Hypertensive heart disease	99%	100%	100%	100%
Ischemic heart disease	100%	100%	100%	100%
Disasters	0.05%	0.02%	0%	0%
Diabetes mellitus	98%	100%	100%	100%
EPOC	99%	100%	100%	100%
Chronic kidney disease	98%	100%	100%	100%
Homicide	99%	67%	94%	91%
Lower respiratory infection	99%	100%	100%	100%
Mechanical injuries	11%	10%	0.3%	0.3%
Cardiomyopathy	95%	92%	100%	67%
Unintentional injuries	34%	13%	21%	17%
Other transportation-related injuries	3%	1%	0%	0.01%
Contact with animals	0.4%	0.06%	0%	0%
Suicide	39%	19%	0.8%	32%
Total SEV	66%	61%	61%	65%

Table A1.16. Summary Exposure Values Central Andean Zone Exhibition 2010–2019

Cause of death	Bogotá	Boyacá	Cundinamarca	Huila	Tolima
Traffic accident	0.1%	11%	14%	68%	60%
ACV	100%	100%	100%	98%	98%
Drowning	100%	99%	100%	100%	96%
Hypertensive heart disease	100%	100%	99%	85%	88%
Ischemic heart disease	100%	100%	100%	99%	99%
Disasters	0%	0.002%	0%	0.003%	0.02%
Diabetes mellitus	100%	100%	99%	83%	86%
EPOC	100%	100%	99%	91%	92%
Chronic kidney disease	100%	100%	99%	81%	84%
Homicide	46%	29%	40%	95%	93%
Lower respiratory infection	100%	100%	100%	88%	90%
Mechanical injuries	0.3%	4%	1.6%	8%	17%
Cardiomyopathy	100%	97%	95%	71%	73%
Unintentional injuries	12%	6%	8%	49%	47%
Other transportation-related injuries	0%	3%	0.5%	5%	7%
Contact with animals	0%	0.02%	0.14%	0.5%	1%
Suicide	0.17%	9%	11%	54%	58%
Total SEV	56%	56%	57%	63%	64%

In the Eastern Zone, Norte de Santander has the highest proportion of SEVS (74 percent), where the main causes of SVS are ischemic heart disease (99.8 percent), cerebrovascular disease (99.7 percent), and COPD (98.6 percent) (Table A1.17).

Table A1.17. Summary Exposure Values Exhibition Eastern Zone 2010–2019

Cause of death	Norte de Santander	Santander
Traffic accident	91%	56%
Stroke (cerebrovascular disease)	100%	100%
Drowning	97%	96%
Hypertensive heart disease	96%	99%
Ischemic heart disease	100%	100%
Disasters	0.07%	0%
Diabetes mellitus	96%	99%
EPOC	98%	99%
Chronic kidney disease	95%	99%
Homicide	93%	94%
Lower respiratory infection	98%	99%
Mechanical injuries	54%	14%
Cardiomyopathy	83%	71%
Unintentional injuries	58%	24%
Other transportation-related injuries	7%	5%
Contact with animals	0.4%	0.06%
Suicide	89%	53%
Total SEV	74%	65%

Chocó is the department in the Western Zone with the highest proportion of SEV (72 percent), followed by Valle (34 percent). Stroke is the cause that has the greatest impact (98.6 percent), followed by drowning (98.3 percent) and ischemic heart disease (97.9 percent) (Table A1.18).

Table A1.18. Summary Exposure Values Western Zone Exhibition 2010–2019

Cause of death	Cauca	Chocó	Nariño	Valley
Traffic accident	44%	100%	33%	97%
Stroke (cerebrovascular disease)	99%	98%	98%	99%
Drowning	100%	97%	98%	99%
Hypertensive heart disease	99%	96%	97%	97%
Ischemic heart disease	100%	98%	96%	98%
Disasters	0.01%	0%	0%	0%
Diabetes mellitus	98%	96%	96%	97%
EPOC	99%	97%	97%	97%
Chronic kidney disease	98%	96%	87%	96%
Homicide	82%	100%	46%	97%
Lower respiratory infection	99%	97%	97%	98%
Mechanical injuries	0.2%	32%	0.08%	0.2%
Cardiomyopathy	96%	89%	90%	43%
Unintentional injuries	22%	31%	6%	30%
Other transportation-related injuries	0.1%	1%	0.03%	0.4%
Contact with animals	0.09%	0.2%	0%	0.001%
Suicide	28%	98%	28%	83%
Total SEV	62%	72%	57%	67%

In the Caribbean region, the departments of Magdalena (74 percent), Bolívar (73 percent), and Sucre (73 percent) have the highest percentage of SEV. Among the causes, those with the highest proportion are homicides (99.9 percent), followed by traffic accidents (99.6 percent) and stroke (99.4 percent) (Table A1.19).

Table A1.19. Summary Exposure Values Exhibition Caribbean Region 2010–2019

Cause of death	Atlantic	Bolívar	Cesar	Córdoba	Guajira	Magdalena	Sugar	San Andres
Traffic accident	100%	100%	98%	100%	100%	100%	100%	100%
Stroke (cerebrovascular disease)	100%	100%	98%	100%	98%	100%	100%	100%
Drowning	16%	25%	84%	22%	47%	59%	21%	49%
Hypertensive heart disease	100%	100%	86%	99%	94%	100%	100%	92%
Ischemic heart disease	100%	100%	100%	100%	98%	100%	100%	88%
Disasters	0%	0%	0%	0%	0.01%	0%	0%	0%
Diabetes mellitus	100%	99%	82%	99%	93%	100%	100%	100%
EPOC	100%	100%	92%	99%	95%	100%	100%	93%
Chronic kidney disease	100%	99%	75%	99%	91%	100%	100%	81%
Homicide	100%	100%	100%	100%	100%	100%	100%	100%
Lower respiratory infection	100%	100%	90%	99%	95%	100%	100%	100%
Mechanical injuries	97%	96%	44%	96%	75%	78%	98%	4%
Cardiomyopathy	100%	98%	54%	98%	82%	98%	100%	100%
Unintentional injuries	1.4%	8%	54%	5%	26%	10%	4%	0%
Other transportation-related injuries	1.8%	14%	27%	7%	8%	10%	17%	0%
Contact with animals	0%	0.03%	0.7%	0.01%	0.1%	0.004%	0%	0%
Suicide	100%	100%	98%	100%	100%	100%	100%	89%
Total SEV	71%	73%	70%	72%	71%	74%	73%	64%

In the Orinoquia, Vichada is the department with the highest proportion of SEV (77 percent), followed by Arauca (74 percent) and Casanare (72 percent). The causes of death with the highest percentage in this region are drowning (99.4 percent), homicides (99.1 percent) and traffic accidents (98.9 percent) (Table A1.20).

Table A1.20. Summary Exposure Values Orinoquia Exhibition 2010–2019

Cause of death	Meta	Arauca	Casanare	Guainía	Guaviare	Vichada
Traffic accident	98%	96%	99%	100%	100%	100%
Stroke (cerebrovascular disease)	98%	97%	99%	84%	88%	96%
Drowning	100%	99%	100%	100%	100%	98%
Hypertensive heart disease	90%	83%	76%	60%	35%	89%
Ischemic heart disease	98%	99%	99%	83%	93%	96%
Disasters	0.003%	0%	0%	0%	0.01%	0%
Diabetes mellitus	89%	82%	77%	59%	32%	89%
EPOC	93%	89%	85%	68%	56%	91%
Chronic kidney disease	82%	79%	71%	54%	22%	88%
Homicide	98%	98%	99%	100%	100%	100%
Lower respiratory nfection	93%	87%	86%	68%	51%	92%
Mechanical injuries	30%	65%	54%	17%	25%	74%
Cardiomyopathy	54%	76%	64%	52%	15%	87%
Unintentional injuries	70%	80%	85%	67%	93%	90%
Other transportation-related injuries	23%	31%	30%	6%	19%	21%
Contact with animals	3%	1%	6%	0.8%	4%	0.7%
Suicide	82%	93%	99%	100%	100%	100%
Total SEV	71%	74%	72%	60%	55%	77%

In the Amazon, the department with the greatest impact on SEVs is Caquetá (69 percent), followed by Amazonas (61.4 percent). Drowning (100 percent), homicides (97 percent), and traffic accidents (93 percent) are the causes of the highest proportion of SEV in this region (Table A1.21).

Table A1.21. Summary Exposure Values Amazon Exhibition 2010–2019

Cause of death	Caquetá	Putumayo	Amazon	Vaupés
Traffic accident	95%	78%	100%	100%
Stroke (cerebrovascular disease)	98%	95%	87%	80%
Drowning	100%	100%	100%	100%
Hypertensive heart disease	78%	73%	66%	29%
Ischemic heart disease	99%	99%	85%	89%
Disasters	0.02%	0%	0%	0.009%
Diabetes mellitus	78%	69%	67%	21%
EPOC	86%	82%	73%	53%
Chronic kidney disease	73%	61%	62%	13%
Homicide	100%	89%	100%	100%
Lower respiratory infection	85%	79%	73%	41%
Mechanical injuries	24%	9%	8%	4%
Cardiomyopathy	59%	45%	61%	5%
Unintentional injuries	79%	71%	61%	52%
Other transportation-related injuries	18%	9%	2%	5%
Contact with animals	4%	2%	0.3%	1%
Suicide	93%	78%	100%	100%
Total SEV	69%	61.1%	61.4%	46%

Economic Burden

Table A1.22. Productive Years of Life Potentially Lost and Total Economic Burden of the 17 Causes Studied and Attributable to Non-Optimal Temperatures in Colombia, 2001–2019

Cause of death	PYPLL		Economic burden*			
			Total		Attributable	
	Total	Attributable	Floor	Roof	Floor	Roof
Disasters	54,451	-	COP 663,253	COP 3,790,120	COP 0	COP 0
Related animals	18,324	1	COP 223,217	COP 1,183,982	COP 17	COP 144
Transport relationship	17,925	2	COP 218,338	COP 1,314,535	COP 20	COP 281
Unintentional	72,879	58	COP 887,697	COP 4,921,892	COP 704	COP 3,903
Mechanical injuries	18,938	190	COP 230,982	COP 655,107	COP 2,320	COP 6,442
Hypertensive heart disease	83,931	100	COP 1,022,366	COP 6,488,029	COP 1,221	COP 6,535
DM	32,316	426	COP 393,958	COP 1,620,653	COP 5,198	COP 20,214
Cardiomyopathy myocarditis	49,676	670	COP 606,098	COP 1,728,039	COP 8,179	COP 22,583
EPOC	21,744	268	COP 264,854	COP 2,210,132	COP 3,260	COP 24,148
ERC	128,455	1,097	COP 1,565,509	COP 6,949,491	COP 13,366	COP 59,770
IVRI	77,951	993	COP 949,473	COP 8,328,488	COP 12,098	COP 111,345
Suicide	226,682	2,494	COP 2,762,752	COP 11,939,556	COP 30,400	COP 128,361
ACV	590,855	1,810	COP 7,196,996	COP 45,388,635	COP 22,050	COP 144,120
Ischemic heart disease	480,269	5,789	COP 5,855,993	COP 16,410,362	COP 70,585	COP 200,936
Traffic accidents	1,153,960	8,172	COP 14,056,115	COP 95,189,802	COP 99,541	COP 592,761
Drowning	255,877	5,651	COP 3,116,638	COP 24,444,695	COP 68,827	COP 642,750
Homicide	4,009,688	25,166	COP 48,838,770	COP 290,078,534	COP 306,522	COP 1,554,702
Total	7,293,919	52,887	COP 88,853,010	COP 522,642,053	COP 644,308	COP 3,518,995

*Values in millions of Colombian pesos

Table A1.23. PYPLL and Economic Burden Attributable to Heat and Cold by Colombian Departments, 2010–2019, without Discount

Department	PYPLL		Economic burden			
			Cold		Heat	
	Cold	Heat	AMW	GDPpc	AMW	GDPpc
Antioquia	4,844	2,785	COP 59,024A	COP 323,780	COP 33,919	COP 209,557
Atlántico	14	4,431	COP 171	COP 516	COP 53,972	COP 248,708
Bogotá. D.c.	2,533	-	COP 30,874	COP 211,940	COP 0	COP 0
Bolívar	36	3,770	COP 440	COP 1,684	COP 45,919	COP 204,278
Boyacá	555	203	COP 6,760	COP 37,976	COP 2,478	COP 15,642

Department	PYPLL		Economic burden			
			Cold		Heat	
	Cold	Heat	AMW	GDPpc	AMW	PIBpc
Caldas	530	268	COP 6,460	COP 14,190	COP 3,268	COP 8,631
Caquetá	261	392	COP 3,176	COP 8,195	COP 4,774	COP 12,751
Cauca	950	27	COP 11,576	COP 44,569	COP 332	COP 1,392
Cesar	293	2,077	COP 3,572	COP 16,775	COP 25,305	COP 126,452
Córdoba	17	3,509	COP 210	COP 249	COP 42,740	COP 63,418
Cundinamarca	1,130	68	COP 13,777	COP 73,756	COP 826	COP 5,379
Chocó	52	466	COP 635	COP 847	COP 5,677	COP 7,624
Huila	664	473	COP 8,087	COP 18,603	COP 5,762	COP 14,408
La Guajira	64	1,907	COP 784	COP 1,687	COP 23,228	COP 51,250
Magdalena	41	1,953	COP 505	COP 1,021	COP 23,788	COP 53,256
Meta	549	862	COP 6,695	COP 340,666	COP 10,503	COP 588,896
Nariño	587	226	COP 7,153	COP 13,800	COP 2,753	COP 5,954
Norte De Santander	549	2,225	COP 6,685	COP 14,943	COP 27,106	COP 68,932
Quindío	464	-	COP 5,648	COP 16,067	COP 0	COP 0

Department	PYPLL		Economic burden			
			Cold		Heat	
	Cold	Heat	AMW	GDPpc	AMW	PIBpc
Risaralda	741	1	COP 9,034	COP 24,935	COP 12	COP 36
Santander	1,076	766	COP 13,112	COP 86,228	COP 9,334	COP 67,610
Sucre	7	1,803	COP 84	COP 139	COP 21,967	COP 56,360
Tolima	790	757	COP 9,628	COP 24,281	COP 9,219	COP 26,097
Valle Del Cauca	4,196	522	COP 51,119	COP 250,523	COP 6,361	COP 33,721
Arauca	49	814	COP 592	COP 1,028	COP 9,917	COP 17,086
Casanare	136	541	COP 1,661	COP 9,236	COP 6,591	COP 37,851
Putumayo	179	308	COP 2,185	COP 15,282	COP 3,749	COP 27,790
Archipiélago De San Andrés. Providencia Y Santa Catalina	0	69	COP 2	COP 5	COP 842	COP 5,626
Amazonas	1	43	COP 9	COP 26	COP 522	COP 1,226
Guainía	2	22	COP 21	COP 30	COP 274	COP 530
Guaviare	12	127	COP 150	COP 175	COP 1,547	COP 2,296
Vaupés	6	45	COP 69	COP 180	COP 551	COP 1,646
Vichada	2	95	COP 20	COP 16	COP 1,154	COP 1,247

Note: AMW = annual minimum wage; GDPpc = gross domestic product per capita

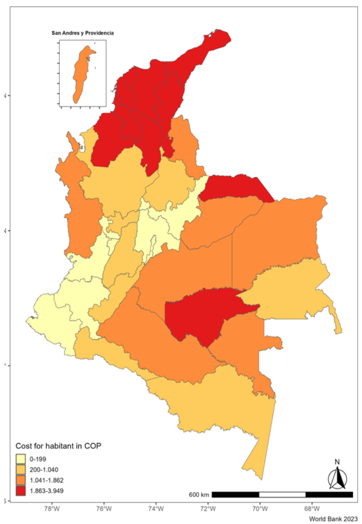
Table A1.24. Economic Burden Attributable to Heat and Cold by Colombian Departments, 2010–2019, with Discount

Department	Economic burden			
	Cold		Heat	
	AMW	GDPpc	AMW	GDPpc
Amazonas	COP 2.6	COP 4.0	COP 110.3	COP 207.1
Antioquia	COP 17,880.2	COP 67,620.2	COP 7,499.2	COP 37,879.2
Arauca	COP 183.2	COP 306.1	COP 2,098.7	COP 3,547.4
San Andrés, P y ST.	COP 1.5	COP 3.5	COP 188.9	COP 1,035.2
Atlántico	COP 69.4	COP 155.4	COP 12,798.4	COP 47,806.2
Bogotá	COP 11,733.7	COP 53,559.2	COP 0.0	COP 0.0
Bolívar	COP 145.9	COP 378.5	COP 10,638.5	COP 38,235.8
Boyacá	COP 2,376.8	COP 8,349.1	COP 668.0	COP 3,096.3
Caldas	COP 2,432.6	COP 3,951.1	COP 771.3	COP 1,698.1
Caquetá	COP 861.4	COP 1,553.1	COP 1,033.8	COP 2,262.3
Casanare	COP 461.6	COP 2,058.8	COP 1,511.0	COP 7,570.0
Cauca	COP 3,211.5	COP 8,360.1	COP 69.1	COP 237.9
Cesar	COP 1,018.2	COP 3,277.6	COP 5,897.7	COP 23,195.4
Chocó	COP 149.6	COP 164.4	COP 1,141.6	COP 1,384.0
Cundinamarca	COP 5,072.5	COP 17,164.4	COP 188.4	COP 966.3
Córdoba	COP 82.2	COP 79.1	COP 10,344.6	COP 13,324.1
Guainía	COP 5.6	COP 7.1	COP 48.1	COP 80.7
Guaviare	COP 63.1	COP 60.0	COP 346.6	COP 444.5
Huila	COP 2,354.9	COP 4,219.6	COP 1,194.8	COP 2,610.6
La Guajira	COP 207.7	COP 355.3	COP 5,206.4	COP 9,980.5
Magdalena	COP 166.4	COP 237.6	COP 5,660.7	COP 10,401.9
Meta	COP 1,960.5	COP 53,734.3	COP 2,322.0	COP 90,885.5
Nariño	COP 2,157.6	COP 2,934.3	COP 593.8	COP 1,079.6
Norte de Santander	COP 2,174.7	COP 3,426.0	COP 6,171.6	COP 13,165.6
Putumayo	COP 588.8	COP 2,633.1	COP 818.0	COP 4,644.5
Quindio	COP 2,024.7	COP 3,973.1	COP 0.0	COP 0.0
Risaralda	COP 2,963.4	COP 6,038.6	COP 3.0	COP 7.6
Santander	COP 4,097.5	COP 18,637.9	COP 2,245.6	COP 12,960.9
Sucre	COP 35.2	COP 44.3	COP 5,708.5	COP 11,336.1
Tolima	COP 3,296.9	COP 6,018.3	COP 2,186.4	COP 5,159.0
Valle del Cauca	COP 14,080.9	COP 50,799.2	COP 1,329.4	COP 5,916.4
Vaupés	COP 16.4	COP 29.7	COP 89.5	COP 237.0
Vichada	COP 9.7	COP 5.8	COP 288.2	COP 262.1

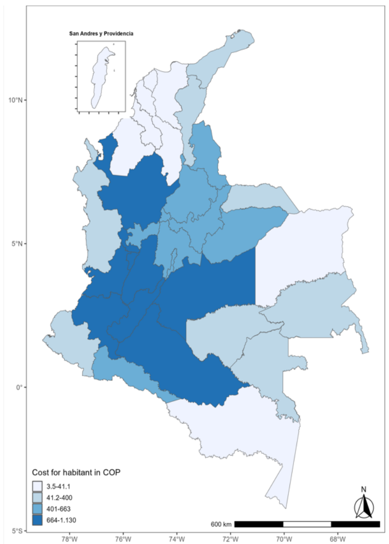
Note: Values in billion Colombian pesos; AMW = annual minimum wage; GDPpc = gross domestic product per capita

Figure A1.15. Indirect Costs per Capita Attributable to Suboptimal Temperatures in Colombia, 2010–2019: Scenario of Annual Minimum Wage (AMW) and GDP per Capita, without Discount

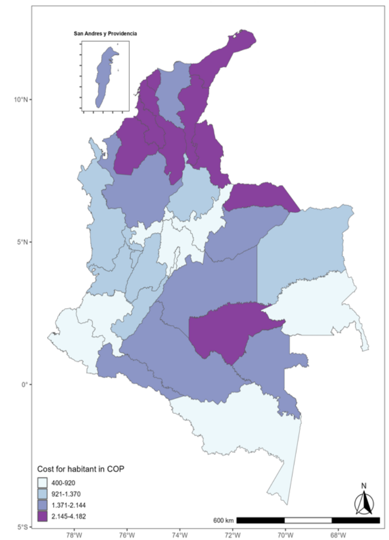
(A) AMW minimum wage for heat



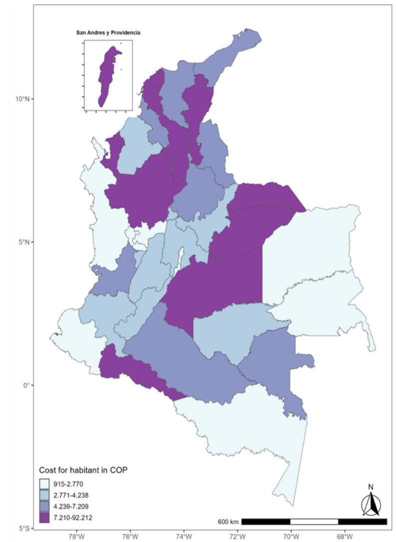
(B) AMW minimum wage for cold



(C) AMW minimum wage – suboptimal temperatures



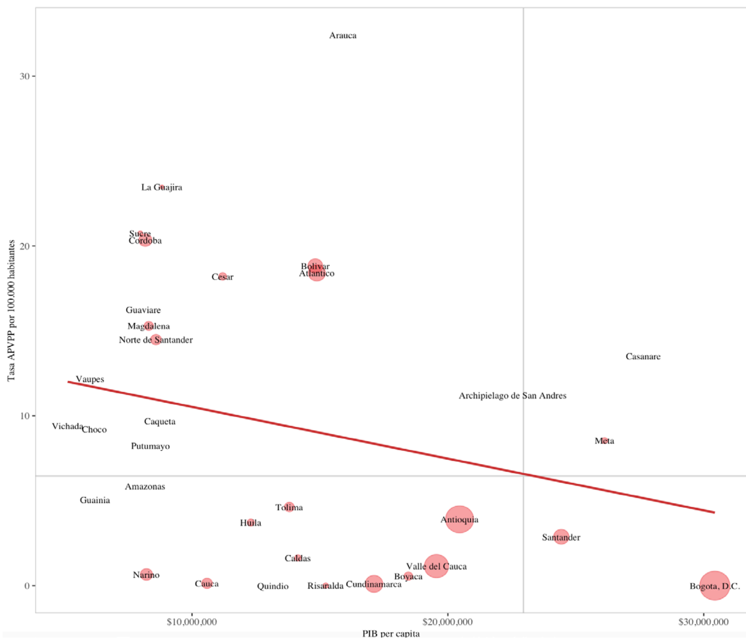
(C) GDPpc minimum suboptimal temperatures



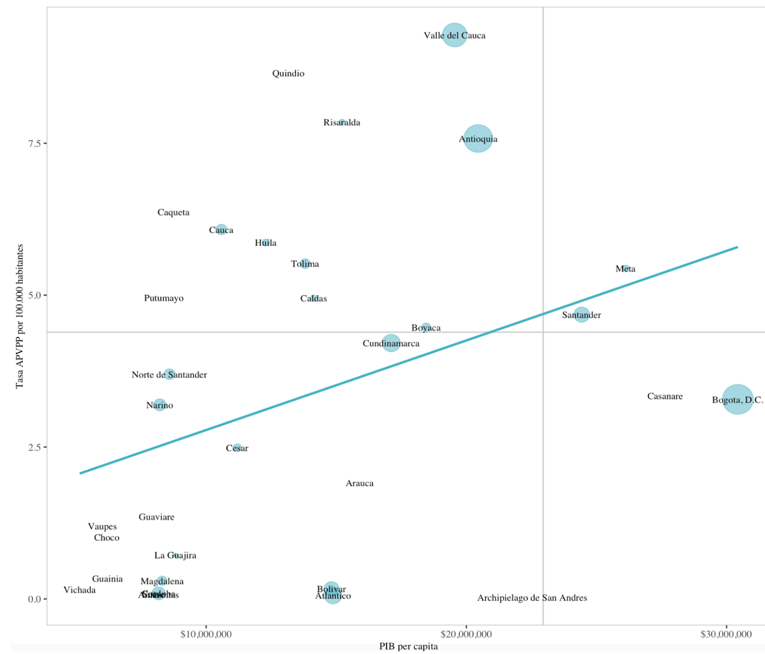
Source: World Bank 2023

Figure A1.16. Relationship between the Rate of YLL Attributable to Cold and Heat and GDP per Capita by Departments in Colombia, 2010–2019

(A) Heat association



(B) Cold association



Disease Burden and Economic Projections

Table A1.25. Average Temperature Projections According to Scenarios by Department

Department	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
	Average Temperature ºC 2020–2100 (Minimum Value-Maximum Value)				
Amazon	27.1 (26.7–27.4)	27.4 (26.6–27.8)	27.8 (26.6–28.8)	28.4 (26.6–30.8)	28.8 (26.6–31.5)
Antioquia	23.1 (22.6–23.6)	23.5 (22.8–23.8)	23.9 (22.8–24.7)	24.3 (22.7–26.3)	24.7 (22.7–27.1)
Arauca	24.8 (24.4–25.4)	25.3 (24.5–25.9)	25.8 (24.4–26.7)	26.3 (24.5–28.7)	26.9 (24.4–29.7)
Atlantic	28.2 (27.8–28.6)	28.5 (27.9–28.9)	28.9 (27.9–29.7)	29.4 (27.8–31.2)	29.8 (27.9–32.1)
Bogotá	15.5 (15.1–16.0)	15.9 (15.4–16.4)	16.4 (15.3–17.4)	17.0 (15.2–19.0)	17.5 (15.3–20.2)
Bolívar	26.9 (26.5–27.3)	27.3 (26.7–27.6)	27.7 (26.6–28.5)	28.2 (26.6–30.3)	28.6 (26.6–31.0)
Boyacá	17.5 (17.0–17.9)	17.9 (17.1–18.4)	18.4 (17.1–18.4)	18.9 (17.1–21.1)	19.4 (17.1–22.2)
Caldas	20.6 (20.1–21.0)	21.0 (20.3–21.4)	21.4 (20.3–22.3)	21.8 (20.3–23.8)	22.3 (20.2–24.8)
Caquetá	26.2 (25.7–26.5)	26.5 (25.8–27.0)	27.0 (25.7–28.0)	27.5 (25.7–29.6)	28.0 (25.8–30.8)
Casanare	26.0 (25.5–26.5)	26.4 (25.6–27.0)	26.9 (25.6–28.0)	27.4 (25.7–29.6)	28.0 (25.6–30.9)
Cauca	21.3 (20.8–21.7)	21.6 (21.0–22.0)	22.1 (20.9–22.9)	22.4 (25.6–29.8)	22.9 (20.9–25.2)
Cesar	28.2 (27.8–28.6)	28.6 (27.9–29.1)	29.1 (27.9–29.9)	29.6 (27.9–31.8)	30.2 (28–32.8)
Chocó	26.5 (25.9–26.8)	26.7 (26.1–27.1)	27.1 (26.1–27.8)	27.4 (26.0–29.0)	27.8 (26–29.7)
Córdoba	25.8 (25.4–26.2)	26.2 (25.6–26.5)	26.6 (25.5–27.3)	27.0 (25.6–28.9)	27.4 (25.5–29.7)
Cundinamarca	20.6 (20.1–21.0)	20.9 (20.2–21.4)	21.4 (20.2–22.5)	21.9 (20.2–24.1)	22.4 (20.2–25.9)
Guainía	27.0 (26.6–27.4)	27.3 (26.5–27.8)	27.8 (26.5–28.7)	28.3 (26.5–30.3)	28.8 (26.4–31.6)
Guaviare	26.2 (25.7–26.6)	26.6 (25.8–27.1)	27.1 (25.8–28.1)	27.6 (25.9–29.7)	28.1 (25.8–30.9)
Huila	19.2 (18.8–19.6)	19.6 (18.9–20.0)	20.0 (18.8–21.0)	20.5 (18.8–22.4)	20.9 (18.8–23.5)
La Guajira	26.3 (25.9–26.6)	26.7 (26.0–27.0)	27.1 (26.0–27.9)	27.5 (25.9–29.5)	27.9 (26.0–30.2)
Magdalena	28.1 (27.7–28.5)	28.5 (27.9–28.8)	28.9 (27.8–29.7)	29.4 (27.7–31.5)	29.9 (27.8–32.4)

Department	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
	Average Temperature ºC 2020–2100 (Minimum Value-Maximum Value)				
Meta	25.5 (25.0–25.9)	25.9 (25.1–26.4)	26.4 (25.1–27.5)	26.9 (25.2–29.2)	27.4 (25.0–30.3)
Nariño	21.2 (20.7–21.6)	21.5 (20.9–21.9)	21.9 (20.8–22.7)	22.3 (20.8–24.1)	22.7 (20.8–25)
Norte de Santander	23.1 (22.6–23.5)	23.5 (22.7–23.9)	23.9 (22.7–25)	24.4 (22.7–26.7)	25.0 (22.8–27.6)
Putumayo	25.2 (24.8–25.6)	25.6 (24.8–26.0)	26.0 (24.8–27.0)	26.5 (24.7–28.6)	27.0 (24.8–29.7)
Quindío	18.4 (17.9–18.9)	18.8 (18.1–19.2)	19.2 (18.0–20.1)	19.6 (18.0–21.5)	20.1 (18.8–22.6)
Risaralda	22.3 (21.8–22.7)	22.6 (22.0–23.0)	23.0 (21.9–23.8)	23.4 (21.9–25.3)	23.9 (21.9–26.2)
Archipelago of San Andrés, Providencia and Santa Catalina	27.3 (27.0–27.6)	27.5 (26.9–27.9)	27.8 (26.9–28.6)	28.1 (26.9–29.5)	28.4 (27–30.2)
Santander	22.4 (22.0–22.9)	22.8 (22.1–23.3)	23.3 (22.1–24.2)	23.8 (22.1–26.0)	24.3 (22.1–26.9)
Sugar	27.6 (27.2–27.9)	27.9 (27.3–28.3)	28.3 (27.3–29.1)	28.8 (27.2–30.7)	29.2 (27.3–31.5)
Tolima	19.4 (18.9–19.9)	19.8 (19.1–20.2)	20.2 (19.1–21.2)	20.7 (19.0–22.7)	21.1 (19.1–23.7)
Valley	24.0 (23.5–24.4)	24.4 (23.7–24.7)	24.7 (23.7–25.5)	25.1 (23.6–27.0)	25.5 (23.6–27.8)
Vaupés	26.6 (26.2–27.0)	26.9 (26.1–27.4)	27.4 (26.1–28.4)	27.9 (26.2–30.1)	28.4 (26.2–31.1)
Vichada	27.6 (27.1–28.1)	28.0 (27.1–28.5)	28.4 (27.1–29.4)	28.9 (27.1–31.1)	29.5 (27.1–32.4)

Table A1.26. Vector of Change (2050–2100) Expected According to Scenarios by Department

Department	SSP1-1.9		SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	Vector of change Period 2020–2050 and Period 2020–2100									
	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
Amazon	2050:-0.03ºC	2100:-0.08 ºC	2050:+0.1ºC	2100: +0.5ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.4ºC	2100:+3.6ºC	2050:+1.7ºC	2100:+4.5ºC
Antioquia	2050:-0.01ºC	2100:-0.04 ºC	2050:+0.1ºC	2100:+0.4ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.2ºC	2100:+3.1ºC	2050:+1.5ºC	2100:+4ºC
Arauca	2050:-0.02ªC	2100:-0.07ºC	2050:+0.2ºC	2100:+0.7ºC	2050:+0.8ºC	2100:+2ºC	2050:+1.5ºC	2100:+3.8ºC	2050:+1.9ºC	2100:+5ºC
Atlantic	2050:+0.003ºC	2100:+0.008ºC	2050:+0.1ºC	2100:+0.5ºC	2050:+0.6ºC	2100:+1.6ºC	2050:+1.2ºC	2100:+3ºC	2050:+1.5ºC	2100:+4ºC
Bogotá	2050:-0.03ºC	2100: -0.08 ºC	2050:+0.1ºC	2100: +0.5ºC	2050:+0.7ºC	2100: +1.9ºC	2050:+1.4ºC	2100: +3.6ºC	2050:+1.8ºC	2100:+4.8ºC
Bolívar	2050:-0.006ºC	2100:-0.01ºC	2050:+0.1ºC	2100:+0.5ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.2ºC	2100:+3.3ºC	2050:+1.6ºC	2100:+4.1ºC
Boyacá	2050:-0.03ºC	2100:-0.08ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.9ºC	2050:+1.4ºC	2100:+3.6ºC	2050:+1.8ºC	2100:+4.7ºC
Caldas	2050:-0.006ºC	2100:-0.01ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.8ºC	2050:+1.2ºC	2100:+3.2ºC	2050:+1.6ºC	2100:+4ºC
Caquetá	2050:-0.03ºC	2100:-0.08ºC	2050:+0.2ºC	2100:+0.6ºC	2050:0.7ºC	2100:+1.9ºC	2050:+1.3ºC	2100:+3.5ºC	2050:+1.7ºC	2100:+4.6ºC
Casanare	2050:-0.02ºC	2100:-0.05ºC	2050:+0.2ºC	2100:+0.7ºC	2050:0.7ºC	2100:+2ºC	2050:+1.4ºC	2100:+3.7ºC	2050:+1.9ºC	2100:+4.9ºC
Cauca	2050:-0.009ºC	2100:-0.02ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.8ºC	2050:+1.2ºC	2100:+3.1ºC	2050:+1.5ºC	2100:+3.9ºC
Cesar	2050:+0.0006ºC	2100:+0.001ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.4ºC	2100:+3.5ºC	2050:+1.8ºC	2100:+4.5ºC
Chocó	2050:+0.009ºC	2100:+0.02ºC	2050:+0.1ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.5ºC	2050:+1ºC	2100:+2.6ºC	2050:+1.4ºC	2100:+3.5ºC
Córdoba	2050:-0.02ºC	2100:-0.07ºC	2050:+0.1ºC	2100:+0.5ºC	2050:+0.6ºC	2100:+1.6ºC	2050:+1.2ºC	2100:+3ºC	2050:+1.5ºC	2100:+3.9ºC
Cundinamarca	2050:-0.01ºC	2100:-0.04ºC	2050:+0.02ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.3ºC	2100:+3.5ºC	2050:+1.7ºC	2100:+4.6ºC
Guainía	2050:-0.02ºC	2100:-0.05ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.9ºC	2050:+1.3ºC	2100:+3.4ºC	2050:+1.8ºC	2100:+4.7ºC
Guaviare	2050:-0.03ºC	2100:-0.08ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.9ºC	2050:+1.3ºC	2100:+3.4ºC	2050:+1.8ºC	2100:+4.6ºC

Huila	2050:-0.03ºC	2100:-0.07ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.3ºC	2100:+3.4ºC	2050:+1.7ºC	2100:+4.3ºC
La Guajira	2050:+0.003ºC	2100:+0.008ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.8ºC	2050:+1.2ºC	2100:+3ºC	2050:+1.5ºC	2100:+3.9ºC
Magdalena	2050:+0.0006ºC	2100:+0.004ºC	2050:+0.2ºC	2100:+0.5ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.3ºC	2100:+3.3ºC	2050:+1.7ºC	2100:+4.2ºC
Meta	2050:-0.03ºC	2100:-0.07ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+2ºC	2050:+1.4ºC	2100:+3.6ºC	2050:+1.8ºC	2100:+4.7ºC
Nariño	2050:-0.0006ºC	2100:-0.001ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.1ºC	2100:+3ºC	2050:+1.5ºC	2100:+3.8ºC
Norte de Santander	2050:-0.009ºC	2100:-0.02ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.4ºC	2100:+3.6ºC	2050:+1.8ºC	2100:+4.6ºC
Putumayo	2050:-0.01ºC	2100:-0.03ºC	2050:+0.02ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.9ºC	2050:+1.4ºC	2100:+3.5ºC	2050:+1.7ºC	2100:+4.4ºC
Quindío	2050: -0.009ºC	2100:-0.02ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.2ºC	2100:+3.2ºC	2050:+1.6ºC	2100:+4.16ºC
Risaralda	2050:+0.001ºC	2100:+0.003ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.1ºC	2100:+3ºC	2050:+1.5ºC	2100:+3.9ºC
Archipelago of San Andrés, Providencia and Santa Catalina	2050:+0.003ºC	2100: +0.008ºC	2050:+0.2ºC	2100:+0.5ºC	2050:+0.5ºC	2100:+1.4ºC	2050:+0.9ºC	2100:+2.3ºC	2050:+1.2ºC	2100:+3ºC
Santander	2050:-0.03ºC	2100:-0.08ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.4ºC	2100:+3.5ºC	2050:+1.7ºC	2100:+4.5ºC
Sugar	2050:-0.01ºC	2100:-0.03ºC	2050:+0.2ºC	2100:+0.5ºC	2050:+0.6ºC	2100:+1.6ºC	2050:+1.2ºC	2100:+3.1ºC	2050:+1.5ºC	2100:+4ºC
Tolima	2050:-0.01ºC	2100:-0.04 ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.3ºC	2100:+3.3ºC	2050:+1.7ºC	2100:+4.2ºC
Valley	2050:-0.006ºC	2100:-0.01ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.6ºC	2100:+1.7ºC	2050:+1.1ºC	2100:+2.9ºC	2050:+1.4ªC	2100:+3.7ºC
Vaupés	2050:-0.03ºC	2100:-0.08ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.8ºC	2050:+1.3ºC	2100:+3.4ºC	2050:+1.8ºC	2100:+4.6ºC
Vichada	2050:-0.01ºC	2100:-0.04ºC	2050:+0.2ºC	2100:+0.6ºC	2050:+0.7ºC	2100:+1.9ºC	2050:+1.4ºC	2100:+3.6ºC	2050:+1.9ºC	2100:+4.9ºC

Table A1.27. Economic Burden Projections Attributable to Heat and Cold by Colombian Departments, 2020-2050, without Discount

Year	Scenario	Cold - AMW	Heat - AMW	Cold - GDPpc	Heat – GDPpc
2020	SSP_585	COP 1,111	COP 883	COP 1,854	COP 1,313
2020	SSP_370	COP 1,110	COP 859	COP 1,852	COP 1,276
2020	SSP_245	COP 1,110	COP 868	COP 1,854	COP 1,296
2020	SSP_126	COP 1,115	COP 942	COP 1,861	COP 1,405
2020	SSP_119	COP 1,116	COP 956	COP 1,863	COP 1,440
2021	SSP_585	COP 1,118	COP 924	COP 1,864	COP 1,378
2021	SSP_370	COP 1,113	COP 857	COP 1,857	COP 1,275
2021	SSP_245	COP 1,118	COP 922	COP 1,863	COP 1,363
2021	SSP_126	COP 1,119	COP 944	COP 1,866	COP 1,411
2021	SSP_119	COP 1,113	COP 852	COP 1,856	COP 1,261
2022	SSP_585	COP 1,121	COP 940	COP 1,867	COP 1,393
2022	SSP_370	COP 1,119	COP 904	COP 1,863	COP 1,346
2022	SSP_245	COP 1,123	COP 973	COP 1,870	COP 1,455
2022	SSP_126	COP 1,120	COP 925	COP 1,865	COP 1,373
2022	SSP_119	COP 1,117	COP 879	COP 1,861	COP 1,303
2023	SSP_585	COP 1,122	COP 943	COP 1,867	COP 1,400
2023	SSP_370	COP 1,121	COP 922	COP 1,865	COP 1,371
2023	SSP_245	COP 1,125	COP 980	COP 1,871	COP 1,464
2023	SSP_126	COP 1,123	COP 946	COP 1,867	COP 1,406
2023	SSP_119	COP 1,123	COP 958	COP 1,869	COP 1,433
2024	SSP_585	COP 1,125	COP 981	COP 1,869	COP 1,460
2024	SSP_370	COP 1,116	COP 854	COP 1,856	COP 1,270
2024	SSP_245	COP 1,127	COP 1,017	COP 1,872	COP 1,517
2024	SSP_126	COP 1,128	COP 1,039	COP 1,874	COP 1,550
2024	SSP_119	COP 1,118	COP 869	COP 1,857	COP 1,278
2025	SSP_585	COP 1,123	COP 970	COP 1,863	COP 1,442
2025	SSP_370	COP 1,120	COP 929	COP 1,860	COP 1,391
2025	SSP_245	COP 1,120	COP 930	COP 1,859	COP 1,370
2025	SSP_126	COP 1,122	COP 957	COP 1,862	COP 1,421
2025	SSP_119	COP 1,120	COP 929	COP 1,859	COP 1,365
2026	SSP_585	COP 1,118	COP 933	COP 1,853	COP 1,373
2026	SSP_370	COP 1,119	COP 951	COP 1,855	COP 1,405
2026	SSP_245	COP 1,123	COP 1,008	COP 1,860	COP 1,492
2026	SSP_126	COP 1,120	COP 961	COP 1,856	COP 1,428
2026	SSP_119	COP 1,117	COP 910	COP 1,852	COP 1,354
2027	SSP_585	COP 1,119	COP 997	COP 1,852	COP 1,479
2027	SSP_370	COP 1,121	COP 1,034	COP 1,856	COP 1,533
2027	SSP_245	COP 1,117	COP 959	COP 1,849	COP 1,417
2027	SSP_126	COP 1,115	COP 926	COP 1,846	COP 1,375
2027	SSP_119	COP 1,108	COP 827	COP 1,835	COP 1,207
2028	SSP_585	COP 1,119	COP 1,056	COP 1,850	COP 1,568
2028	SSP_370	COP 1,115	COP 984	COP 1,843	COP 1,458
2028	SSP_245	COP 1,113	COP 944	COP 1,840	COP 1,396
2028	SSP_126	COP 1,114	COP 970	COP 1,842	COP 1,437

Year	Scenario	Cold - AMW	Heat - AMW	Cold - GDPpc	Heat – GDPpc
2028	SSP_119	COP 1,110	COP 908	COP 1,836	COP 1,343
2029	SSP_585	COP 1,113	COP 1,019	COP 1,838	COP 1,508
2029	SSP_370	COP 1,106	COP 901	COP 1,826	COP 1,327
2029	SSP_245	COP 1,114	COP 1,032	COP 1,839	COP 1,528
2029	SSP_126	COP 1,111	COP 977	COP 1,834	COP 1,445
2029	SSP_119	COP 1,104	COP 863	COP 1,823	COP 1,276
2030	SSP_585	COP 1,111	COP 1,052	COP 1,831	COP 1,554
2030	SSP_370	COP 1,098	COP 842	COP 1,811	COP 1,232
2030	SSP_245	COP 1,102	COP 905	COP 1,818	COP 1,328
2030	SSP_126	COP 1,104	COP 941	COP 1,821	COP 1,388
2030	SSP_119	COP 1,106	COP 960	COP 1,823	COP 1,419
2031	SSP_585	COP 1,107	COP 1,066	COP 1,822	COP 1,570
2031	SSP_370	COP 1,103	COP 999	COP 1,816	COP 1,464
2031	SSP_245	COP 1,102	COP 987	COP 1,816	COP 1,463
2031	SSP_126	COP 1,102	COP 983	COP 1,816	COP 1,457
2031	SSP_119	COP 1,099	COP 928	COP 1,810	COP 1,374
2032	SSP_585	COP 1,097	COP 985	COP 1,804	COP 1,452
2032	SSP_370	COP 1,101	COP 1,064	COP 1,812	COP 1,580
2032	SSP_245	COP 1,098	COP 1,005	COP 1,806	COP 1,481
2032	SSP_126	COP 1,094	COP 941	COP 1,800	COP 1,384
2032	SSP_119	COP 1,075	COP 659	COP 1,771	COP 953
2033	SSP_585	COP 1,090	COP 973	COP 1,791	COP 1,432
2033	SSP_370	COP 1,088	COP 945	COP 1,788	COP 1,385

Year	Scenario	Cold - AMW	Heat - AMW	Cold - GDPpc	Heat – GDPpc
2033	SSP_245	COP 1,088	COP 936	COP 1,789	COP 1,389
2033	SSP_126	COP 1,090	COP 971	COP 1,791	COP 1,426
2033	SSP_119	COP 1,087	COP 929	COP 1,787	COP 1,368
2034	SSP_585	COP 1,086	COP 1,012	COP 1,783	COP 1,489
2034	SSP_370	COP 1,081	COP 923	COP 1,775	COP 1,355
2034	SSP_245	COP 1,079	COP 896	COP 1,772	COP 1,314
2034	SSP_126	COP 1,082	COP 950	COP 1,777	COP 1,392
2034	SSP_119	COP 1,077	COP 864	COP 1,769	COP 1,258
2035	SSP_585	COP 1,083	COP 1,074	COP 1,776	COP 1,581
2035	SSP_370	COP 1,073	COP 903	COP 1,760	COP 1,321
2035	SSP_245	COP 1,075	COP 937	COP 1,764	COP 1,378
2035	SSP_126	COP 1,072	COP 889	COP 1,759	COP 1,305
2035	SSP_119	COP 1,070	COP 860	COP 1,756	COP 1,261
2036	SSP_585	COP 1,078	COP 1,083	COP 1,764	COP 1,592
2036	SSP_370	COP 1,074	COP 1,017	COP 1,759	COP 1,505
2036	SSP_245	COP 1,065	COP 878	COP 1,746	COP 1,285
2036	SSP_126	COP 1,073	COP 1,000	COP 1,757	COP 1,470
2036	SSP_119	COP 1,060	COP 796	COP 1,738	COP 1,176
2037	SSP_585	COP 1,071	COP 1,076	COP 1,752	COP 1,586
2037	SSP_370	COP 1,068	COP 1,017	COP 1,747	COP 1,493
2037	SSP_245	COP 1,067	COP 1,011	COP 1,746	COP 1,483
2037	SSP_126	COP 1,064	COP 960	COP 1,742	COP 1,411
2037	SSP_119	COP 1,056	COP 831	COP 1,729	COP 1,207

Year	Scenario	Cold - AMW	Heat - AMW	Cold - GDPpc	Heat – GDPpc
2038	SSP_585	COP 1,065	COP 1,079	COP 1,740	COP 1,591
2038	SSP_370	COP 1,059	COP 992	COP 1,732	COP 1,449
2038	SSP_245	COP 1,060	COP 1,002	COP 1,733	COP 1,468
2038	SSP_126	COP 1,055	COP 925	COP 1,726	COP 1,346
2038	SSP_119	COP 1,054	COP 896	COP 1,724	COP 1,316
2039	SSP_585	COP 1,058	COP 1,081	COP 1,727	COP 1,589
2039	SSP_370	COP 1,051	COP 966	COP 1,717	COP 1,427
2039	SSP_245	COP 1,052	COP 978	COP 1,718	COP 1,441
2039	SSP_126	COP 1,046	COP 887	COP 1,709	COP 1,287
2039	SSP_119	COP 1,038	COP 758	COP 1,696	COP 1,085
2040	SSP_585	COP 1,056	COP 1,169	COP 1,722	COP 1,727
2040	SSP_370	COP 1,042	COP 936	COP 1,701	COP 1,370
2040	SSP_245	COP 1,041	COP 919	COP 1,699	COP 1,340
2040	SSP_126	COP 1,036	COP 837	COP 1,692	COP 1,222
2040	SSP_119	COP 1,033	COP 794	COP 1,687	COP 1,151
2041	SSP_585	COP 1,043	COP 1,072	COP 1,701	COP 1,587
2041	SSP_370	COP 1,036	COP 954	COP 1,689	COP 1,388
2041	SSP_245	COP 1,035	COP 934	COP 1,688	COP 1,366
2041	SSP_126	COP 1,031	COP 871	COP 1,682	COP 1,268
2041	SSP_119	COP 1,030	COP 854	COP 1,681	COP 1,246
2042	SSP_585	COP 1,039	COP 1,118	COP 1,692	COP 1,650
2042	SSP_370	COP 1,036	COP 1,060	COP 1,687	COP 1,563
2042	SSP_245	COP 1,031	COP 974	COP 1,679	COP 1,424

Year	Scenario	Cold - AMW	Heat - AMW	Cold - GDPpc	Heat – GDPpc
2042	SSP_126	COP 1,028	COP 931	COP 1,675	COP 1,363
2042	SSP_119	COP 1,018	COP 776	COP 1,660	COP 1,123
2043	SSP_585	COP 1,035	COP 1,159	COP 1,682	COP 1,703
2043	SSP_370	COP 1,027	COP 1,033	COP 1,671	COP 1,514
2043	SSP_245	COP 1,021	COP 933	COP 1,662	COP 1,364
2043	SSP_126	COP 1,016	COP 843	COP 1,654	COP 1,228
2043	SSP_119	COP 1,005	COP 681	COP 1,638	COP 988
2044	SSP_585	COP 1,025	COP 1,124	COP 1,666	COP 1,653
2044	SSP_370	COP 1,016	COP 958	COP 1,651	COP 1,403
2044	SSP_245	COP 1,015	COP 957	COP 1,651	COP 1,402
2044	SSP_126	COP 1,009	COP 840	COP 1,640	COP 1,221
2044	SSP_119	COP 1,006	COP 798	COP 1,637	COP 1,162
2045	SSP_585	COP 1,018	COP 1,120	COP 1,652	COP 1,641
2045	SSP_370	COP 1,007	COP 939	COP 1,636	COP 1,364
2045	SSP_245	COP 1,005	COP 897	COP 1,632	COP 1,305
2045	SSP_126	COP 1,000	COP 817	COP 1,625	COP 1,183
2045	SSP_119	COP 1,002	COP 856	COP 1,629	COP 1,254
2046	SSP_585	COP 1,009	COP 1,097	COP 1,638	COP 1,624
2046	SSP_370	COP 1,006	COP 1,035	COP 1,632	COP 1,511
2046	SSP_245	COP 1,002	COP 965	COP 1,626	COP 1,419
2046	SSP_126	COP 1,000	COP 940	COP 1,623	COP 1,370
2046	SSP_119	COP 991	COP 782	COP 1,609	COP 1,137
2047	SSP_585	COP 1,006	COP 1,159	COP 1,630	COP 1,705

Year	Scenario	Cold - AMW	Heat - AMW	Cold - GDPpc	Heat – GDPpc
2047	SSP_370	COP 999	COP 1,045	COP 1,620	COP 1,527
2047	SSP_245	COP 992	COP 931	COP 1,610	COP 1,355
2047	SSP_126	COP 986	COP 829	COP 1,601	COP 1,208
2047	SSP_119	COP 982	COP 761	COP 1,595	COP 1,104
2048	SSP_585	COP 1,001	COP 1,189	COP 1,620	COP 1,745
2048	SSP_370	COP 988	COP 979	COP 1,601	COP 1,429
2048	SSP_245	COP 991	COP 1,023	COP 1,605	COP 1,488
2048	SSP_126	COP 981	COP 853	COP 1,590	COP 1,244
2048	SSP_119	COP 970	COP 684	COP 1,573	COP 979
2049	SSP_585	COP 1,000	COP 1,297	COP 1,617	COP 1,918
2049	SSP_370	COP 989	COP 1,105	COP 1,600	COP 1,634
2049	SSP_245	COP 977	COP 904	COP 1,582	COP 1,322
2049	SSP_126	COP 976	COP 898	COP 1,581	COP 1,310
2049	SSP_119	COP 958	COP 610	COP 1,554	COP 878
2050	SSP_585	COP 985	COP 1,174	COP 1,593	COP 1,730
2050	SSP_370	COP 974	COP 979	COP 1,575	COP 1,417
2050	SSP_245	COP 969	COP 892	COP 1,568	COP 1,298
2050	SSP_126	COP 970	COP 905	COP 1,569	COP 1,321
2050	SSP_119	COP 955	COP 669	COP 1,547	COP 968

*Values in billion Colombian pesos; AMW = annual minimum wage; GDPpc = gross domestic product per capita

C. Limitations and Methodological Considerations

- Temperatures vary greatly, particularly in departments located in the Andean zone, and the aggregation by departments could mask the differing temperature values of subregions and municipalities, both in departments with high temperature averages and in those with low averages. This leads to losing some awareness of the temperature variability.
- This analysis used the exposure response curves (temperature – risk of death) of the GBD by climatic zone; although they are constructed, including data from Colombia, they are not specific to the country, so the effect may have been underestimated or overestimated.
- The use of deaths by place of residence (rather than deaths by place of occurrence) could potentially influence the observed results. However, this approach was preferred as it captures exposure more accurately, because migration in Colombia results in a large floating population, large numbers of internally displaced persons, and high immigration.
- A variation of the GBD approach was used with respect to population attributable fractions, which were computed with mortality on a daily basis and not annually. This makes

the results less comparable with those of GBD. However, this methodology may be more precise because it more accurately captures the daily variations in mortality due to daily exposure to temperature.

- The use of the modified human capital method—which refers to the capital embodied in workers, considering GDP per capita as a statistical contribution of the year of life to society—was justified in the sense that the analysis considered two scenarios of economic burden: (i) assessing premature mortality through the use of the annual minimum wage and (ii) through the average productivity of a Colombian by GDP per capita.
- What value should be used to determine the potential loss of a person who dies prematurely due to climate variability? In Colombia, the income structure shows that 86 percent of Colombians earn a monthly minimum wage. This means that it would be plausible to assume that a person who dies before fulfilling his working life expectancy would continue to earn this salary. On the other hand, a ceiling scenario, such as GDP per capita, enables assessment of the average productivity of labor in the country.
- A limitation of the modified human capital approach is that the values resulting from the loss of productivity may have biases caused by inaccuracies in obtaining representative income patterns for each population group. In addition, this approach measures the "potential" productivity loss, rather than the actual loss experienced by society. This leads to high estimated values of productivity loss, particularly for chronic diseases or concerning young populations.
- Another method used in estimates of economic burden of premature mortality is the statistical value of life method. However, existing estimates are mainly for high-income countries, such as the United States and European countries (Toloo et al. 2015).
- Burden projections in climate scenarios were used to model, in a linear fashion, annual attributable mortality rates. This probably leads to an underestimation of the burden because the variability of the daily temperature is partially lost. However, it is estimated that the results do capture the trends and a part of the variability, and therefore are useful for decision making.
- The temperature and mortality projections are an approximation of the potential effect of the different interventions to mitigate greenhouse gas emissions, but it is important to bear in mind that there is a high uncertainty in the future consequences estimates due to the complex nature of the relationship between temperature and health.

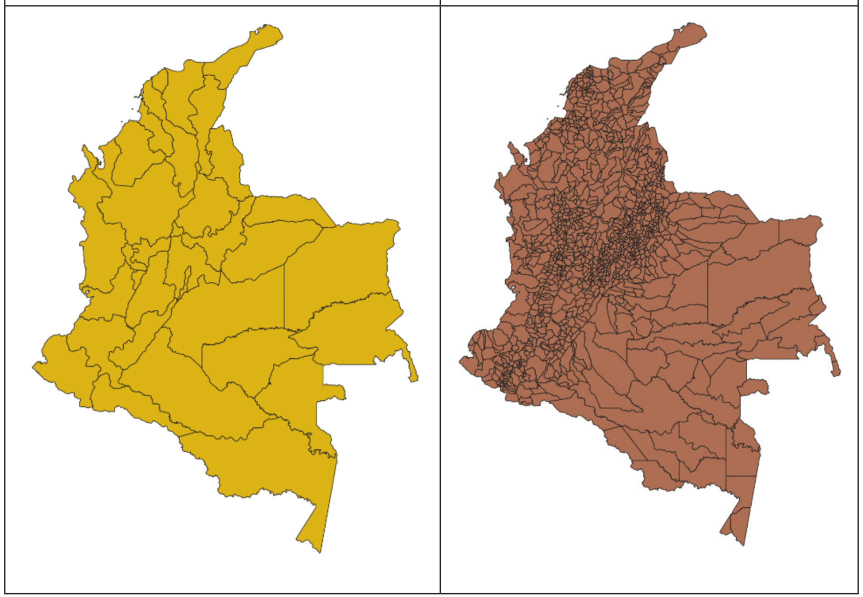
ANNEX 2. COMPONENT 2

All the maps and tables are produced by authors as part of this work. The information on data sources are included for additionally.

Boundaries

Figure A2.1. Colombia Political Divisions

Departments	Municipalities

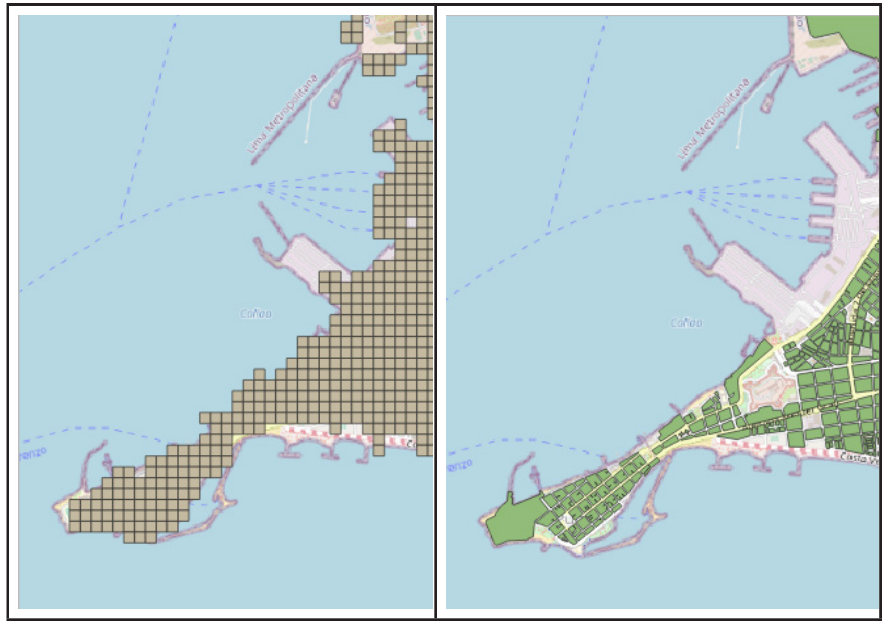


Source: WBG staff using data from Geological Service of Colombia

Population Maps

Figure A2.2. Geolocated Population Representation Examples

(A) (Un)constrain	(B) Census block level



Hazard Maps

Figure A2.3. Examples of Floods and Fault Line as Proxy to Landslides in Colombia

Floods 1 in 100 years return period

Fault Line as proxy to high risk of landslides

Population Exposure to Hazards

Figure A2.4. Colombian Population Exposed to Floods and Fault Lines as Proxy of Landslides

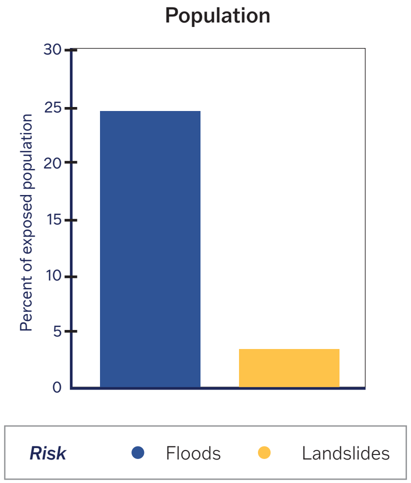
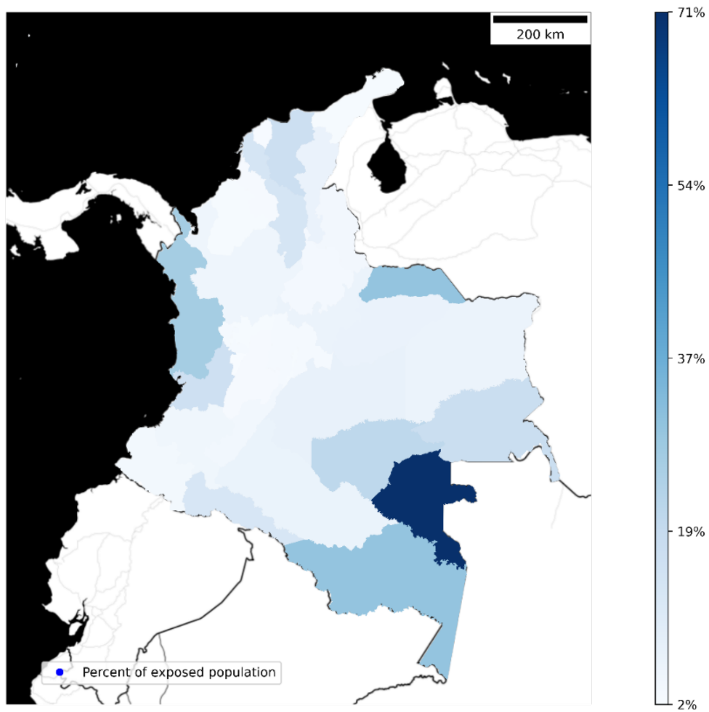


Figure A2.5. Population Exposed to Floods, Department Level



Note: Spatial resolution = 30 m (meters) * 30 m.

Table A2.1. Exposed Population to Floods at Department Level Order by Percentage of Exposed Population

Department code	Department name	Exposed population	Percentage of exposed population
97	Vaupés	71,438	71.82
91	Amazonas	72,433	53.01
81	Arauca	241,176	52.98
27	Chocó	352,937	50.85
95	Guaviare	86,106	46.75
94	Guainía	51,075	43.95
47	Magdalena	712,430	43.32
76	Valle del Cauca	2,404,441	42.71
13	Bolívar	1,336,889	40.03
86	Putumayo	213,882	39.19
50	Meta	376,764	30.38
85	Casanare	266,655	29.2
20	Cesar	362,323	29.18
18	Caquetá	192,218	28.6
99	Vichada	27,112	28.34
15	Boyacá	417,348	28.3
5	Antioquia	2,021,317	25.51
19	Cauca	446,907	24.67
41	Huila	334,501	22.72
54	Norte de Santander	351,457	22.28
52	Nariño	467,848	21.16
68	Santander	538,812	20.14
25	Cundinamarca	756,054	19.35
66	Risaralda	209,250	18.44
73	Tolima	296,877	17.06
70	Sucre	172,909	16.91
23	Córdoba	413,465	16.31
44	La Guajira	239,360	16.15
11	Bogotá	1,658,847	16.15
17	Caldas	159,520	14.87
8	Atlántico	433,689	13.51
63	Quindio	52,648	7.51
88	San Andres	2,370	2.19

Figure A2.6. Population Exposed to Fault Lines as Proxy of Landslides at Department Level

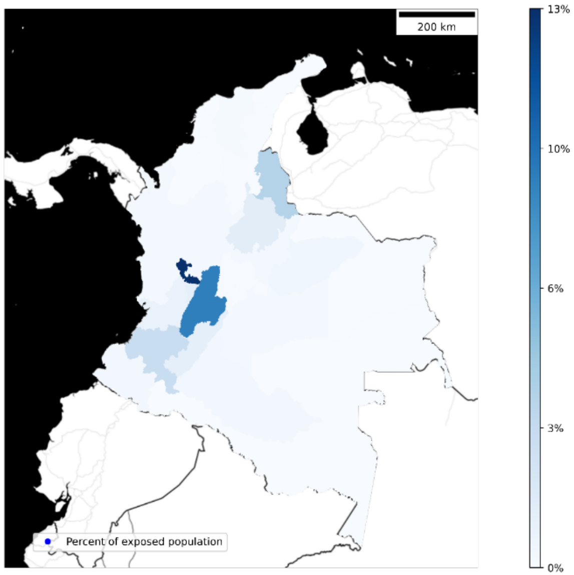


Table A2.2. Exposed Population to Landslides at Department Level, Ordered by Percentage of Exposed Population

Department code	Department name	Exposed population	Percentage of exposed population
66	Risaralda	152,899	13.47
73	Tolima	207,919	11.95
54	Norte de Santander	143,245	9.08
19	Cauca	150,655	8.32
68	Santander	171,284	6.4
63	Quindio	43,361	6.19
41	Huila	89,468	6.08
76	Valle del Cauca	313,288	5.56
85	Casanare	40,958	4.48
18	Caquetá	29,510	4.39
52	Nariño	90,980	4.11
27	Chocó	27,756	4
17	Caldas	41,404	3.86
5	Antioquia	298,374	3.77
50	Meta	46,497	3.75
15	Boyacá	53,915	3.66
88	San Andres	3,735	3.45
47	Magdalena	56,581	3.44
20	Cesar	31,984	2.58
99	Vichada	2,270	2.37
25	Cundinamarca	90,983	2.33

Department code	Department name	Exposed population	Percentage of exposed population
13	Bolívar	74,110	2.22
23	Córdoba	51,012	2.01
86	Putumayo	9,068	1.66
44	La Guajira	23,375	1.58
81	Arauca	6,840	1.5
70	Sucre	12,297	1.2
97	Vaupés	142	0.14
8	Atlántico	2,075	0.06
11	Bogotá	2,198	0.02
91	Amazonas	0	0
94	Guainía	0	0
95	Guaviare	0	0

Infrastructure Exposure to Hazards

Figure A2.7. Exposed Healthcare Facilities to Floods and Fault Lines as Proxy of Landslides, Where (A) Depicts the Exposed Primary Healthcare Facilities, and (B) and (C) Illustrate the Exposed Hospitals

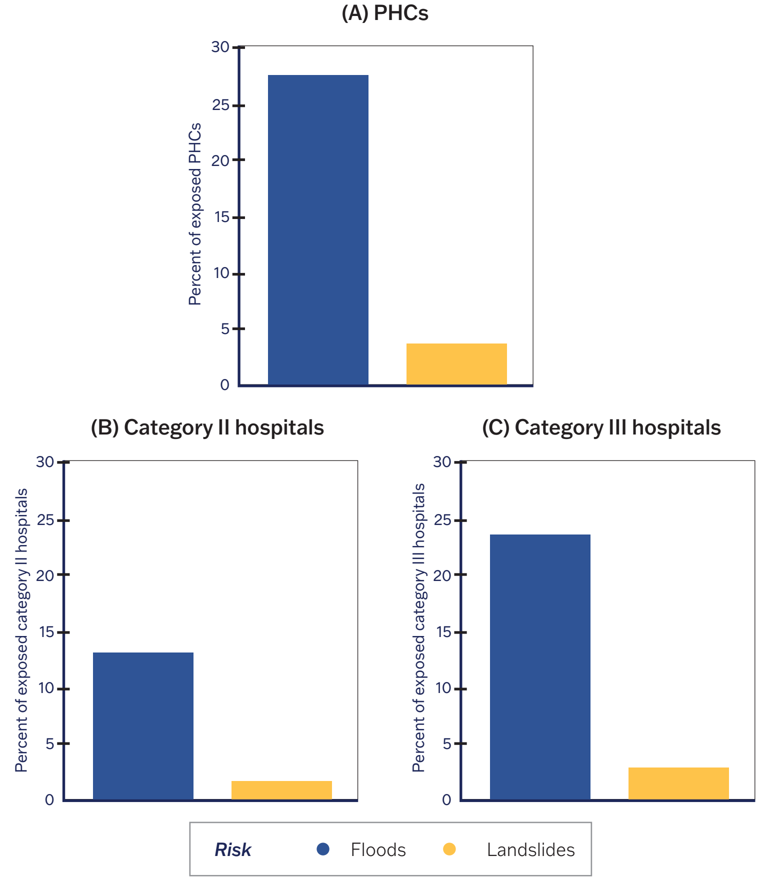


Figure A2.8. Exposed Primary Health Care Facilities to Floods, by Department

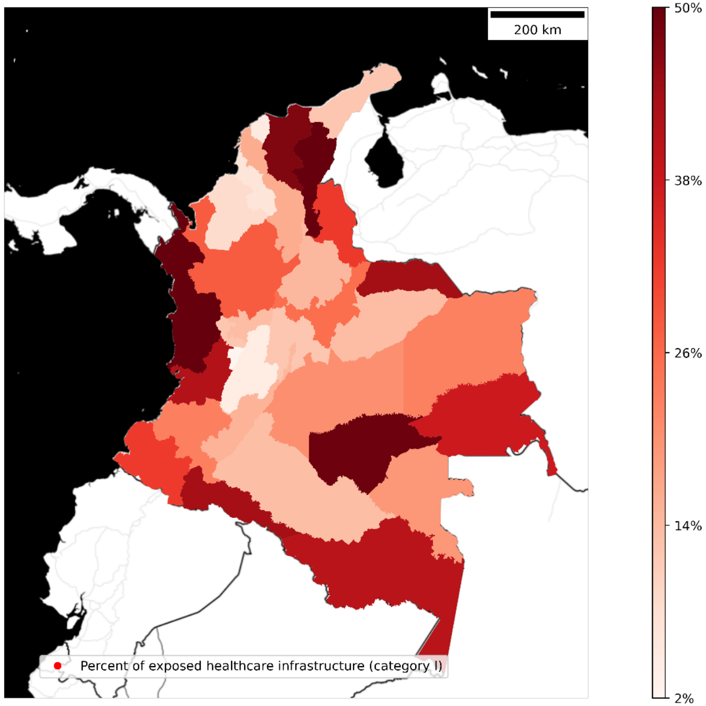


Figure A2.9. Hospitals Exposed to Floods by Department

(A) Category II hospitals exposed to floods by department

(B) Category III hospitals to exposed floods by department

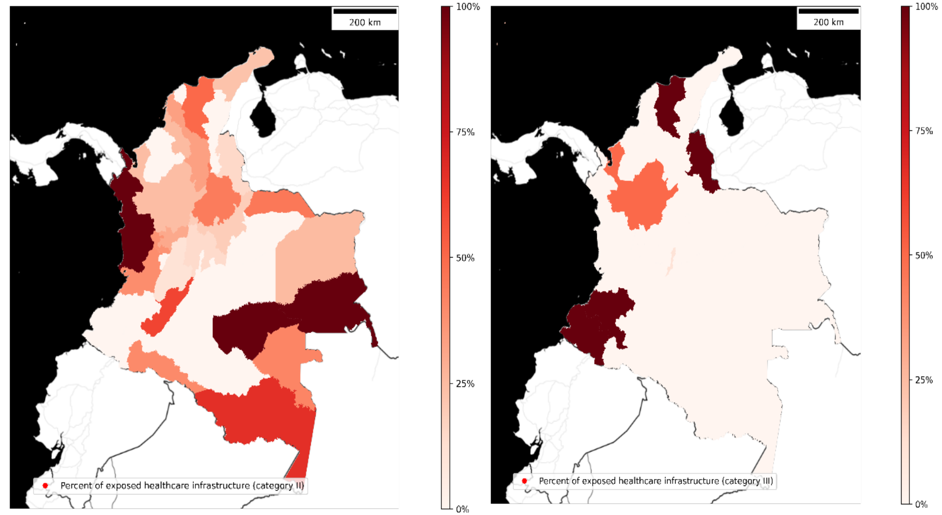


Table A2.3. Healthcare Infrastructure Exposed to Floods at Department Level, Ordered by Percentage of Exposed Population

Department code	Department name	Number of healthcare facilities exposed to floods			Percent of healthcare facilities exposed to floods			
		PHC	Category II	Category III	PHC	Category II	Category III	Total
95	Guaviare	14	1	0	50	100	0	51.72
27	Chocó	135	1	0	50.75	100	0	50.94
91	Amazonas	10	8	0	41.67	66.67	0	50
20	Cesar	306	0	0	50.58	0	0	49.92
47	Magdalena	309	7	1	48.13	50	100	48.25
81	Arauca	74	5	0	44.85	45.45	0	44.89
86	Putumayo	53	4	0	44.54	40	0	44.19
94	Guainía	5	1	0	38.46	100	0	42.86
76	Valle del Cauca	813	9	0	42.37	39.13	0	42.28
97	Vaupés	4	17	0	20	41.46	0	34.43
52	Nariño	245	0	1	32.8	0	100	32.71
54	Norte de Santander	166	3	1	32.94	15	100	32.38
5	Antioquia	603	22	4	28.38	24.44	50	28.3
15	Boyacá	141	7	0	26.01	18.92	0	25.52
99	Vichada	3	1	0	23.08	25	0	23.53
19	Cauca	111	0	1	23.37	0	100	23.33
50	Meta	96	0	0	21.15	0	0	21.05
13	Bolívar	165	3	0	16.8	33.33	0	16.94
41	Huila	57	3	0	15.79	60	0	16.26
68	Santander	164	4	0	15.05	44.44	0	15.23
11	Bogotá	438	0	14	15.02	0	10.69	14.81

Department code	Department name	Number of healthcare facilities exposed to floods			Percent of healthcare facilities exposed to floods			
		PHC	Category II	Category III	PHC	Category II	Category III	Total
17	Caldas	49	4	0	14.29	30.77	0	14.76
85	Casanare	29	0	0	14.36	0	0	14.29
18	Caquetá	15	0	0	14.15	0	0	13.64
44	La Guajira	46	7	0	12.74	22.58	0	13.52
66	Risaralda	47	3	0	12.84	37.5	0	13.33
25	Cundinamarca	96	8	0	12.83	14.29	0	12.94
23	Córdoba	78	0	0	9.29	0	0	9.22
88	San Andres	1	0	1	4.55	0	25	7.69
70	Sucre	40	1	0	7.14	25	0	7.27
8	Atlántico	69	0	0	5.76	0	0	5.74
73	Tolima	28	1	0	5.27	11.11	0	5.35
63	Quindio	6	0	0	2.54	0	0	2.42

Figure A2.10. Primary Health Care Facilities Exposed to Landslides by Department

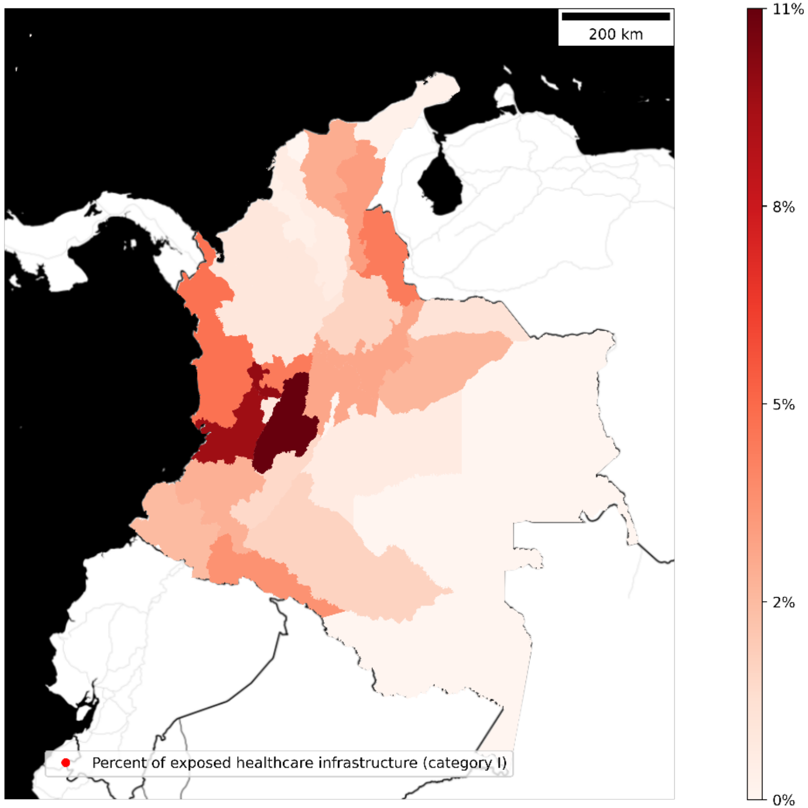


Figure A2.11. Hospitals Exposed to Landslides by Department

(A) Category II hospitals exposed to landslides by department

(B) Category III hospitals to exposed landslides by department

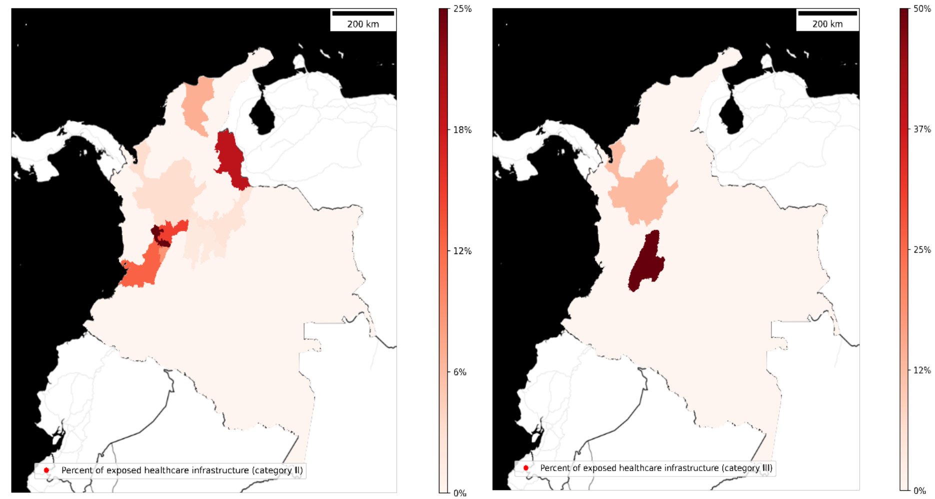


Table A2.4. Healthcare Infrastructure to Exposed Landslides at Department Level, Ordered by Percentage of Exposed Population

Department code	Department name	Number of healthcare facilities exposed to floods			Percent of healthcare facilities exposed to floods			
		PHC	Category II	Category III	PHC	Category II	Category III	Total
73	Tolima	59	0	1	11.11	0	50	11.07
66	Risaralda	37	2	0	10.11	25	0	10.4
76	Valle del Cauca	189	3	0	9.85	13.04	0	9.88
54	Norte de Santander	25	4	0	4.96	20	0	5.52
17	Caldas	17	2	0	4.96	15.38	0	5.29
27	Chocó	14	0	0	5.26	0	0	5.24
86	Putumayo	5	0	0	4.2	0	0	3.88
20	Cesar	23	0	0	3.8	0	0	3.75
15	Boyacá	19	1	0	3.51	2.7	0	3.45
25	Cundinamarca	26	1	0	3.48	1.79	0	3.36
47	Magdalena	21	1	0	3.27	7.14	0	3.35
19	Cauca	15	0	0	3.16	0	0	3.12
85	Casanare	6	0	0	2.97	0	0	2.96
52	Nariño	21	0	0	2.81	0	0	2.79
18	Caquetá	2	0	0	1.89	0	0	1.82
68	Santander	20	0	0	1.83	0	0	1.81
41	Huila	6	0	0	1.66	0	0	1.63
63	Quindio	2	1	0	0.85	9.09	0	1.21
81	Arauca	2	0	0	1.21	0	0	1.14
5	Antioquia	20	3	1	0.94	3.33	12.5	1.08

Department code	Department name	Number of healthcare facilities exposed to floods			Percent of healthcare facilities exposed to floods			
		PHC	Category II	Category III	PHC	Category II	Category III	Total
23	Córdoba	8	0	0	0.95	0	0	0.95
50	Meta	3	0	0	0.66	0	0	0.66
13	Bolívar	6	0	0	0.61	0	0	0.6
70	Sucre	2	0	0	0.36	0	0	0.35
44	La Guajira	1	0	0	0.28	0	0	0.26
8	Atlántico	0	0	0	0	0	0	0
11	Bogotá	0	0	0	0	0	0	0
88	San Andres	0	0	0	0	0	0	0
91	Amazonas	0	0	0	0	0	0	0
94	Guainía	0	0	0	0	0	0	0
95	Guaviare	0	0	0	0	0	0	0
97	Vaupés	0	0	0	0	0	0	0
99	Vichada	0	0	0	0	0	0	0

Table A2.5. Information Used for Clustering Departments Exposed to Floods

Department name	Percentage of exposed population	Percentage of exposed Primary healthcare	Percentage of exposed hospital category II	Percentage of exposed hospital category III	Female Headed Households With No Spouse And Children Under The Age Of 18	No Electricity	No Sewerage	No Internet	Households With More Than Two Families	Prevalence Of Protein Intake Deficiency By Department	Chronic Malnutrition In Children 0 To 4 Years Old	Mortality Rate Due To Malnutrition Per 100,000 Inhabitants Females	Mortality Rate Due To Malnutrition Per 100,000 Inhabitants Males	Average Distance To Primary Health Care (Km)	Average Distance To Hospitals (Km)	Native And Indigenous Population	Number Of Beds Per Department	Number Of Physicians Per Department	Number Of Nurses Per Department	Integrated Risk Index
VICHADA	0.28	0.23	0.25	0.00	0.17	0.57	0.94	0.95	0.06	0.89	0.16	0.03	0.09	1.00	0.71	0.47	0.41	0.11	0.11	0.68
GUAINÍA	0.44	0.38	1.00	0.00	0.17	0.38	0.72	0.93	0.05	0.94	0.23	0.16	0.34	0.67	1.00	0.29	0.15	0.09	0.10	0.70
META	0.30	0.21	0.00	0.00	0.09	0.08	0.22	0.66	0.04	0.71	0.08	0.05	0.07	0.12	0.40	0.02	0.69	0.01	0.01	0.73
AMAZONAS	0.53	0.42	0.67	0.00	0.17	0.22	0.66	0.95	0.04	0.86	0.29	0.14	0.05	0.71	0.30	0.28	0.73	0.10	0.06	0.76
CAQUETÁ	0.29	0.14	0.00	0.00	0.11	0.16	0.34	0.85	0.04	0.62	0.10	0.03	0.03	0.13	0.37	0.01	0.39	0.01	0.01	0.78
CASANARE	0.29	0.14	0.00	0.00	0.10	0.07	0.27	0.75	0.05	0.36	0.23	0.01	0.03	0.09	0.24	0.01	0.37	0.02	0.01	0.80
SUCRE	0.17	0.07	0.25	0.00	0.13	0.03	0.44	0.84	0.04	0.81	0.14	0.03	0.04	0.04	0.24	0.10	0.94	0.01	0.01	0.80
NARIÑO	0.21	0.33	0.00	1.00	0.11	0.09	0.51	0.83	0.08	0.78	0.17	0.07	0.05	0.02	0.52	0.09	0.50	0.01	0.00	0.81
CALDAS	0.15	0.14	0.31	0.00	0.06	0.01	0.19	0.57	0.01	0.46	0.12	0.02	0.05	0.02	0.06	0.05	1.02	0.02	0.01	0.81
ARCHIPIÉLAGO DE SAN AN	0.02	0.05	0.00	0.25	0.06	0.01	0.83	0.73	0.01	0.67	0.04	0.03	0.00	0.00	0.00	0.00	0.72	0.14	0.11	0.81
QUINDIO	0.08	0.03	0.00	0.00	0.07	0.01	0.09	0.54	0.02	0.58	0.10	0.03	0.04	0.01	0.06	0.00	0.80	0.03	0.02	0.81
CHOCÓ	0.51	0.51	1.00	0.00	0.15	0.24	0.80	0.87	0.03	0.85	0.13	0.03	0.04	0.08	0.51	0.10	0.51	0.01	0.01	0.82
RISARALDA	0.18	0.13	0.38	0.00	0.07	0.01	0.12	0.48	0.01	0.55	0.10	0.06	0.06	0.01	0.03	0.03	0.90	0.02	0.02	0.83
LA GUAJIRA	0.16	0.13	0.23	0.00	0.21	0.39	0.58	0.89	0.04	0.77	0.28	0.04	0.04	0.08	0.35	0.27	0.41	0.01	0.00	0.83
CESAR	0.29	0.51	0.00	0.00	0.13	0.06	0.26	0.74	0.06	0.70	0.16	0.04	0.06	0.01	0.06	0.04	1.27	0.01	0.01	0.83
SANTANDER	0.20	0.15	0.44	0.00	0.09	0.01	0.24	0.55	0.05	0.50	0.09	0.01	0.02	0.01	0.06	0.00	0.92	0.01	0.01	0.83
MAGDALENA	0.43	0.48	0.50	1.00	0.13	0.06	0.47	0.75	0.06	0.80	0.18	0.05	0.04	0.10	0.29	0.01	0.84	0.01	0.01	0.83
GUAVIARE	0.47	0.50	1.00	0.00	0.09	0.26	0.54	0.87	0.02	0.93	0.12	0.02	0.02	0.21	0.33	0.04	0.35	0.04	0.05	0.83
BOLÍVAR	0.40	0.17	0.33	0.00	0.12	0.05	0.49	0.74	0.05	0.74	0.17	0.08	0.06	0.04	0.22	0.00	0.61	0.00	0.00	0.84
HUILA	0.23	0.16	0.60	0.00	0.11	0.04	0.31	0.74	0.05	0.63	0.12	0.05	0.03	0.04	0.16	0.01	0.70	0.01	0.01	0.84
ATLÁNTICO	0.14	0.06	0.00	0.00	0.12	0.01	0.15	0.54	0.03	0.68	0.16	0.03	0.04	0.00	0.02	0.01	1.00	0.01	0.00	0.84
VALLE DEL CAUCA	0.43	0.42	0.39	0.00	0.08	0.01	0.09	0.44	0.02	0.63	0.06	0.05	0.05	0.00	0.10	0.01	0.78	0.00	0.00	0.84
BOGOTÁ, D.C.	0.16	0.15	0.00	0.11	0.08	0.00	0.01	0.25	0.05	0.54	0.11	0.02	0.02	0.00	0.00	0.00	0.76	0.00	0.00	0.84
PUTUMAYO	0.39	0.45	0.40	0.00	0.11	0.22	0.45	0.89	0.12	0.76	0.10	0.02	0.05	0.05	0.24	0.09	0.49	0.02	0.01	0.85
CÓRDOBA	0.16	0.09	0.00	0.00	0.15	0.04	0.58	0.82	0.11	0.79	0.16	0.04	0.03	0.02	0.19	0.08	0.56	0.00	0.00	0.85
ANTIOQUIA	0.26	0.28	0.24	0.50	0.07	0.01	0.17	0.48	0.02	0.47	0.10	0.02	0.02	0.01	0.03	0.00	0.81	0.00	0.00	0.86
TOLIMA	0.17	0.05	0.11	0.00	0.09	0.02	0.26	0.70	0.03	0.71	0.11	0.04	0.07	0.01	0.06	0.03	0.68	0.01	0.00	0.86
BOYACÁ	0.28	0.26	0.19	0.00	0.08	0.03	0.37	0.75	0.03	0.76	0.14	0.04	0.04	0.03	0.10	0.00	0.57	0.01	0.01	0.87
NORTE DE SANTANDER	0.22	0.33	0.15	1.00	0.10	0.04	0.21	0.72	0.03	0.49	0.10	0.07	0.06	0.07	0.11	0.00	0.68	0.01	0.01	0.87
CAUCA	0.25	0.23	0.00	1.00	0.12	0.08	0.56	0.84	0.12	0.80	0.12	0.04	0.04	0.05	0.24	0.17	0.45	0.01	0.00	0.87
CUNDINAMARCA	0.19	0.13	0.14	0.00	0.09	0.02	0.23	0.58	0.04	0.65	0.13	0.02	0.04	0.01	0.04	0.00	0.43	0.00	0.00	0.89
ARAUCA	0.53	0.45	0.45	0.00	0.11	0.08	0.42	0.87	0.05	0.58	0.13	0.03	0.02	0.05	0.09	0.01	0.39	0.03	0.02	0.89
VAUPÉS	0.72	0.20	0.41	0.00	0.19	0.52	0.69	0.96	0.02	0.97	0.35	0.05	0.05	0.32	0.03	0.31	0.14	0.04	0.07	0.90

Table A2.6. Information Used for Clustering Departments Exposed to Fault Line as Proxy for Landslides

Department name	Percentage of exposed population	Percentage of exposed Primary healthcare	Percentage of exposed hospital category II	Percentage of exposed hospital category III	Female Headed Households With No Spouse And Children Under The Age Of 18	No Electricity	No Sewerage	No Internet	Households With More Than Two Families	Prevalence Of Protein Intake Deficiency By Department	Chronic Malnutrition In Children 0 To 4 Years Old	Mortality Rate Due To Malnutrition Per 100,000 Inhabitants Females	Mortality Rate Due To Malnutrition Per 100,000 Inhabitants Males	Average Distance To Primary Health Care (Km)	Average Distance To Hospitals (Km)	Native And Indigenous Population	Number Of Beds Per Department	Number Of Physicians Per Department	Number Of Nurses Per Department	Integrated Risk Index
VICHADA	0.02	0.00	0.00	0.00	0.17	0.57	0.94	0.95	0.06	0.89	0.16	0.03	0.09	1.00	0.71	0.47	0.41	0.11	0.11	0.68
META	0.04	0.01	0.00	0.00	0.09	0.08	0.22	0.66	0.04	0.71	0.08	0.05	0.07	0.12	0.40	0.02	0.69	0.01	0.01	0.72
NARIÑO	0.04	0.03	0.00	0.00	0.11	0.09	0.51	0.83	0.08	0.78	0.17	0.07	0.05	0.02	0.52	0.09	0.50	0.01	0.00	0.76
CAQUETÁ	0.04	0.02	0.00	0.00	0.11	0.16	0.34	0.85	0.04	0.62	0.10	0.03	0.03	0.13	0.37	0.01	0.39	0.01	0.01	0.78
CHOCÓ	0.04	0.05	0.00	0.00	0.15	0.24	0.80	0.87	0.03	0.85	0.13	0.03	0.04	0.08	0.51	0.10	0.51	0.01	0.01	0.78
MAGDALENA	0.03	0.03	0.07	0.00	0.13	0.06	0.47	0.75	0.06	0.80	0.18	0.05	0.04	0.10	0.29	0.01	0.84	0.01	0.01	0.78
CASANARE	0.04	0.03	0.00	0.00	0.10	0.07	0.27	0.75	0.05	0.36	0.23	0.01	0.03	0.09	0.24	0.01	0.37	0.02	0.01	0.79
SUCRE	0.01	0.00	0.00	0.00	0.13	0.03	0.44	0.84	0.04	0.81	0.14	0.03	0.04	0.04	0.24	0.10	0.94	0.01	0.01	0.80
CALDAS	0.04	0.05	0.15	0.00	0.06	0.01	0.19	0.57	0.01	0.46	0.12	0.02	0.05	0.02	0.06	0.05	1.02	0.02	0.01	0.80
ARCHIPIÉLAGO DE SAN A	0.03	0.00	0.00	0.00	0.06	0.01	0.83	0.73	0.01	0.67	0.04	0.03	0.00	0.00	0.00	0.00	0.72	0.14	0.11	0.81
QUINDIO	0.06	0.01	0.09	0.00	0.07	0.01	0.09	0.54	0.02	0.58	0.10	0.03	0.04	0.01	0.06	0.00	0.80	0.03	0.02	0.81
VALLE DEL CAUCA	0.06	0.10	0.13	0.00	0.08	0.01	0.09	0.44	0.02	0.63	0.06	0.05	0.05	0.00	0.10	0.01	0.78	0.00	0.00	0.82
SANTANDER	0.06	0.02	0.00	0.00	0.09	0.01	0.24	0.55	0.05	0.50	0.09	0.01	0.02	0.01	0.06	0.00	0.92	0.01	0.01	0.82
HUILA	0.06	0.02	0.00	0.00	0.11	0.04	0.31	0.74	0.05	0.63	0.12	0.05	0.03	0.04	0.16	0.01	0.70	0.01	0.01	0.82
CESAR	0.03	0.04	0.00	0.00	0.13	0.06	0.26	0.74	0.06	0.70	0.16	0.04	0.06	0.01	0.06	0.04	1.27	0.01	0.01	0.82
RISARALDA	0.13	0.10	0.25	0.00	0.07	0.01	0.12	0.48	0.01	0.55	0.10	0.06	0.06	0.01	0.03	0.03	0.90	0.02	0.02	0.82
NORTE DE SANTANDER	0.09	0.05	0.20	0.00	0.10	0.04	0.21	0.72	0.03	0.49	0.10	0.07	0.06	0.07	0.11	0.00	0.68	0.01	0.01	0.82
BOLÍVAR	0.02	0.01	0.00	0.00	0.12	0.05	0.49	0.74	0.05	0.74	0.17	0.08	0.06	0.04	0.22	0.00	0.61	0.00	0.00	0.82
LA GUAJIRA	0.02	0.00	0.00	0.00	0.21	0.39	0.58	0.89	0.04	0.77	0.28	0.04	0.04	0.08	0.35	0.27	0.41	0.01	0.00	0.83
PUTUMAYO	0.02	0.04	0.00	0.00	0.11	0.22	0.45	0.89	0.12	0.76	0.10	0.02	0.05	0.05	0.24	0.09	0.49	0.02	0.01	0.83
ANTIOQUIA	0.04	0.01	0.03	0.13	0.07	0.01	0.17	0.48	0.02	0.47	0.10	0.02	0.02	0.01	0.03	0.00	0.81	0.00	0.00	0.83
ATLÁNTICO	0.00	0.00	0.00	0.00	0.12	0.01	0.15	0.54	0.03	0.68	0.16	0.03	0.04	0.00	0.02	0.01	1.00	0.01	0.00	0.84
BOGOTÁ, D.C.	0.00	0.00	0.00	0.00	0.08	0.00	0.01	0.25	0.05	0.54	0.11	0.02	0.02	0.00	0.00	0.00	0.76	0.00	0.00	0.84
CAUCA	0.08	0.03	0.00	0.00	0.12	0.08	0.56	0.84	0.12	0.80	0.12	0.04	0.04	0.05	0.24	0.17	0.45	0.01	0.00	0.84
CÓRDOBA	0.02	0.01	0.00	0.00	0.15	0.04	0.58	0.82	0.11	0.79	0.16	0.04	0.03	0.02	0.19	0.08	0.56	0.00	0.00	0.85
BOYACÁ	0.04	0.04	0.03	0.00	0.08	0.03	0.37	0.75	0.03	0.76	0.14	0.04	0.04	0.03	0.10	0.00	0.57	0.01	0.01	0.86
TOLIMA	0.12	0.11	0.00	0.50	0.09	0.02	0.26	0.70	0.03	0.71	0.11	0.04	0.07	0.01	0.06	0.03	0.68	0.01	0.00	0.87
ARAUCA	0.02	0.01	0.00	0.00	0.11	0.08	0.42	0.87	0.05	0.58	0.13	0.03	0.02	0.05	0.09	0.01	0.39	0.03	0.02	0.87
CUNDINAMARCA	0.02	0.03	0.02	0.00	0.09	0.02	0.23	0.58	0.04	0.65	0.13	0.02	0.04	0.01	0.04	0.00	0.43	0.00	0.00	0.89
VAUPÉS	0.00	0.00	0.00	0.00	0.19	0.52	0.69	0.96	0.02	0.97	0.35	0.05	0.05	0.32	0.03	0.31	0.14	0.04	0.07	0.89

Facility Prioritizations

Table A2.7. Health Facility Prioritization at Department Level, Top Three PHCs for Flooding

Hospital/PHC ID	Name	Category	Priority	Department
910010001901	--	1	1	Amazonas
915400001925	--	1	2	Amazonas
917980001927	--	1	3	Amazonas
53900509001	Empresa Social del Estado Hospital Antonio Roldan Betancur	1	1	Antioquia
55850472501	Empresa Social del Estado Hospital Octavio Olivares	1	2	Antioquia
58370556846	--	1	3	Antioquia
810010053901	--	1	1	Arauca
810010006101	Empresa Social del Estado Jaime Alvarado y Castilla	1	2	Arauca
817940020634	E.S.E. Moreno y Clavijo	1	3	Arauca
880010027904	--	1	1	Archipielago de San Andres, Providencia y Santa Catalina
80010322901	--	1	3	Atlantico
80010445421	--	1	1	Atlántico
80010423901	--	1	2	Atlántico
110010101031	--	1	1	Bogotá, D.C.
110011617101	--	1	2	Bogotá, D.C.
110011552801	--	1	3	Bogotá, D.C.
135490035501	--	1	1	Bolívar
135490009501	E.S.E. Hospital San Nicolas de Tolentino	1	2	Bolívar
135490009504	E.S.E. Hospital San Nicolas de Tolentino	1	3	Bolívar
152380277101	--	1	1	Boyacá
151760162001	--	1	2	Boyacá
150470210507	--	1	3	Boyacá
238070092904	--	1	1	Córdoba
230680209605	--	1	2	Córdoba
238070010607	E.S.E. Hospital San Jose de Tierralta	1	3	Córdoba
177770005401	E.S.E. Hospital San Lorenzo de Supia	1	1	Caldas
173800051903	--	1	2	Caldas
173800051905	--	1	3	Caldas
180010755103	--	1	1	Caquetá
187530747501	--	1	2	Caquetá
182470748201	--	1	3	Caquetá
853250010001	--	1	1	Casanare

Hospital/PHC ID	Name	Category	Priority	Department
853250042213	Red Salud Casanare E.S.E.	1	2	Casanare
852500282501	--	1	3	Casanare
195130719602	Empresa Social del Estado Norte 3 - E.S.E.	1	1	Cauca
193000913901	--	1	2	Cauca
195730618805	--	1	3	Cauca
203830045301	Hospital San Jose E.S.E.	1	1	Cesar
200130167803	--	1	2	Cesar
200010046440	E.S.E. Hospital Eduardo Arredondo Daza	1	3	Cesar
274950007115	--	1	2	Chocó
276150111201	--	1	1	Chocó
270010002617	E.S.E. Hospital Local Ismael Roldan Valencia	1	3	Chocó
257540380801	--	1	1	Cundinamarca
252690222101	--	1	2	Cundinamarca
252690014925	--	1	3	Cundinamarca
85730070701	--	1	2	Guainía
85730200501	--	1	3	Guainía
943430005702	--	1	1	Guainía

Hospital/PHC ID	Name	Category	Priority	Department
950010000302	Empresa Social del Estado Red de Servicios de Salud de Primer Nivel	1	1	Guaviare
950010013701	--	1	2	Guaviare
950010000101	--	1	3	Guaviare
413960129508	--	1	1	Huila
410010217001	--	1	2	Huila
413960043213	E.S.E. San Sebastian de La Plata Huila	1	3	Huila
443780033910	--	1	1	La Guajira
443780057101	--	1	2	La Guajira
440900033914	--	1	3	La Guajira
475700024401	E.S.E. Hospital Local San Jose	1	1	Magdalena
471890024205	--	1	2	Magdalena
471890024208	--	1	3	Magdalena
500010149203	--	1	1	Meta
500010054022	E.S.E. del Municipio de Villavicencio	1	2	Meta
500010199501	--	1	3	Meta
528350090509	Centro Hospital Divino Niño E.S.E.	1	1	Nariño
524900066925	--	1	2	Nariño
520010145712	Empresa Social del Estado Pasto Salud E.S.E.	1	3	Nariño

Hospital/PHC ID	Name	Category	Priority	Department
544050100801	E.S.E. Hospital Local Municipio Los Patios	1	1	Norte de Santander
540010086112	E E.S.E. Imsalud	1	2	Norte de Santander
540010060304	--	1	3	Norte de Santander
868650001001	E.S.E. Hospital Sagrado Corazon de Jesus	1	1	Putumayo
868650001006	E.S.E. Hospital Sagrado Corazon de Jesus	1	2	Putumayo
867600079403	--	1	3	Putumayo
633020043001	E.S.E. Hospital San Vicente de Paul	1	1	Quindio
632120050301	Hospital San Roque de Cordoba Quindio Empresa Social del Estado	1	2	Quindio
631300040306	--	1	3	Quindio
664000120302	--	1	1	Risaralda
664000186101	--	1	2	Risaralda
664000020811	--	1	3	Risaralda
683070214401	--	1	1	Santander
683070212014	--	1	2	Santander
680810502902	--	1	3	Santander
707130039008	E.S.E. Hospital Local de San Onofre	1	1	Sucre
707710129802	--	1	2	Sucre

Hospital/PHC ID	Name	Category	Priority	Department
702650099401	E.S.E. Centro de Salud de Guaranda	1	3	Sucre
734490011101	--	1	1	Tolima
730670081801	Hospital Nuestra Señora de Lourdes E.S.E.	1	2	Tolima
734490197501	--	1	3	Tolima
763640375607	--	1	1	Valle del Cauca
763641109802	--	1	2	Valle del Cauca
760010395725	Red de Salud del Oriente Empresa Social del Estado E.S.E	1	3	Valle del Cauca
970010000601	--	1	1	Vaupés
970010001301	--	1	2	Vaupés
970010000101	--	1	3	Vaupés
996240012201	--	1	1	Vichada
996240000609	--	1	2	Vichada
995240000608	--	1	3	Vichada

Table A2.8. Health Facility Prioritization at Department Level, Top Three Hospitals for Flooding

Hospital ID	Name	Category	Priority	Department
917980001927	Centro de Salud Tarapaca - E.S.E Hospital San Rafael de Leticia	2	1	Amazonas
916690001926	Centro de Salud Tarapaca - E.S.E Hospital San Rafael de Leticia	2	2	Amazonas
915360001920	Centro de Salud Puerto Arica- E.S.E Hospital San Rafael de Leticia	2	3	Amazonas
51540220101	ESE Hospital Cesar Uribe Piedrahita	2	1	Antioquia
53600433902	ESE Hospital San Rafael de Itagui	2	2	Antioquia
58370228703	Centro de Salud Felix Londoño	2	3	Antioquia
810010007701	Hospital San Vicente ESE	2	1	Arauca
817360006711	Puesto de Salud Bajo San Joaquin	2	2	Arauca
817360006715	Puesto de Salud Puerto Lleras	2	3	Arauca
885640027901	Hospital Local de Providencia	3	1	Archipielago de San Andres, Providencia y Santa Catalina
110013029640	Unidad de Servicios de Salud San Bernardino	3	1	Bogotá, D.C.
110013029131	Unidad de Servicios de Salud Orquideas	3	2	Bogotá, D.C.
110013029132	Unidad de Servicios de Salud Verbenal	3	3	Bogotá, D.C.
134680049204	E.S.E. Hospital La Divina Misericordia Sede San Juan de Dios Mompós	2	1	Bolívar
134300049205	Santisima Trinidad	2	2	Bolívar
132440049301	E.S.E. Hospital Nuestra SeVëora del Carmen	2	3	Bolívar
155180079803	Unidad Basica de Atencion del Municipio de Pajarito	2	1	Boyaca
157590079801	Hospital Regional de Sogamoso Empresa Social del Estado	2	2	Boyaca
155720080702	Puesto de Salud Pueblo Nuevo	2	3	Boyaca
176140087404	Centro de Salud San Lorenzo	2	1	Caldas
176530064609	Centro de Salud San Felix	2	2	Caldas
173800051903	Puesto de Salud de Guarinocito	2	3	Caldas
190010003101	Hospital Universitario San Jose de Popayan Empresa Social del Estado	3	1	Cauca
270010116901	Nueva Empresa Social del Estado Hospital Departamental San Francisco de Asis	2	1	Chocó
257450002603	Centro de Salud de Simijaca - (257450002603)	2	1	Cundinamarca

Hospital ID	Name	Category	Priority	Department
255130002801	E.S.E. Hospital San Rafael de Pacho - (255130002801)	2	2	Cundinamarca
255350003611	Puesto de Salud de Pasca - (255350003611)	2	3	Cundinamarca
975110000155	U.B.P. Puerto Esperanza	2	1	Guainía
950010000101	Empresa Social del Estado Hospital San Jose del Guaviare	2	1	Guaviare
413960040702	Ese Hospital Departamental San Antonio de Padua	2	1	Huila
412980041902	Centro Integral de Terapias	2	2	Huila
412980041903	Sede Ambulatoria	2	3	Huila
446500028614	Puesto de Salud Los Tunales	2	1	La Guajira
446500028607	Centro de Salud Caracoli	2	2	La Guajira
446500028601	Empresa Social del Estado Hospital San Rafael	2	3	La Guajira
472450024901	Empresa Social del Estado Hospital La Candelaria	2	1	Magdalena
470010065001	Hospital Universitario Julio Mendez Barreneche	3	2	Magdalena
471890024207	Puesto de Salud Miramar	2	3	Magdalena
520010110201	Hospital Universitario Departamental de Nariño	3	1	Nariño
540010037101	E.S.E Hospital Universitario Erasmo Meoz	3	1	Norte de Santander

Hospital ID	Name	Category	Priority	Department
545180037201	Hospital San Juan de Dios de Pamplona	2	2	Norte de Santander
542230037206	Centro de Salud Divino Niño de Cucutilla	2	3	Norte de Santander
865730018505	Puesto de Salud Pi√ëu√ëa negro	2	1	Putumayo
867490001703	Centro de Salud Santiago Rengifo	2	2	Putumayo
860010003823	Jose María Hernandez Promoción y Mantenimiento de La Salud	2	3	Putumayo
664000071601	Empresa Social del Estado Hospital San Pedro y San Pablo La Virginia	2	1	Risaralda
661700027805	Centro de Atención Ambulatorio Santa Teresita	2	2	Risaralda
661700027803	Puesto de Salud Frailes	2	3	Risaralda
680810079701	Empresa Social del Estado Hospital Regional del Magdalena Medio	2	1	Santander
682760071701	Empresa Social del Estado Hospital San Juan de Dios de Floridablanca	2	2	Santander
680810070202	Hospital Psiquiatrico San Camilo Sede Barrancabermeja	2	3	Santander
707080033101	Ese Hospital Regional Ii Nivel de San Marcos	2	1	Sucre

Hospital ID	Name	Category	Priority	Department
732680079401	Hospital San Rafael de El Espinal Empresa Social del Estado E.S.E.	2	1	Tolima
760010511501	Hospital Isaias Duarte Cancino Empresa Social del Estado	2	1	Valle del Cauca
768340465201	E.S.E. Hospital Departamental Tomas Uribe Uribe de Tulua Ese Empresa Social del Estado	2	2	Valle del Cauca
766220170911	Puesto de Salud De Cajamarca	2	3	Valle del Cauca
970010000154	U.B.P. Camanaos	2	1	Vaupes
970010000150	U.B.P. Virabazu	2	2	Vaupes
970010000101	E.S.E. Hospital San Antonio	2	3	Vaupes
996240000609	Hospital Sede Santa Rosalia	2	1	Vichada

Table A2.9. Health Facility Prioritization at Department Level, Top Three PHCs for Landslides

PHC ID	Name	Category	Priority	Department
50010210903	--	1	1	Antioquia
51010213902	--	1	2	Antioquia
51010213903	--	1	3	Antioquia
817940029501	--	1	1	Arauca
817940011701	--	1	2	Arauca
136700007601	E.S.E. Hospital Local San Pablo	1	1	Bolívar
138100002707	E.S.E. Hospital San Juan De Puerto Rico	1	3	Bolívar
138730074801	--	1	2	Bolívar
151760202902	--	1	1	Boyaca
153670006401	Empresa Social del Estado Centro de Salud Jenesano	1	2	Boyaca
151760193501	--	1	3	Boyaca
235550198901	--	1	1	Córdoba
235550189302	--	1	2	Córdoba
236860045311	E.S.E. Camu De San Pelayo	1	3	Córdoba
170010020402	--	1	1	Caldas
170010081746	Assbasalud E.S.E.	1	2	Caldas
170010221601	--	1	3	Caldas
182560200203	E.S.E. Sor Teresa Adele	1	1	Caqueta
182470705501	--	1	2	Caqueta

PHC ID	Name	Category	Priority	Department
852790042217	Red Salud Casanare E.S.E.	1	1	Casanare
850010014406	Empresa Social del Estado Salud Yopal	1	2	Casanare
852300042209	Red Salud Casanare E.S.E.	1	3	Casanare
198210004001	Cxayu`ce Jxut Empresa Social del Estado	1	1	Cauca
190500011413	Ese Sur Occidente	1	2	Cauca
191100000505	Empresa Social del Estado Norte 1 E.S.E.	1	3	Cauca
202380053102	Hospital San Roque Ese	1	1	Cesar
205170051801	Hospital Heli Moreno Blanco E.S.E	1	2	Cesar
201750036015	E.S.E. Hospital Inmaculada Concepcion de Chimihcagua	1	3	Cesar
277870040702	--	1	1	Chocó
273610034201	--	1	2	Chocó
277870009701	E.S.E. Hospital San Jose de Tado	1	3	Chocó
252690222101	--	1	1	Cundinamarca
252690014925	--	1	2	Cundinamarca
252690396801	--	1	3	Cundinamarca
413590042402	E.S.E. Hospital San Jose de Isnos	1	1	Huila
413570047401	Empresa Social del Estado Hospital Maria Auxiliadora	1	2	Huila
410010045107	E.S.E. Carmen Emilia Ospina	1	3	Huila

PHC ID	Name	Category	Priority	Department
446500028613	--	1	1	La Guajira
479800023813	Empresa Social del Estado Hospital Local de Zona Bananera	1	1	Magdalena
470010007129	Ese Alejandro Prospero Reverend	1	2	Magdalena
470010114801	--	1	3	Magdalena
500010133101	--	1	1	Meta
506890150501	--	1	2	Meta
506890045701	Empresa Social del Estado Hospital Local de San Martin de Los Llanos	1	3	Meta
526850137801	Ese Centro de Salud San Bernardo	1	1	Nariño
520010202302	--	1	2	Nariño
526850137802	Ese Centro de Salud San Bernardo	1	3	Nariño
542450102016	Empresa Social del Estado Hospital Regional Noroccidental	1	1	Norte de Santander
544980190101	--	1	2	Norte de Santander
540010206602	--	1	3	Norte de Santander
867550001704	--	1	1	Putumayo
867490068501	--	1	2	Putumayo
867550079405	--	1	3	Putumayo
630010122302	--	1	1	Quindio

PHC ID	Name	Category	Priority	Department
630010114501	--	1	2	Quindio
661700227002	--	1	1	Risaralda
661700027804	--	1	2	Risaralda
661700075907	--	1	3	Risaralda
682550239101	--	1	1	Santander
680010070117	Empresa Social del Estado Instituto de Salud de Bucaramanga	1	2	Santander
680010427302	--	1	3	Santander
705080189201	--	1	1	Sucre
700010139601	--	1	2	Sucre
730010297401	--	1	1	Tolima
735550103101	Hospital Centro E.S.E. de Planadas	1	2	Tolima
730010255901	--	1	3	Tolima
760011261801	--	1	1	Valle del Cauca
760010395903	Red de Salud de Ladera Empresa Social del Estado	1	2	Valle del Cauca
760010837601	--	1	3	Valle del Cauca

Table A2.10. Health Facility Prioritization at Department Level, Top Three Hospitals for Landslides

Hospital	Name	Nivel	Priority	Department
51290214601	E.S.E Hospital San Vicente de Pa√öl de Caldas	2	1	Antioquia
50040547802	Ese Hospital San Juan de Dios de Abriaqui	2	2	Antioquia
51010213901	E.S.E Hospital La Merced de Ciudad Bolivar	2	3	Antioquia
156730033202	Centro de Salud de San Mateo	2	1	Boyaca
176530064609	Centro de Salud San Felix	2	1	Caldas
176530064607	Centro de Promocion y Prevencion	2	2	Caldas
251230004313	Puesto de Salud Pe√ëa Negra - (251230004313)	2	1	Cundinamarca
471890024204	Puesto de Salud de Palmor	2	1	Magdalena
544980054701	Empresa Social del Estado Hospital Emiro Quintero Ca√ëizares	2	1	Norte de Santander
544980054704	Puesto de Salud Otare	2	2	Norte de Santander
543440054709	Centro de Salud de Hacari	2	3	Norte de Santander
631300040307	Centro de Salud Balcones	2	1	Quindio
661700027803	Puesto de Salud Frailes	2	1	Risaralda
661700027804	Centro de Atención Ambulatorio Jap√în	2	2	Risaralda
730010104701	Hospital Federico Lleras Acosta E.S.E.	3	1	Tolima
760010360902	Centro de Rehabilitación En Salud Mental - Cresm	2	1	Valle del Cauca
760010360901	E.S.E. Hospital Departamental Psiquiátrico Universitario del Valle	2	2	Valle del Cauca
766220170904	Puesto de Salud Higueroncito	2	3	Valle del Cauca

Artificial Intelligence-Based Integrated Climate-Sensitive Risk Index: Method Details

This section describes the methodology to compute the risk index for the exposed population and healthcare infrastructure impacted by a natural hazard as depicted in Figure 25.

The first part of the methodology takes as input a natural hazard under study (c.f. Figure A2.4). The natural hazard is represented as geometric location and attributes information of geographical entities. The geographic entities are represented by points, lines, or polygons (areas). Associated with geographical information, the spatial entity contains attribute values representing the intensity or quantity of the hazard. This element will be used to identify both the population and the healthcare infrastructure exposed to the natural hazard.

The second step looks at the geolocated population and the location of the healthcare facilities. Regarding the geolocated population representation, the method is able to digest top-down unconstrained population grid (National Service of Meteorology and Hydrology of Peru 2023; Gaughan et al. 2016; Sorichetta et al. 2015), which is most suitable for historical or change analyses. For some countries, top-down constrained population grid (Sorichetta 2015; WorldPop 2023) is more convenient and accurate, or block-level population census (Stevens et al. 2015). Figure A2.2a (above) illustrates examples of the (un)constrain and block-level geolocated population representation, respectively.

This approach can also handle different political divisions to perform a national or subnational exposure analysis. Thus, different administrative levels are supported. For instance, Figure A2.2 (above) shows different administrative levels where the exposure analysis can be performed.

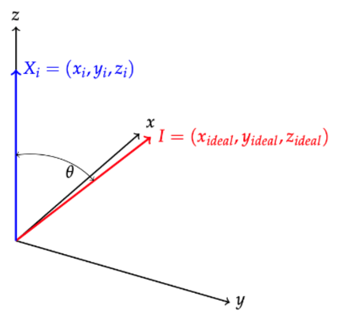
A spatial intersection can be defined as a point where two or more spatial objects, like lines or polygons, intersect. Intersection points are used for different objectives, such as location identification, relationship definition between features, and spatial analysis. For example, an intersection can be used to determine if a census unit block overlaps a hazard polygon. If a spatial object A intersects all its surfaces with another spatial entity B, it can be inferred that B includes A. Thus, this operation is used to determine whether a healthcare facility is contained in a polygon representing a hazard for exposure analysis. It is essential to highlight that census units or blocks outside administrative boundaries are assigned to the closest administrative region.

To output the exposure analysis for population, our approach counts the number of individuals where the census units or blocks centroid intersects with the polygon representing the natural hazard. For healthcare facilities, the method counts the number of facilities contained in a polygon modeling a natural hazard filtered by healthcare service complexity, such as primary healthcare and hospitals.

Once the exposed population and healthcare infrastructure are identified, it is necessary to integrate these results to the population's sociodemographic characteristics and healthcare facilities' features.

The idea behind the use of these variables, by territorial unit, is to represent the vulnerability of the exposed population and healthcare infrastructure. Additionally, vulnerability could be composed of different elements such as sensibility or fragility, adaptive capacity, health damage, etc. The proposed tool is flexible in integrating different vulnerability conceptual frameworks.

Figure A2.12. Cosine Similarity Between the Ideal Vector I and a Vector X Representing Two Districts



To characterize a territorial unit, the method uses vectors composed of different dimensions, such as poverty, hospital density, number of native populations, percentage of exposed population, percentage of exposed primary healthcare infrastructure, percentage of exposed hospitals, accessibility time to the healthcare system (Tariverdi et al. 2023), etc. For instance, Figure A2.12 depicts the similarity *θ of vectors X and I,* which represent two different districts. In this example, x is the poverty index, y is the percentage of exposed population, and z is the percentage of exposed hospitals. Thus, to compute the distance between them, the Cosine Similarity represented by the following equation is used.

$$Cos(I, X) = 1 - \frac{I \cdot X}{||I|| * ||X||}$$

There are two methods to establish the risk level (very high, high, medium, or low) of the territorial units: grouping and risk index. The former relies on an unsupervised Machine Learning technique called k-means (Hartigan and Wong 1979), which uses the Cosine similarity (Lahitani, Permanasari and Setiawan 2016) as distance function. Therefore, the k-means algorithm is able to group the territorial units into four different groups (k=4) sharing the same hazard exposure, socioeconomic attributes, and infrastructure features.

The risk index method establishes a risk index ranking using cosine similarity. Accordingly, an ideal vector I, capturing country objectives is defined. For example, an ideal vector could be represented by 10 percent of poor population, 5 percent of exposed population, and 15 percent of the exposed hospitals. Therefore, the ranking measures how far a territorial unit is from the ideal values. Then, the quarterlies of the ranking are tagged as very high, high, medium, and low risk level. It is important to note that the example only consider three features, but the groups method can handle high dimensional characterizations depending on the sector under study and availability of data.

Table A2.11. Targets of Different Factor Variables

	Target value %
Female-headed households with no spouse and children under the age of 18	0.05
No access to reliable electricity	0.05
No sewerage system at dwelling	0.05
No access to internet	0.05
Dwelling with more than two families	0.01
Prevalence of protein intake deficiency by department	0.05
Chronic malnutrition in children 0 to 4 years old	0.065
Mortality rate due to malnutrition per 100,000 inhabitants females	0.065
Mortality rate due to malnutrition per 100,000 inhabitants males	0.065
Average distance to primary health care (km)	2
Average distance to hospitals (km)	5
Exposed population	0.05
Percentage of exposed Primary healthcare	0.01
Percentage of exposed hospital category II	0.01
Percentage of exposed hospital category III	0.01
Native and indigenous population	0.05
Number of beds per department*	2.2
Number of physicians per department*	3.5
Number of nurses per department*	9

** The consulted document reports statistics for the year 2016.*

ANNEX 3. COMPONENT 3

Figure A3.1. Results of Performance Measurements at the Departmental Level in Colombia, 2021

Departament	Financial Dependency (2021)	Execution of own income budget (2021)	Human Resources (2021)	Disaster Risk Management (2021)	Goal completion: Environment and Sustainable Development (2022)	Goal completion: Health and Social Protection (2022)
ANTIOQUIA	37.2%	82	86.66	50.29	21.52	64.97
Atlántico	36.4%	80	75.79	40.21	50	58.75
BOLÍVAR	61.0%	61	65.06	52.89	100	75.38
BOYACÁ	64.0%	61	88.97	54.59	97.34	99.81
CALDAS	46.7%	94	98.50	51.56		
CAQUETÁ	73.0%	81	70.61	48.10	100	85.92
CAUCA	78.1%	66	69.14	56.04	100	92.09
CESAR	75.7%	18	78.05	51.06	81.04	84.11
CÓRDOBA	76.8%	61	78.82	47.02	34.97	93.08
CUNDINAMARCA	35.4%	78	99.12	51.85	80.86	87.92
CHOCÓ	73.7%	63	64.87	56.10	100	100
HUILA	64.7%	64	79.85	51.40	100	96.43
LA GUAJIRA	73.7%	56	81.37	54.39	11.11	90.73
MAGDALENA	61.8%	65	70.99	51.46	18.18	64.18
META	51.7%	69	97.97	43.04	49.3	87.55
NARIÑO	64.1%	56	73.73	53.08	63.86	98.22
NORTE DE SANTANDER	68.6%	46	83.62	61.18	97.57	98.65
QUINDÍO	52.3%	75	98.07	45.32	50.54	88.94
RISARALDA	42.8%	72	84.89	50.36	91.06	90.3
SANTANDER	47.6%	64	79.30	51.61	90.91	98.14
SUCRE	80.5%	75	85.80	45.49	100	87.67
TOLIMA	58.7%	56	85.32	52.01	59.37	75.46
VALLE DEL CAUCA	31.2%	87	78.72	48.17	29.71	73.44
ARAUCA	78.9%	20	77.75	55.95	17.65	56.14
CASANARE	66.9%	21	76.82	48.48	99.81	89.33
PUTUMAYO	79.6%	36	64.22	44.80	87.73	79.33
ARCH SAN ANDRÉS	39.3%	45	66.75	34.51	17.7	82.53
AMAZONAS	88.6%	33	56.83	45.48	12.63	82.28
GUAINÍA	72.2%	52	59.39	46.10	66.33	84.27
GUAVIARE	73.2%	90	56.65	43.02	45.64	87.72
VAUPÉS	83.3%	47	74.12	42.24	58.47	56.43
VICHADA	81.4%	18	60.54	47.32	25	66.56

Source: Prepared using data from the DNP (2021).

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