Climate change and cardiovascular diseases in India and South Africa: Impacts, perceptions and policy responses

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"The greatest threat to our planet is the belief that someone else will save it"

- Robert Swan

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Executive Summary

Background

As a result of anthropogenic climate change, global average temperatures, the severity, frequency and intensity of extreme weather events are on the rise. Several diseases, including vector borne diseases, mental health, conflicts and non-communicable diseases, such as cardiovascular diseases (CVDs), are climate-sensitive and climate change is contributing to driving their disease burden.

Primarily a lifestyle disease, CVDs are already the leading cause of mortality worldwide, with environmental factors such as temperature and air pollution further contributing to their burden. The impacts of climate change are highly regional and depend on contextual vulnerabilities. This especially poses a major public health challenge in low- and middle-income (LMIC) countries, which have limited resources availability and capacity to react to the threat.

Despite a growing body of evidence on the association between climate change variables, such as temperature, and CVDs, there remains a large knowledge and evidence gap on this topic in LMICs, including India and South Africa, which have been examined in this body of work. The findings contribute to furthering our understanding of how climate change affects CVDs in India and South Africa.

Methods

A multi-methods approach was used, comprising of quantitative and qualitative approaches. The association between apparent temperature (T_{app}) and in-hospital CVD mortalities was modelled using a case crossover approach with a distributed lag non-linear model (dlnm) in Puducherry, India. A similar approach using a negative binomial distribution with the dlnm was used to model the association between T_{app} and CVD morbidity, measured through CVD hospitalizations, in the Limpopo Province of South Africa. Both models considered a 21-day lag period.

Key informant interviews were carried out in Puducherry with medical professionals, environmentalists and government officials to understand their perspectives on climate change and health, with a focus on CVDs. In light of the paucity of research on climate change and health in India, these interviews were also used to understand the research barriers and challenges for climate change and health research in Puducherry. The findings were analysed using qualitative thematic analysis following the Framework method.

National and State level policies and document pertaining to climate change, adaptation, health, environment and CVDs were systematically reviewed. The policies were analysed qualitatively using the Framework method and content analysis to understand how CVDs are represented in the climate change adaptation policy space in India and the gaps therein.

Findings

The optimal T_{app} range for Puducherry is between 30 to 36°C, with temperatures above and below this associated with an increased risk of CVD mortality. Up to 17% of in-hospital mortalities were attributable to non-optimal T_{app} in Puducherry between 2011 and 2020. Out of this 9.1% and 8.3% of the burden was attributable to heat and cold respectively, with males being more vulnerable to cold and females over 60 years of age affected predominantly by heat. Patients were more prone to cerebrovascular accidents during hot periods. In Limpopo, the optimal T_{app} range is between 25 to 27°C, and 8.5% of CVD hospital admissions were attributable to heat and 1.1% to cold.

In Puducherry, the perceived health risks from climate change were largely a product of individual knowledge of the local public health burden and vulnerabilities, with some level of scepticism on the association between climate change and CVDs. There was a perceived gap in technical education about climate change and health, despite awareness of the same as a concept. Informants also expressed a need for multi-level, inclusive awareness programs targeting different social groups. Data collection systems, access to health data and underdeveloped technical and methodological research capacity were considered the biggest research barriers when it came to climate change and health. The topic was not considered a research or political priority, with limited resources being allocated to most climate sensitive outcomes. Informants also described a tendency for environmental health research to centre on conventional health outcomes, as opposed to CVDs.

Most Indian national and State policies are focused on vector borne diseases and heat-related illnesses, the latter of which does not fully encompass all temperature sensitive CVDs, as part of the efforts to address climate change impacts on health. Strengthening health surveillance systems to capture CVDs could also contribute to improving research output on the topic from India and strengthen contextual adaptation planning. The political commitment to addressing the health impacts of climate change as well as CVD management could be used in tandem to facilitate interventions and actions on climate change and CVDs. Many of the State level plans were found to be incomplete or simply templates, and thus there is an urgent need to focus on ensuring the development or completion of these plans.

Conclusion

Climate change impacts on CVDs are an emerging problem of concern for both India and South Africa. Non-optimal temperatures are associated with increasing the risk of CVD events in both countries. Parallel streams focusing on improving awareness and education and improving monitoring and surveillance systems could potentially contribute to addressing this issue in India. There is a pressing need to improve evidence synthesis on the topic in both countries, with efforts taken to ensure climate change and health becomes a priority for both research and policy supported interventions and actions for adaptation.

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List of abbreviations

AF	Attributable Fraction
AIC	Akaike Information Criterion
CH_4	Methane
CI	Confidence Intervals
CO_2	Carbon Dioxide
COVID-19	Coronavirus Disease 2019
CPD	Cardio-pulmonary Diseases
CV	Cardiovascular
CVA	Cerebrovascular Accidents
CVAAPICF	Climate Vulnerability Assessment for Adaptation Planning in India using a Common Framework
CVD	Cardiovascular Disease
Dlnm	Distributed Lag Non-Linear Model
DOW	Day of the Week
DSTE	Department of Science, Technology and Environment
EWS	Early Warning System
GHG	Greenhouse Gases
hPa	Vapour Pressure
HRI	Heat Related Illness
HVACC	Health Vulnerability Assessment in the Context of Climate Change
ICD-10	International Classification of Diseases-10
ICF	Informed Consent Form
IDSP	Integrated Disease Surveillance Program
IGGGH	Indira Gandhi Government General Hospital and Post Graduate
IHD	Ischemic Heart Diseases
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
JIPMER	Jawaharlal Institute of Postgraduate Medical Education and Research
LMIC	Low- and Middle-Income Countries
MMT	Minimum Mortality Temperature
MoEF&CC	Ministry of Environment, Forests and Climate Change's
MoHFW	Ministry of Health and Family Welfare
N_2O	Nitrous Oxide
NAPCC	National Action Plan on Climate Change
NAPCCHH	National Action Plan on Climate Change and Human Health
NAPCPD	National Adaptation Plan for Cardiopulmonary Diseases
NAPDAP	National Action Plan for Diseases due to Air Pollution
NAPHRI	National Action Plan for Heat Related Illnesses
NAPMFNCD	National Action Plan and Monitoring Framework for Prevention and Control of NCDs in India
NCD	Non-communicable Diseases
NCDC	National Centre for Disease Control
NHAPCCRD	National Health Adaptation for Climate Change Related Disasters
NMAPNCD	National Multi-sectoral Action Plan for Prevention and Control of Non-communicable Diseases

NPCDCS	National Program for Prevention and Control of Cancer, Diabetes, Cardiovascular diseases and Stroke
O_3	Ozone
PM	Particulate Matter
PMCCC	Prime Minister's Council on Climate Change
RCP	Regional Concentration Pathways
RH	Relative Humidity
RR	Relative Risk
SAPCCHH	State Action Plan on Climate Change and Human Health
T_a	Dry Bulb Temperature
T_{app}	Apparent Temperature
T_{max}	Maximum Temperature
T_{min}	Minimum Temperature
UNFCCC	United Nations Framework Convention on Climate Change (
USD	United States Dollar
UT	Union Territory
WBGT	Wet Bulb Global Temperature
WHO	World Health Organization
WS	Wind Speed
ZAR	South African Rand

BACKGROUND

Chapter 1. Introduction

1.1. Climate change: the science and impacts

As perhaps the most pervasive threat faced by the world today, climate change has catastrophic impacts on the natural environment and many aspects of human society. The natural climate system primarily comprises of short wave solar radiation that passes through the atmosphere to warm the Earth's surface. Some of this is reflected back into the space in the form of infrared radiation, which green house gases (GHGs) in the atmosphere trap, creating an overall warming effect over the planet. This greenhouse effect maintains the temperature necessary to sustain life on Earth. The main GHGs are methane (CH_4), nitrous oxide (N_2O), ozone (O_3), water vapour and carbon dioxide (CO_2) [8]. Aside from natural GHG sources, anthropogenic activities since the industrial revolution have increased the emissions and concentrations of these gases in the atmosphere. Many of the GHGs are notoriously hard to eliminate and CO_2 is particularly persistent, with parts remaining in the atmosphere for thousands of years, despite efforts to counteract it [9]. Anthropogenic emissions predominantly originate from fossil fuel combustion, agricultural practices, deforestation and changes in land use patterns [10, 11]. A robust body of scientific evidence has shown that unmitigated greenhouse gas emissions since the mid-18th century have led to an increased heat trapping within the atmosphere, contributing to an amplified overall global warming and accelerating the pace of climate change [12].

Climate change manifests primarily as changes in the weather patterns. A global trend of rise in surface and ocean temperature, the subsequent reduction of polar ice-cover and rise in sea-levels; changes in atmospheric and ocean circulation leading to changes in rainfall patterns; and an increased frequency and severity of droughts, floods, heatwaves and storms are some of the hallmark traits of climate change [13]. The combination of historical emissions that are still prevalent in the atmosphere and continued GHG emissions means that we are on track of an increasingly warming world in the coming decades [1, 9]. Anthropogenic climate change has already led to the warming of the mean global surface temperature by 1.1°C compared to the pre-industrialized era, with the past seven years being the warmest on record [14].

While records of historical climate trends can be extracted from ice-sheets, tree rings and measuring sea-level rise, temperature remains one of the most reliable measurements of climate change [15]. Temperature is also the most commonly used predictor for projecting future climate scenarios. These projections show that, at present, by 2100 the global temperature will be 2.4 to 3.5°C higher than the pre-industrial average, which will have catastrophic impacts on natural and social systems [13].

Recognizing this, there have been several international agreements, such as the Paris Agreement, which were signed in an effort to mitigate GHG emissions [16]. One of the global aims for climate action is to prevent a rise in temperature above 1.5°C [16]. However, research shows that there is a 48% chance this threshold will be exceeded in the next five years, prompting the need for urgent efforts to understand and adapt to the impacts of climate change [13]. An important global actor is the Intergovernmental Panel on Climate Change (IPCC), which has been instrumental in raising awareness globally, tracking the progress on climate change impacts and efforts for adaptation and mitigation [17]. Such agreements have not only contributed to an increased understanding of climate change impacts, but also highlighted global opportunities for climate action, encompassing adaptation and mitigation. The core focus of this thesis remains in adaptation to climate change.

Climate change accelerates the frequency, magnitude and intensity of extreme weather events, the pace of which outweighs the ability of natural and human systems to respond to it, leading to far-reaching impacts across sectors. Not only that, but climate change also manifests unevenly across the globe and thus, so do its impacts [12]. Most of these impacts are evident and interrelated with sectors such as agriculture and food security, air quality, health, infrastructure, livelihood, energy, biodiversity, ecosystems and safety being affected [18]. Given the broad range of impact pathways, which all ultimately affect health, climate change is also considered to be a global health crisis [19].

1.2. Climate change: A public health burden

Health is affected by climate change in a myriad of ways, with complex interaction pathways that can be direct or indirect through social or eco-system mediated pathways, as shown in Figure 1 [1]. The health risks it presents are undeniable, with both direct and indirect impacts that have the potential to undermine several decades of advancements in global health. It is worth noting that quantifying and projecting the health impacts of climate change is challenging to execute with precision, given the many drivers, mediating factors and determinants [1].

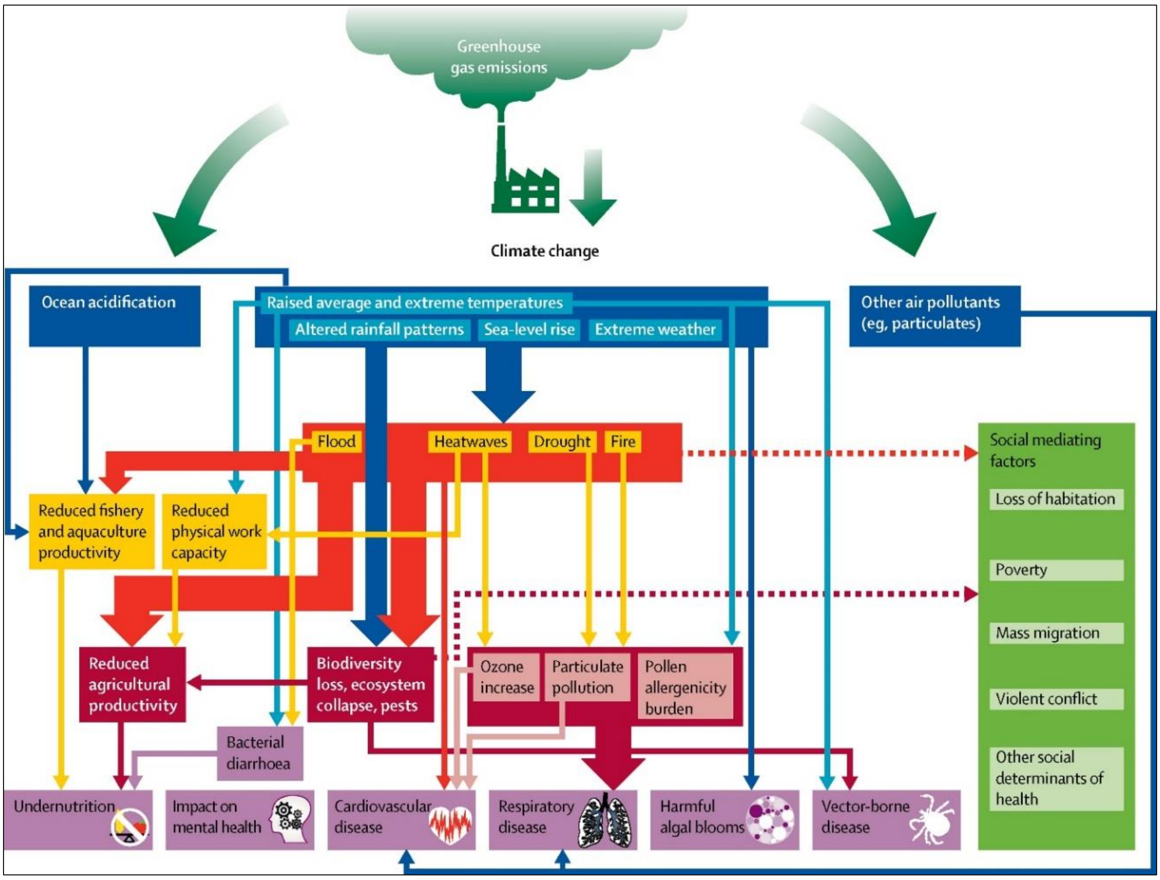

Figure 1: *A summary of interaction pathways showing the links between climate change, its impacts and direct and indirect impacts on health. Figure from [1].*

Extreme weather events such as heatwaves, floods and drought directly affect human health. For example, heatwaves have been linked to several adverse health risks amongst vulnerable populations, including cardiovascular diseases (CVDs) and respiratory illnesses. Increased air pollution has been linked to cardio-respiratory illnesses. Floods and droughts have also been shown to directly increase excess mortalities [20, 21].

The indirect health impacts of climate change are mediated by changes in the environmental or social systems. For example, climate change induced changes in vector breeding windows or reduced agricultural yield leading to increases in the prevalence of vector borne diseases and under-nutrition respectively [22, 23]. Changes in water quality have also been linked to a spread of infectious diseases, such as cholera [24]. On the other hand, climate related disasters have been linked to food insecurity, destruction of livelihoods and forced migration, through changes in land use, loss of land to natural disaster. This has also been linked to violent conflicts, injuries and mental illnesses [25]. Similarly, loss of livelihood and income insecurity also contributes to adverse health impacts. The health risks associated with climate change are projected to magnify over time, leading to an overall decline in community health and a non-linear expansion of vulnerabilities [25].

The climate change associated health risks are unevenly and inequitably spread between and within regions and communities, driven by socio-economic, geographical, technological, infrastructural, political and health services related factors. In addition to creating new health risks, several impacts often occur simultaneously, thereby compounding existing health vulnerabilities and leading to cascading health effects [25]. While climate related health risks will indiscriminately affect everyone, specific groups, including women and children; elderly; socio-economically disadvantaged; people in dense urban conglomerates; low lying and coastal areas; and people with existing health conditions, are disproportionately more vulnerable and will experience heightened health impacts [1].

The severity of the impacts is modified and amplified by a broad range of factors including geographical location, socio-economic factor, existing policies and capacity to respond to the threat [25]. Regional vulnerabilities and resilience to climate change also compound the complexity of the relationships [13]. This highlights the need to understand regional and local specific health impacts of climate change, depending on environmental, social and many other factors.

As our understanding of climate change impacts on health has advanced, environmental risk factors are being recognized as an important cause of the global disease burden [26]. In fact, non-optimal temperature has now been added as an independent risk factor in the IHME and GBD 2019 risk factor list [27, 28] Non-optimal temperature can be defined as an aggregate of hot and cold temperatures outside the range that can be attributed to the lowest burden of health outcomes.

A recent study covering 750 locations across 43 countries found 5,083,173 mortalities attributable to non-optimal temperature annually, making up 9.43% of all deaths. Of this, 8.52% of mortalities were attributable to cold and 0.91% of deaths attributable to heat [29]. Of note, there was a geographical variation in the distribution of the mortality burden, with over 50% occurring in Asia. The highest cold-related mortalities were found in sub-Saharan Africa [29]. The 6th edition of the IPCC report identifies eleven categories of climate-sensitive diseases. One of the disease groups with established links to climate change, specially temperature, is CVDs, a group occupying also more and more the first place in the ranking of causes of death in the world [30].

1.3. Cardiovascular diseases

1.3.1. Epidemiology and risk factors of CVDs

CVDs is an umbrella term used for a group of disorders affecting the heart and vasculature. These include coronary artery disease, hypertension, congestive heart failure, cardiomyopathy, myocardial infarction, arrhythmia, cerebrovascular diseases, rheumatic heart disease, peripheral artery disease, deep vein thrombosis and pulmonary embolism [31]. Globally, CVDs are the leading cause of death representing 32% of all global deaths [32]. In 2019, an estimated 18.6 million global mortalities were due to CVDs, 85% of which were from myocardial infarctions and cerebrovascular disease [32]. While the prevalence of CVDs is generally higher in developed countries, as LMICs undergo epidemiological transitions, the CVD prevalence in these regions is also on the rise. The mortality burden is unequally distributed across the world with around 75% of global CVD mortalities falling on LMICs [32].

Traditionally thought of as a lifestyle disease, there are many risk factors associated with CVDs, exposure to which drives up the disease burden. Today, the CVD risk profile has been expanded to include non-modifiable, behavioural and socio-environmental risk factors, as shown in Figure 2. Non-modifiable risk factors include gender, age and genetic predisposition. Behavioural risk factors mainly include lifestyle behaviours such as unhealthy dietary patterns, high consumption of salt, low levels of physical activity, excess tobacco and alcohol consumption. Examples of socio-environmental risk factors include psychological stress, low socio-economic status, low education levels and environmental factors such as exposure to air pollution, noise pollution, heat and non-optimal temperature [33].

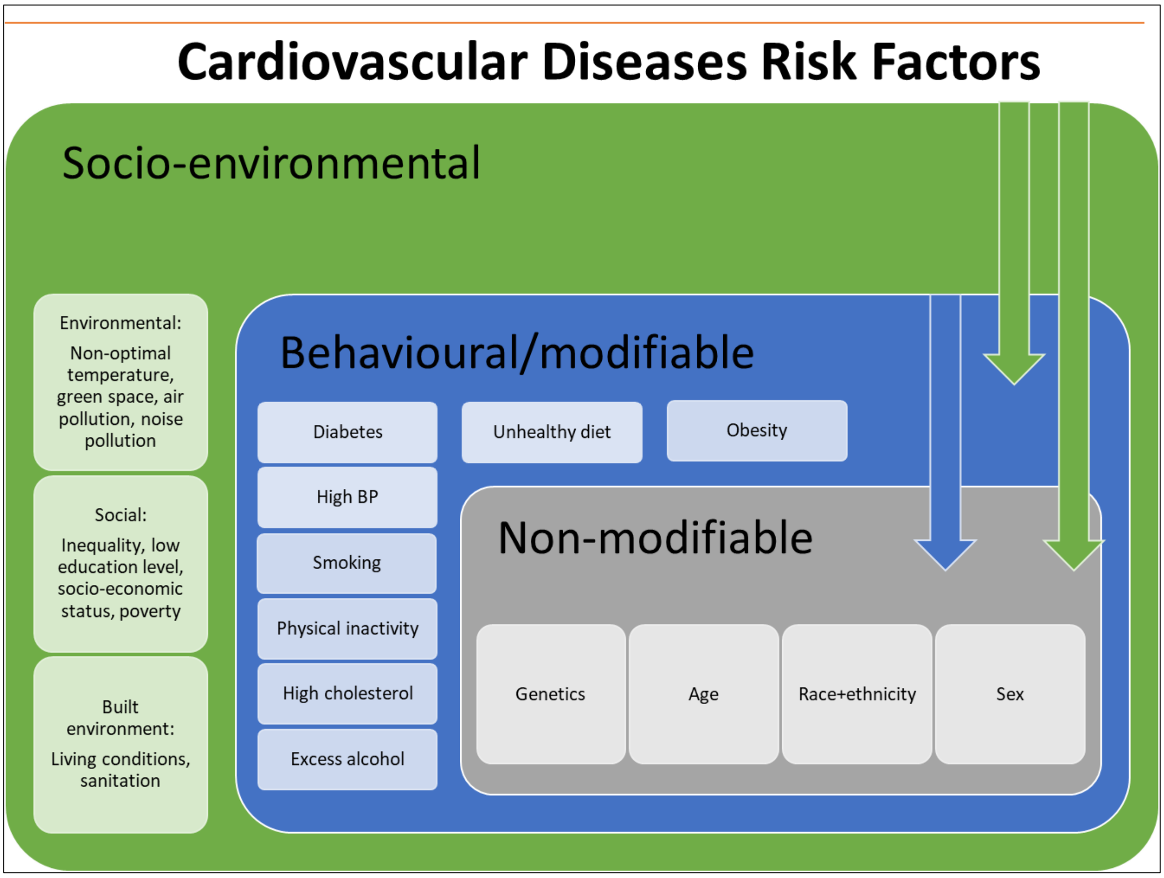

Figure 2: *An overview of different categories of CVD risk factors and their interactions.*

1.3.2. Climate change and CVDs

With climate change leading to changes in temperature patterns and an increase in air pollution, the CVDs attributed to it are also projected to increase with high confidence around the world [25]. Direct exposure to extreme weather, non-optimal temperature, including heat waves and cold spells, and air pollution can exacerbate the risk of adverse CVD events amongst vulnerable population groups, such as those with underlying conditions, and contribute to the development of CVDs in otherwise healthy population [5]. It is important to note that the individual susceptibility to CVDs related to climate change depends on several factors, which indirectly contribute to cardiovascular health. For example, the built physical environment is an important vulnerability determinant. Indoor thermal conditions including adequate ventilation, air conditioning and quality, building material and green spaces all contribute to individual susceptibility to climate change related CVDs. Occupation is also a contributing factor, with people engaged in manual and outdoor labour being more vulnerable [34]. An overview of the effects of climate change on CVDs has been shown in Figure 3.

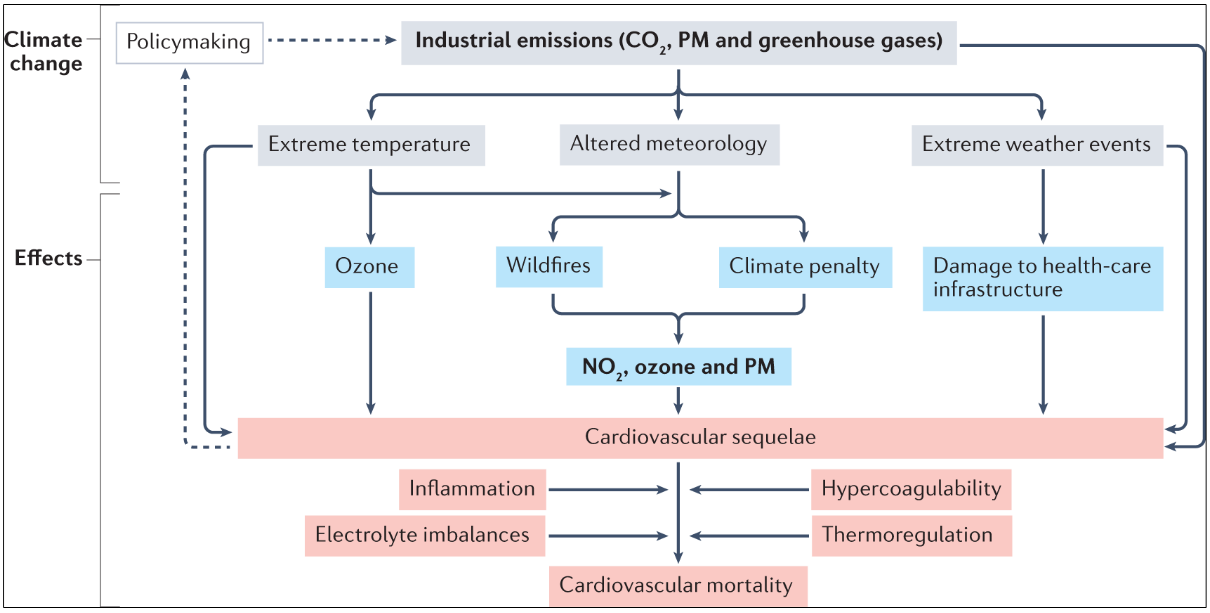

***Figure 3**: An overview of the pathways involved in the development of CVDs associated with climate change. Figure from [5]*

Air pollution has been linked extensively to various CVDs, including an increase in hypertension, myocardial infarction, cardiac failure, stroke, cardio-respiratory diseases and even risks of mortality [5]. Recent global meta analyses also show the association between NO_2 and CVD mortality and stroke [35, 36]. Multiple studies have also shown the association between short term exposure to GHGs (except O_3), particulate matter (PM) 2.5 and PM10 and a risk of myocardial infarction and heart failure [37].

There is a robust body of research showing that CVDs are temperature-sensitive, both to heat and cold [5, 29]. In fact, more CVD mortalities are attributable to cold than hot temperature globally, showing the need to consider temperature as a whole in designing interventions [27]. Although CVDs are affected by several environmental risk factors, including air pollution the main focus of this thesis is on temperature.

1.3.3. Temperature and CVDs: the burden and the mechanism

Non-optimal temperature is estimated to globally account for 597,000 mortalities and 11 million disability adjusted life years (DALYs) from ischemic heart disease [38]. As with all-cause mortality, the optimal temperature or minimum mortality temperature (MMT), defined as the temperature at which the least number of mortalities occurs, varies regionally by climate zone, and population vulnerabilities[5]. The cultural, demographic and population vulnerabilities, such as adaptation to local temperatures, all play a role in the burden of CVDs attributable to non-optimal temperature [39]. Regional temperature and the adaptation of the local population to it is an important factor in what the optimal temperature for CVDs is within the community. Societies are adapted to the local climate and extreme temperatures outside the range of the optimal temperature represents a risk to vulnerable populations. In those whose capacity for homeostasis is limited by factors like age, tolerance is reduced, leading to a greater risk of adverse events [5] .

The association between CVDs and temperature is not linear and follows a delayed or 'lagged' exposure-outcome pattern with the relationship curve normally following a J- or U-shape, thus further compounding the challenges in estimating the risk [40-44]. Previous studies have found temperature to be a contributing factor to the burden of both mortality and morbidity of CVDs, with varying associations found contingent to the region, population studied and local temperature range [5, 30].

A study from Spain found that the relative risk of mortality from CVDs attributed to heat was higher in females and older individuals, while males had a higher relative risk from cold temperatures [45]. A recent multi-country study found that extreme temperatures were associated with increased CVD mortalities in 27 countries across 5 continents. Hot days were associated with 2.2 of excess CVD deaths while cold days contributed to 9.1 for every 1000 CVD deaths [46]. Similarly, a recent systematic review of heat associated CVD mortalities found that a 1 degree rise in temperature was associated with CVD mortalities, with women, those above 65 years of age, individuals in tropical climates and LMICs being more at risk [47].

A study on CVD admissions among the elderly in Vietnam found that the least admissions occurred at 26° C and below and above this temperature was associated with an increased risk of admission, with a significantly increased risk of morbidity at colder temperatures [48]. In a study conducted in Western China among farmers, there was a J-shaped association between temperature and CVD morbidity, with the heat effect leading to an increased risk of hospital admission. Additionally, females and those below 65 years of age had a higher risk from cold temperature compared to males and those above 65, who were more susceptible to heat. Overall 21.04% of the CVD morbidity burden was attributed to ambient temperature with 19.26% being due to moderate heat [49]. Similarly, a national level study in China found that short-term variability in temperature can increase the risk of CVD admission [50]. A study examining weather changes and CVD and stroke hospitalizations found that among the elderly, temperature changes resulted in an increased hospitalization for most CVD outcomes [51]. Heat has also been associate with an increase in emergency CVD hospitalizations in New York among older adults [52].

There are several postulations for the mechanism of how temperature affects CVDs. When the body undergoes heat stress, part of the thermoregulatory response involves sympathetic activation, an increase in peripheral circulation along with an increase in the body temperature. It also can result in hypovolemia and subsequent tachycardia or cardiogenic shock [53]. Sympathetic activation due to heat exposure, especially in people with pre-existing CVDs, can lead to a hypermetabolic state with an increased oxygen consumption, potentially causing demand ischemia or plaque rupture [30]. Heat exhaustion, when the core body temperature rises above 38°C, can impair physical and cognitive functions. A body temperature above 40.6°C has been associated with heat strokes, an increased risk of organ damage and mortality [54]. Dehydration, a common side effect of inadequate fluid consumption especially during warmer periods, can also result in haemoconcentration, contributing to hypercoagulation and an increased risk of thrombosis and myocardial infarctions. When the cardiac output is unable to compensate for this, the resulting heat intolerance leads to a cardiovascular event [31, 55]. Extreme heat exposure can also induce changes at the cellular level, with conformational changes being instituted in heat shock proteins, leading to systemic inflammation and potential organ failure, through the activation of leukocytes and endothelial cells [56, 57]. Arrhythmias have also been associated with hyperthermia, which can trigger electrolyte imbalance [58].

On the other hand, as a response to cold exposure, there is an increase in the sympathetic response, the cardiac workload increases causing a sustained increase in systemic blood pressure and subsequent cardiovascular dysregulation, primarily through vasoconstriction which reduces both blood flow and oxygen supply to the heart [59]. It can also lead to bradycardia, decreased conduction velocity and arrhythmias including ventricular fibrillation and asystole [60, 61]. In order to conserve and generate heat, there is also an elevation in the skeletal muscle tone, which is accompanied by an increased oxygen demand and catecholaminergic elevated blood pressure [5, 62]. Exposure to extreme cold is also known to cause hypercoagulopathy from haemoconcentration and increased blood viscosity [63]. Cholesterol crystallization in existing atherosclerotic plaques is also a downstream consequence of extreme cold exposure, leading to an increase in the risk of myocardial infarctions through plaque rupture [64].

The mechanism of the cardiovascular response to exposure to temperature is shown in the Figure 4 below.

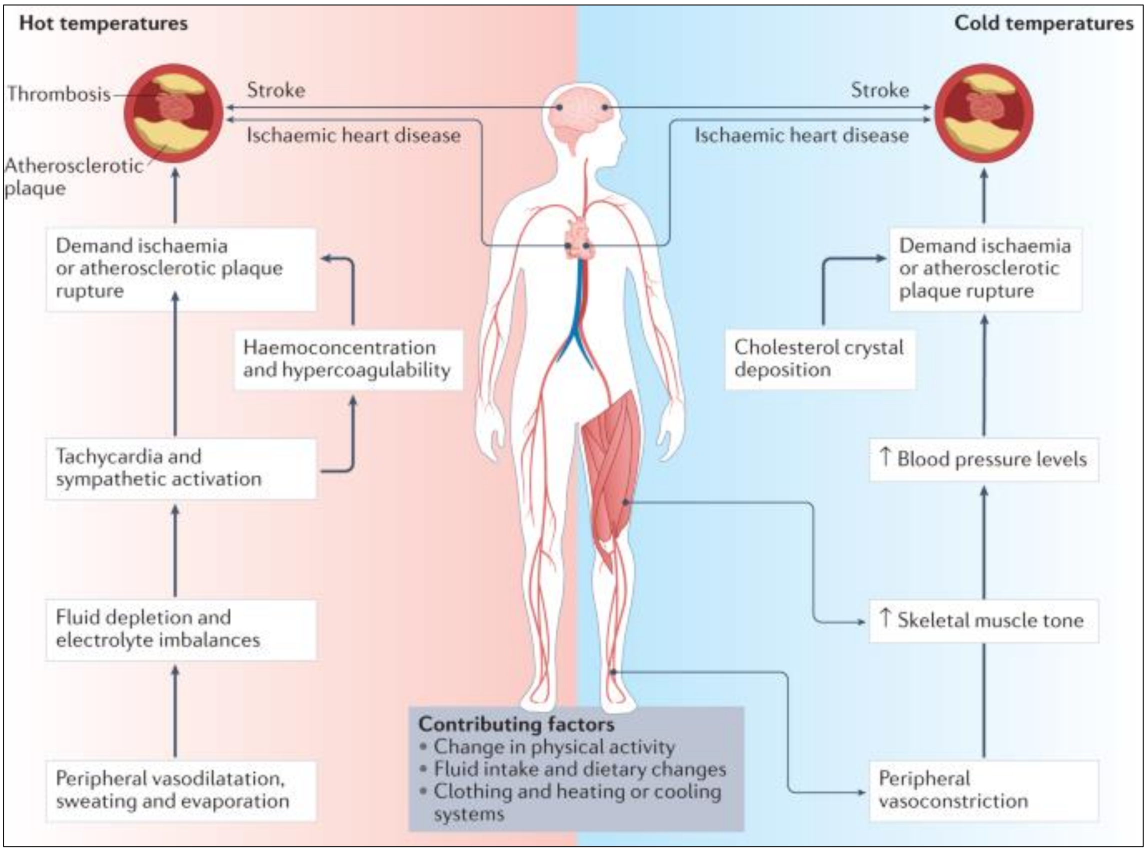

Figure 4: *The pathophysiological mechanisms mediating the effects of temperature on the development of CVDs. Figure from [5].*

1.3.4. Cardiovascular diseases and climate change in India

The Republic of India is the most populous country in the world with a population of over 1.4 billion as of 2023 [65]. India has a diverse climate profile, with six main Köppen-Geiger climate classification zones which range from arid to tropical wet as shown in Figure 5 [2]. It is prone to weather extremes and its geographical location, population size and economic underdevelopment make it a country highly vulnerable to climate risks. In terms of mean annual temperature, there is a broad range observed across the country, with sub-0 temperatures observed in the northern mountainous regions to >30°C in the tropical southern parts[2]. Mean annual temperatures have been rising in recent decades. Compared to 1981-2010, the annual mean land surface temperature over India was 0.4°C higher than 2021 [66].

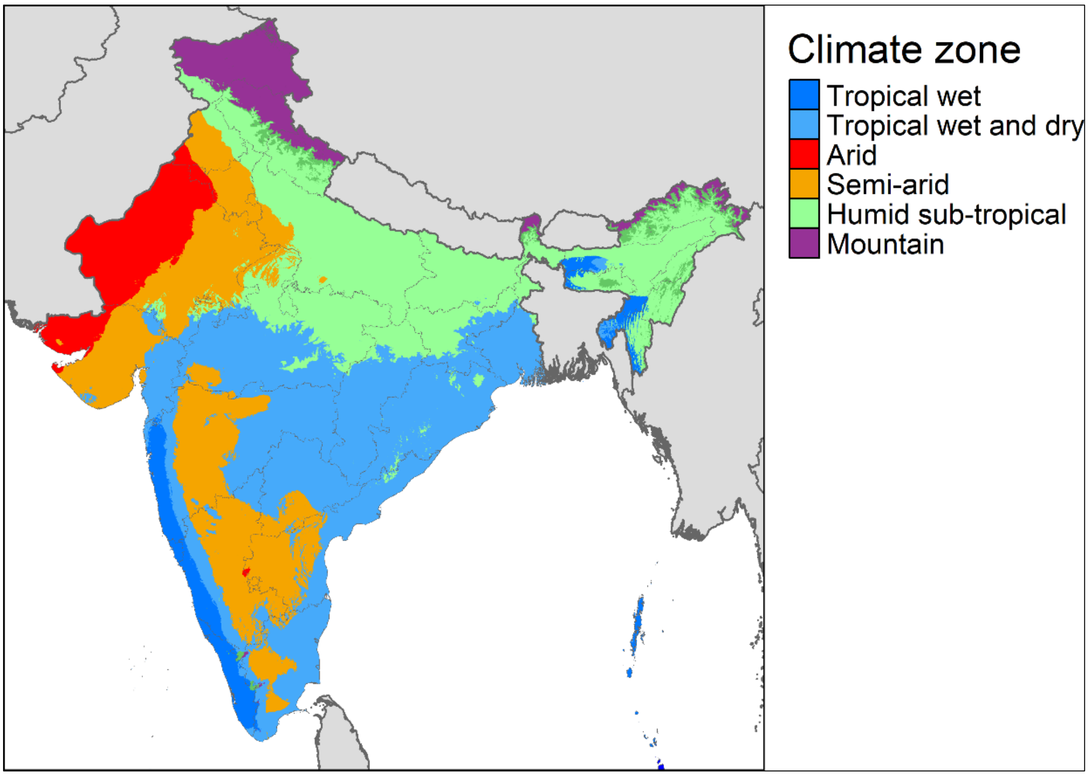

Figure 5: *Köppen-Geiger climate zone classification of India. Image from [2].*

The vast diversity and socio-cultural differences observed between communities and regions contributes to the country's health vulnerabilities. India has a high burden of NCDs, surpassing the burden from infectious diseases. Over the past decade, CVDs have emerged as the leading cause of death, with IHD, chronic obstructive pulmonary disease, strokes being the top three causes. There has been a 40% and 28.4% increase in mortalities caused by IHDs and strokes over the past ten years respectively [67].

Given the multitude of factors influencing how temperature affect CVDs, it is essential to understand the microclimatic effects on this association regionally in India. There is limited research on this topic thus far, with no cause-specific regional specific studies conducted on temperature and CVDs to our knowledge. A national level study found excess risk of mortality from all-causes, IHD, respiratory diseases and stroke associated with both hot and cold non-optimal temperature, with more deaths attributed to moderately cold temperature [68]. It also highlights the difference in MMT based on cause of death and age. City-specific studies have found 6.5% of all cause mortality attributable to extreme temperature in Pune city and an increase in daily mortality during heat and cold spells in Varanasi respectively [69, 70]. There are a few studies showing the association between heat waves or high temperature and mortality across communities in India, highlighting the dangers of high temperatures on health, even in inherently hot regions [71-73]. A large component of this thesis focuses on the Puducherry Union Territory of India, with further details on the site given in chapter 4.

1.3.5. Cardiovascular diseases and climate change in South Africa

The Republic of South Africa is on the southernmost tip of Africa with a population of over 60,284,192 [74] It has three main Köppen-Geiger climate zones in South Africa, namely arid, temperate wet and temperate dry as shown in Figure 6 [3]. The temperatures in South Africa range from 15 to 36°C during the summer and -2 to 26°C during winters. It is located in the sub-Saharan 'drought belt' and is the 5th most water-scarce region in the area with rising temperature and climate change threatening to escalate this risk [75]. The country is highly vulnerable to climate variability and extreme weather events, with temperatures over the region rising faster than the global rate [76]. Air temperatures have been increasing at a rate of 0.02°C per year between 1980 and 2016 [77]. The high exposure to climate variability, economic inequality and limited capacity for adaptation further compounds South Africa's climate vulnerability, with health and development challenges predicted to exacerbate in the coming years [78].

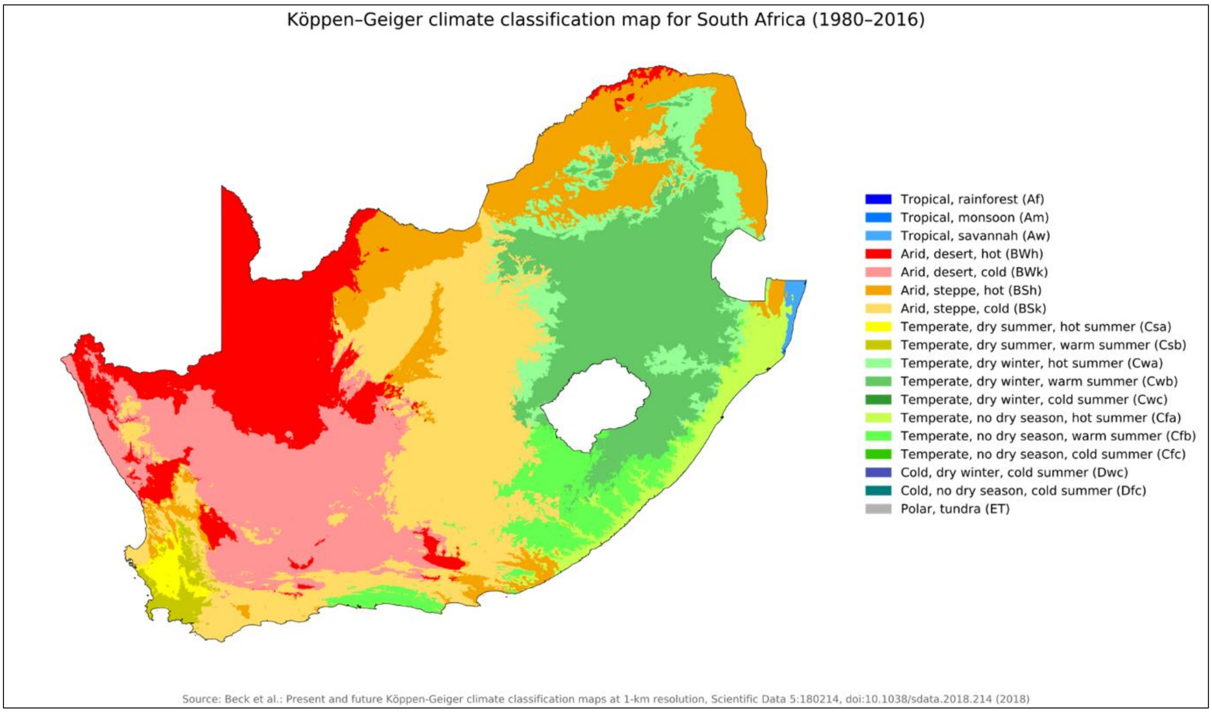

Figure 6: *Köppen-Geiger climate zone classification of South Africa. Image from [3]*

South Africa has a high burden of disease, with a quadruple threat from human immunodeficiency virus/ acquired immunodeficiency syndrome (HIV/AIDS), communicable diseases, NCDs and accidents and injuries. This burden is further challenged by persistent socio-economic inequalities and inequitable access to healthcare services [79]. CVDs are becoming increasingly prevalent in South Africa, with IHD contributing to a 0.3% increase over the past ten years. Similarly, strokes are also in the top three causes of mortality [80]. There have been some studies done on temperature and CVDs in South Africa, but there remains a large gap in the regional understanding, especially in remote and rural areas.

A countrywide study on ambient temperature and all-cause mortality found 3.4% of deaths were attributable to non-optimal temperatures, with cold having a higher attributable burden than heat [42]. The strongest association was found among children and the elderly and was attributed to cardio-respiratory diseases. Another study examining this at a city-level found a significant increase in mortality above city-specific apparent temperatures, especially among the elderly, in Cape Town, Durban and Johannesburg [81]. With respect to CVDs, a study from Cape Town found an association between air pollutants, apparent temperature and CVD mortalities, with females being more susceptible at high and moderate apparent temperatures [82]. This thesis primarily focuses on the Limpopo Province of South Africa, with further details given in chapter 5.

1.4. Evidence informed adaptation response to protect health

The recent IPCC report found with a high confidence that proactive, timely and effective adaptation can reduce certain health risks due to climate change and eliminate others entirely. The IPCC also states with high confidence that the risks of climate change will worsen over time, affecting an increasing number of people, especially those most vulnerable [25]. There is an urgent need for adaptive measures to reduce the health burden of climate change. Integrative solutions to protect cardiovascular health from environmental causes include adaptation, mitigation, and policy responses all of which need to be informed by a community or regional level assessment of the CVD risk from climate change. These are in essence similar to the general measures focusing on protecting public health from climate change impacts. CVDs are unique in the sense that mitigation efforts will directly also lower their burden, given their association with temperature and air pollution both.

In light of the complexity and scale of this problem, it is clear that there is no single solution. There is an urgent need for a global impetus to design contextual interventions, all of which need to be cross-sectoral, with collaborative and complimentary efforts to build climate resilient health systems and protect community health. In parallel, continued mitigation measures will also contribute to achieving health co-benefits of climate actions [1, 83]. Examples of these efforts includes the emphasis on climate informed health policies and programs, managing the environmental determinants of health, emergency preparedness and response strategies, education and awareness on the impacts of climate change on health, climate change and health research, integrated risk monitoring an early warning systems for specific diseases and vulnerability assessments. Strengthening the resilience of the healthcare system is another major aspect of the adaptation response, along with climate change focused reforms in other sectors, including infrastructure and labour to protect workers' and population health, especially during unfavourable weather conditions [1, 13, 25].

The health implications of climate change need to be effectively communicated to build a stronger uptake and support for the interventions. This also needs the support and understanding of crucial stakeholders in the climate change and health space to also further localized interventions and health co-benefits. The health agenda can contribute in a big way to the climate change response, primarily through international cooperation, promoting awareness on climate change and health amongst the public and policy makers, identifying opportunities for health and health equity promotion in climate actions [13]. Additionally, increased awareness among population, strengthening research capacity, investments and funding, collaborative action, public communication, mitigative actions such as clean energy can also contribute to protecting the community from the adverse health impacts of climate change [13, 25].

1.5. Research gaps and rationale

Climate change is indisputably affecting human health and will only exacerbate in the future, prompting the need for appropriate actions to protect public health. Climate change specific policies are a work-in-progress in most countries, given the limited national database of evidence. It is only in recent years that the health impacts of climate change have been gaining importance in the policy space. Historically, health policies did not account for climate change as a risk factor, especially in designing and implementing interventions. As the global knowledge base of health impacts of climate change grows, there is a need to modify and strengthen policies taking into account the new evidence [1, 25].

There is a major gap in the evidence of the impacts of climate change on health, especially when it comes to NCDs, such as CVDs, from LMICs, such as India and South Africa. There are frequently large contextual knowledge gaps between the national, regional and city-level within the same country, driven by vast differences in availability and quality of data needed to model these associations. Lack of technical know-how and the uncertainty of the modelled associations further drives this gap. Thus, there exist great limitations in the regional understanding and synthesis of disease specific evidence needed to design and implement context appropriate adaptation measures. Given that climate change has regional variations in its health impacts, regional and contextual adaptation plans are key to protecting the population and improving resilience [25].

Moreover, both India and South Africa are members of the BRICS group of countries, which accounts for 41% of the entire global population [84]. India and South Africa both also hold membership to regional associations such as the South Asian Association for Regional Cooperation (SAARC) and the African Union (AU) respectively. There is thus potential for India and South Africa to set an example in their respective regions with climate-health policies. Both these countries have displayed a commitment towards tackling global issues such as climate change. Although not yet as accountable as Western countries, the BRICS have the potential to collaborate in order to play a decisive role structuring future global climate and health policies [85].

Public health organizations around the world have described climate change as a global health issue with an urgent need to develop national workforces dedicated to researching and addressing the health impacts of climate change [86]. There are also large gaps in understanding the perceptions and role of stakeholders such as policy makers, medical professionals, environmentalists in the capacity for evidence synthesis and interventions [86, 87]. The IPCC says with high confidence that while national planning on climate change and health is advancing, there is a gap in the comprehensiveness of strategies [25]. Action and adaptation plans need to be strengthened and fortified with evidence on the topic from the region, especially as implementation of climate change and health actions is challenging.

1.6. Thesis structure

This doctoral thesis stems from an ever-growing importance of understanding different health outcomes in the context of an increasing frequency of climate change induced threats to health. The work done in thus represents a timely effort to comprehensively fill in the gaps with regards to temperature and CVDs in India and South Africa. The core part of this thesis is divided into three components, namely quantitative studies, qualitative studies and a policy review, consisting of five chapters. The key findings are presented over these five chapters, through a series of original research articles, published in peer-reviewed journals.

The thesis starts with an overview of the aims, objectives and methodological approaches in chapter 2 and 3 respectively. The first section of quantitative studies follows a robust methodology to model climate change-CVD associations, spread across chapters 4 and 5. Chapter 4 consists of a quantitative study on the association between CVD mortalities and apparent temperature in Puducherry, India. Chapter 5 presents the association between apparent temperature and CVD hospital admissions in Limpopo province, South Africa. The second section on qualitative studies is presented in chapters 6 and 7. It contains findings from qualitative studies conducted amongst key stakeholders, comprising of medical professionals, government officers and environmentalists working on the local adaptation plan. The aim of these studies was to understand the perceived knowledge and awareness on climate change and health and the perceived barriers to conducting research on this topic respectively. The third section on the policy review is presented in Chapter 8. It consists of a policy review of key climate change and health policies in the Indian policy space to assess the incorporation and representation of CVDs from a climate change lens. The thesis is concluded with a general discussion and conclusion in chapter 9 and 10 respectively, where the findings of the studies are examined in a wider context, including broader implications for global health as well as future directions.

Chapter 2. Aim and specific objectives

2.1. Aims

The primary aim of this thesis is to provide a comprehensive understanding of how climate change affects CVDs in selected LMICs and the social and political dimensions for appropriate climate health actions. Its objective is to estimate the CVD risks attributable to climate change, to understand the perspectives of key stakeholders as well as perceived research barriers for climate change and health and CVDs. Additionally, by analysing relevant policies, it also aims at understanding how CVD specific actions are integrated in the climate change policy space. The main focus is on two regions in the respective countries, namely Puducherry, India and Limpopo Province, South Africa.

2.2. Specific Objective and research questions

The project has three main objectives, guided by specific research questions, which are summarised in Figure 7.

Specific Objective 1: Analysing the association between apparent temperature and CVDs

1. **Research Question 1: Chapter 4**
   What is the association between apparent temperature and CVD mortalities in Puducherry? How does this association vary between demographic groups and types of CVDs?
2. **Research Question 2: Chapter 5**
   What is the association between apparent temperature and CVD morbidity in the Limpopo Province of South Africa?

Specific Objective 2: Understanding relevant stakeholders' perceptions on climate change and health

3. **Research Question 3: Chapter 6**
   How do stakeholders from Puducherry, such as medical professionals, environmentalists and policy makers, perceive the health risks from climate change, with an emphasis on CVDs?
4. **Research Question 4: Chapter 7**
   Amongst relevant experts in Puducherry, such as medical professionals, environmentalists and policy makers, what are the perceived research barriers for climate change and health?

Specific Objective 3: Reviewing existing national climate change and CVD related policies.

5. Research Question 5: Chapter 8

How do relevant national policies view and integrate climate change and CVDs in India?

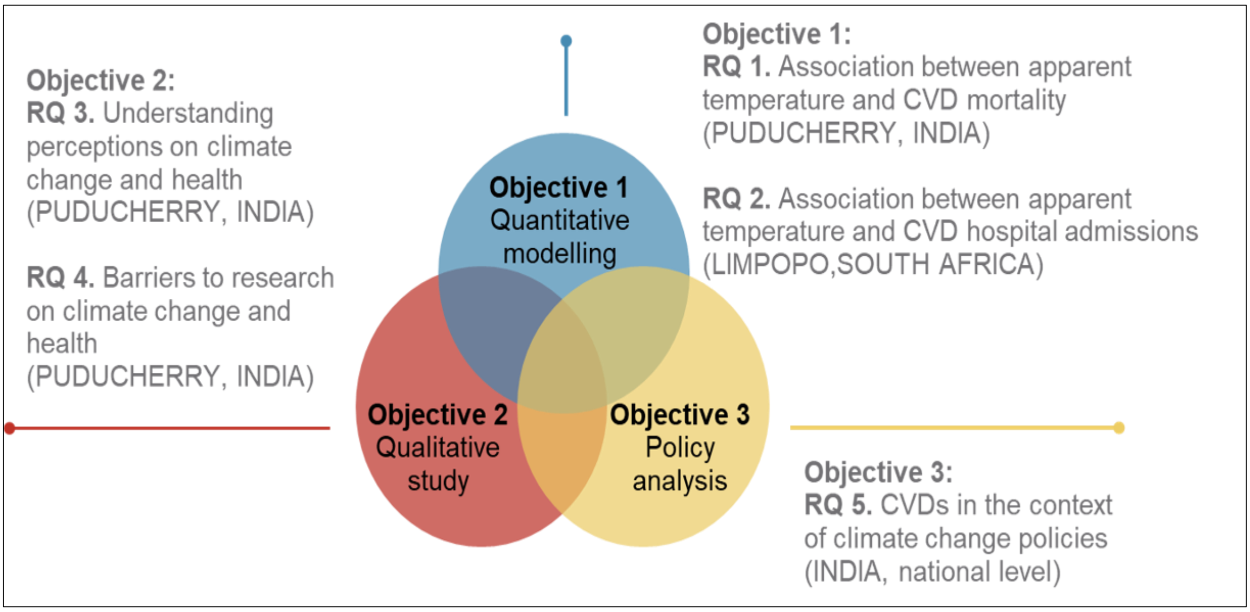

Figure 7: *An overview of the objectives, methodology and research questions of this thesis.*

Chapter 3. Methodology

3. General methodology

This thesis follow a multi-methods approach, employing data from both primary and secondary sources. A detailed description of the methodological approach used for each research question is provided in the respective chapter. In this chapter, the general methodological approach has been summarized in Table 1.

Table 1: *An overview of the analytical methodology and outputs of the three main objectives.*

Objective	**1**	**2**	**3**
Methodology	Quantitative exposure-outcome modelling	Qualitative key informant interviews	Systematic policy review and analysis
Analytical approach	Distributed lag non-linear model with: (i.) case crossover model following binomial likelihood (Puducherry); or (ii.) negative binomial regression (Limpopo)	Thematic analysis with the framework method	Thematic analysis with the framework method and manifest content analysis.
Time period/participants/policies	**Puducherry:** 2011 to 2020 **Limpopo:** 2009 to 2016	16 participants	12 national policies and 29 state level health adaptation plans
Data sources	**Puducherry:** (i.) Meteorological data from the Indian Meteorological Department; and (ii.) Health data from the Indira Gandhi Government General Hospital and Post Graduate Institute,	Primary data collected through key informant interviews with key stakeholders in Puducherry between January and March 2022	Data collected from policies of the Indian Government available on the public domain in English

	Puducherry through the Department of Health and Family Welfare Services, Government of Puducherry **Limpopo:** (i.) Meteorological data from the South Africa Weather Service; and (ii.) Health data from Nkhensani Hospital and Maphutha L. Malatjie Hopsital		
Chapter/paper	**Chapter 4:** Non-optimal apparent temperature and cardiovascular mortality: the association in Puducherry, India between 2011 and 2020 **Chapter 5:** The Association between Apparent Temperature and Hospital Admissions for Cardiovascular Disease in Limpopo Province, South Africa	**Chapter 6:** "Climate change and health?": Knowledge and perceptions among key stakeholders in Puducherry, India **Chapter 7:** Barriers to climate change and health research in India: A qualitative study	**Chapter 8:** Climate change and cardiovascular diseases in the Indian policy context: A document analysis

QUANTITATIVE STUDIES

MODELLING CLIMATE CHANGE AND CARDIOVASCULAR DISEASE ASSOCIATIONS

Chapter 4. Non-optimal apparent temperature and cardiovascular mortality: the association in Puducherry, India between 2011 and 2020

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RESEARCH — Open Access

Non-optimal apparent temperature and cardiovascular mortality: the association in Puducherry, India between 2011 and 2020

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Abstract

Background Cardiovascular diseases (CVDs), the leading cause of death worldwide, are sensitive to temperature. In light of the reported climate change trends, it is important to understand the burden of CVDs attributable to temperature, both hot and cold. The association between CVDs and temperature is region-specific, with relatively few studies focusing on low-and middle-income countries. This study investigates this association in Puducherry, a district in southern India lying on the Bay of Bengal, for the first time.

Methods Using in-hospital CVD mortality data and climate data from the Indian Meteorological Department, we analyzed the association between apparent temperature (T_{app}) and in-hospital CVD mortalities in Puducherry between 2011 and 2020. We used a case-crossover model with a binomial likelihood distribution combined with a distributed lag non-linear model to capture the delayed and non-linear trends over a 21-day lag period to identify the optimal temperature range for Puducherry. The results are expressed as the fraction of CVD mortalities attributable to heat and cold, defined relative to the optimal temperature. We also performed stratified analyses to explore the associations between T_{app} and age-and-sex, grouped and considered together, and different types of CVDs. Sensitivity analyses were performed, including using a quasi-Poisson time-series approach.

Results We found that the optimal temperature range for Puducherry is between 30°C and 36°C with respect to CVDs. Both cold and hot non-optimal T_{app} were associated with an increased risk of overall in-hospital CVD mortalities, resulting in a U-shaped association curve. Cumulatively, up to 17% of the CVD deaths could be attributable to non-optimal temperatures, with a slightly higher burden attributable to heat (9.1%) than cold (8.3%). We also found that males were more vulnerable to colder temperature; females above 60 years were more vulnerable to heat while females below 60 years were affected by both heat and cold. Mortality with cerebrovascular accidents was associated more with heat compared to cold, while ischemic heart diseases did not seem to be affected by temperature.

Conclusion Both heat and cold contribute to the burden of CVDs attributable to non-optimal temperatures in the tropical Puducherry. Our study also identified the age-and-sex and CVD type differences in temperature attributable CVD mortalities. Further studies from India could identify regional associations, inform our understanding of the health implications of climate change in India and enhance the development of regional and contextual climate-health action-plans.

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4.1. Abstract

Background

Cardiovascular diseases (CVDs), the leading cause of death worldwide, are sensitive to temperature. In light of the reported climate change trends, it is important to understand the burden of CVDs attributable to temperature, both hot and cold. The association between CVDs and temperature is region-specific, with relatively few studies focusing on low-and middle-income countries. This study investigates this association in Puducherry, a district in southern India lying on the Bay of Bengal, for the first time.

Methods

Using in-hospital CVD mortality data and climate data from the Indian Meteorological Department, we analysed the association between apparent temperature (T_{app}) and in-hospital CVD mortalities in Puducherry between 2011 and 2020. We used a case-crossover model with a binomial likelihood distribution combined with a distributed lag non-linear model to capture the delayed and non-linear trends over a 21-day lag period to identify the optimal temperature range for Puducherry. The results are expressed as the fraction of CVD mortalities attributable to heat and cold, defined relative to the optimal temperature. We also performed stratified analyses to explore the associations between T_{app} and age-and-sex, grouped and considered together, and different types of CVDs. Sensitivity analyses were performed, including using a quasi-Poisson time-series approach.

Results

We found that the optimal temperature range for Puducherry is between 30°C and 36°C with respect to CVDs. Both cold and hot non-optimal T_{app} were associated with an increased risk of overall in-hospital CVD mortalities, resulting in a U-shaped association curve. Cumulatively, up to 17% of the CVD deaths could be attributable to non-optimal temperatures, with a slightly higher burden attributable to heat (9.1%) than cold (8.3%). We also found that males were more vulnerable to colder temperature; females above 60 years were more vulnerable to heat while females below 60 years were affected by both heat and cold. Mortality with cerebrovascular accidents was associated more with heat compared to cold, while ischemic heart diseases did not seem to be affected by temperature.

Conclusion

Both heat and cold contribute to the burden of CVDs attributable to non-optimal temperatures in the tropical Puducherry. Our study also identified the age-and-sex and CVD type differences in temperature attributable CVD mortalities. Further studies from India could identify regional associations, inform our understanding of the health implications of climate change in India and enhance the development of regional and contextual climate-health action-plans.

4.2. Background

Anthropogenic activity contributes to the accelerating pace of natural climate change leading to an increase in the frequency, intensity and impact of extreme weather events and a global rise in temperatures [88, 89]. The last decade has seen the highest temperatures recorded with 2016 and 2020 emerging as the hottest years on record [19].

Climate change has emerged as a threat to human health and a major public health challenge over the past few decades [90]. Indeed, the recent Global Burden of Disease Study showed that non-optimal temperatures are now among the top-10 leading causes of death globally [91]. Climate change and health research has recently expanded to include direct and indirect effects of temperature, mainly heat, on non-communicable diseases (NCDs) such as cardiovascular diseases (CVDs) [25, 92, 93].

CVDs is an umbrella term for a multifactorial group of diseases affecting the structure and function of the heart. They are the leading cause of death globally, claiming an estimated 17.9 million lives each year, accounting for 32% of global deaths [32]. Most CVDs are linked to lifestyle and environmental exposures such as smoking, alcohol and substance abuse, obesity, physical inactivity, stress, unhealthy diets, air pollution and noise. In addition, ethnicity, biological sex and age are also important factors driving the risk for the development of CVDs [31, 32].

CVDs are also climate-sensitive, with the risk of mortality or severe illness exacerbating with very high and low ambient temperatures [55, 93-96]. There are several mechanisms postulated to explain the increased risk of temperature-CVD mortality. The cardio-regulatory response to heat stress involves an increase in peripheral circulation to allow for thermoregulation along with an increase in core body temperature. When the cardiac output cannot compensate for this, it results in heat intolerance leading to a CV event [31, 96]. Meanwhile, the cardiac workload increases as a response to cold, along with a sustained increase in systemic blood pressure, leading to CV dysregulation, primarily through vasoconstriction, which reduces both blood flow and oxygen supply to the heart [59].

The effects of temperature on CVDs are global, although the exact relationship varies by region, climate and population [93, 97]. A systematic review found that out of 34 studies on temperature-CVD associations, two-thirds (64%) were conducted in high-income countries with little research from low- and-middle income countries (LMICs), most of it being from The People's Republic of China [93]. With a lower adaptive capacity and relative lack of resources to face the challenge, understanding the regional temperature-CVD association in LMICs is a priority research area, especially as the burden of both extreme temperatures and CVDs is projected to increase in the future [98, 99].

India has already seen an increase in the burden of CVDs over the past decade with CVDs now being the leading cause of mortality and a major public health problem. Ischemic heart disease (IHD) has seen a 40% rise in the number of deaths reported between 2009 and 2019 [67]. Related CVDs such as strokes or co-morbidities incluing diabetes have also become more prevalent over this period [67, 100]. It is therefore important to consider the role temperature might play as a CVD risk factor. The air surface temperature might rise by as much as 4.4°C by the end of the 21st century, based on the Regional Concentration Pathway (RCP) 8.5 scenario, thereby posing a serious threat to many aspects of life, including human health [101].

The climate and socio-cultural diversity is one of the bigger challenges faced when studying climate-health relationships for India. There are six major Köppen-Geiger climate classification zones in India with temperatures ranging from >0°C to <40°C [68]. The socio-cultural differences between regions and communities is also an important factor determining health and vulnerability. The dense population concentration and movement in urban areas, along with factors such as the urban heat island effect, lead to urban communities, particularly those on the lower socio-economic level in informal settlements, being more vulnerable to climate disasters and heat, despite the relative paucity of cooling facilities in rural areas [39, 102, 103]. Additionally, coastal regions, such as Puducherry, are particularly vulnerable to climate hazards [103, 104]. Given these variations, there is a need to comprehensively study regional CVD-temperature associations in India in order to reduce the burden of CVDs and be prepared for challenges of the future.

We conducted an exploratory study analysing the effects of apparent temperature (T_{app}) on CVD mortality in Puducherry, India. To our knowledge, there were no previous region specific studies done on the association between apparent temperature and CVD mortality from this region.

4.3. Methods

Our exploratory study analysed the fraction of in-hospital CVD-related mortalities attributable to T_{app}, the so-called 'fatal admissions' using a case-crossover design with a distributed lag non-linear model (dlnm).

4.3.1. Study area

Puducherry is a unique Union Territory (UT) in India, comprising of four erstwhile French colonies (i.e Puducherry District, Karaikal, Mahe and Yanam region). Puducherry and Karaikal lie on the eastern coast, within the state of Tamil Nadu, while Yanam, also on the east coast, is surrounded by the state of Andra Pradesh. Mahe lies on the western coast within the state of Kerala. The total area of the UT is 492 km^2 as seen in Figure 8A.

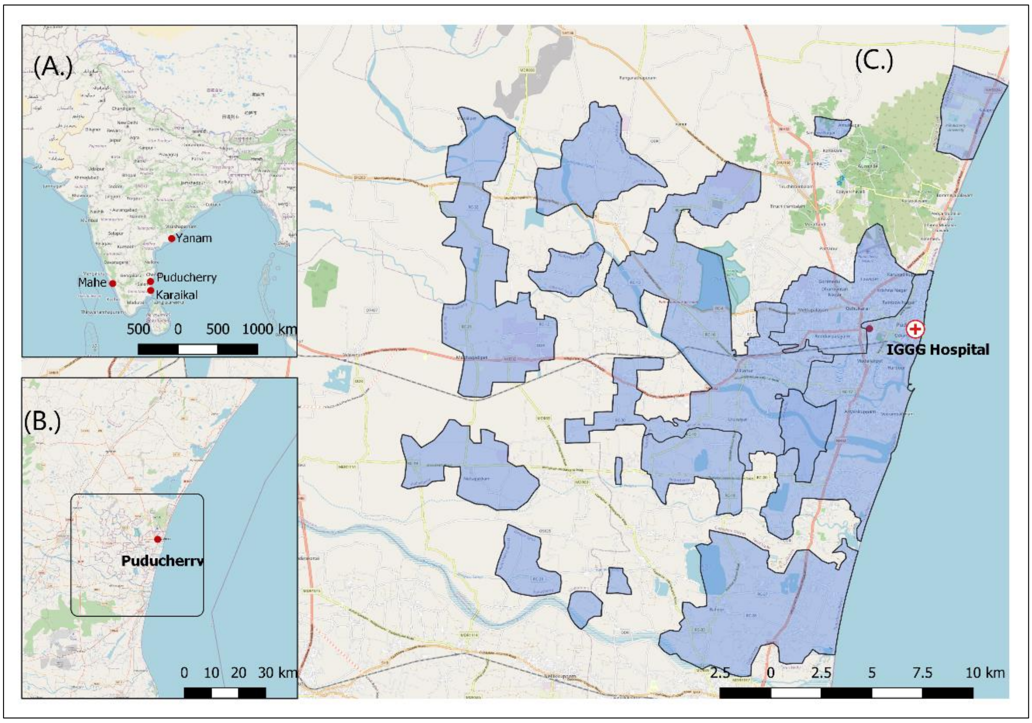

Figure 8*: Map showing the four districts of the Union Territory of Puducherry. (A) shows the location of the four districts that make up the Union Territory of Puducherry, namely Puducherry, Karaikal, Mahe and Yanam, spread out on either side of the coast of India. (B) Focuses on Puducherry district which is nestled within the state of Tamil Nadu with Andra Pradesh to the north (inlaid map). The shaded area in panel (C) highlights the non-continuous geographical area of Puducherry district.*

This study focuses on Puducherry, which itself covers an area of 294 km^2 spread out over 4 non-continuous sub-districts or 'Taluks' as shown in Figure 8B and Figure 8C. As per the Government of India census of 2011, the population of Puducherry is 950,289 with 69.2% of the population residing in urban areas and an almost equal distribution of males and females [105, 106].

Puducherry falls within the tropical savannah with a dry winter climate type as per the Köppen-Geiger classification. The region has a tropical climate with a generally high relative humidity, which is around 80% during October to April and around 70% in June and July. The mean annual temperature is around 30^{o} C.

There are two state government run tertiary care hospitals in Puducherry, out of which only the Indira Gandhi Government General Hospital and Post Graduate Institute (IGGGH) is a large, multispecialty general hospital with a cardiology department. In addition, there is another large, multi-speciality tertiary care hospital, the Jawaharlal Institute of Postgraduate Medical Education and Research. However, this is administered on the central governmental or federal level and due to inaccessibility of health data, our project was limited to IGGGH, serving the entire Puducherry district. It is estimated that between 85-90% of Puducherry's population is served by IGGGH, as the district headquarters with speciality services available. The remaining 10-15% of the population is likely to seek treatment from the Central Government Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER) or other smaller clinics or private health facilities [107].

The unique characteristics of Puducherry added to our interest in focusing on it. First, there are no studies on this topic from this region. Second, as a small area with one main state-government multi-speciality hospital; the quality of the individual level patient data we were allowed access to was suitable for the exploratory study; and finally, as a coastal and one of the most urbanized cities of India, it is more vulnerable to the effects of climate change [25, 28].

4.3.2. Health data

Daily hospital mortality records were obtained from the IGGGH for the ten year period 2011 to 2020 (n=7,190). The extracted data was de-identified and included information on age, sex, date of admission, date of death, hours spent in hospital before death and cause of death.

For the period 2011-2015, mortality records were only available from the cardiology department (n=633) in a non-digital format with several missing months due to fire damaged files, while records for 2016-2020 were in a digital format and included data from all hospital departments (n=6,552). For this latter period, cases from all other departments that had a CVD involvement were identified and included in the analysis (n=3,327). As cases were not classified by ICD codes, CVD cases were identified with a cardiologist consultant and classified into categories. We made three broad categories based on ICD-10 codes; (i) IHD; (ii) cerebrovascular accidents (CVA); and (iii) other. Other is comprised of cardiopulmonary diseases, hypertensive disorders, peripheral vascular disease, rheumatic heart disease, congenital heart disease, aortopathies and all other CVDs. A total of 3,960 mortality cases over the ten year period with CVD involvement were included in the study. The codebook is presented in Appendix A table S1.

Our main analysis was based on the aforementioned individual CVD mortality data. We also obtained the monthly hospital records for the entire hospital and cardiology department showing the total monthly admissions and deaths and presented it graphically to highlight the overall trends in hospital mortalities and admissions (Appendix A, Figure S5). Missing records were assumed to be missing-at-random, since missingness was likely only related to time. As time was accounted for in our model a complete case analysis, one in which the analysis is restricted to all individuals for which data are available, should give unbiased estimates.

4.3.3. Meteorological data

Daily weather records from two weather stations serving Puducherry (i.e, Puducherry city and Cuddalore) covering the period 2010 to 2020, were obtained from the Indian Meteorological Department (IMD). The variables included maximum temperature (T_{max}), minimum temperature (T_{min}), average wind speed (WS), dry bulb temperature (Ta) and relative humidity (RH).

We chose to use T_{app} as the main exposure variable of interest as it also accounts for the effect of RH and vapour pressure (hPa) along with temperature, thereby better capturing the physiologically 'felt' exposure. An average T_{app} for Puducherry was calculated by combining individual station data with the Steadman's equation [108],as follows:

$$T_{APP} = Ta + 0.33 \times hPa - 0.7 \times WS - 4$$

$$hPa = \frac{RH}{100} \times 6.105 \times e^{(\frac{17.27 \times Ta}{237.7 + Ta})}$$

where Ta is the dry bulb temperature (°C), hPa is the vapour pressure, RH is the relative humidity (%) and WS is the wind speed (m/s). The daily T_{app} calculated for both weather stations was then grouped by date, from which we calculated a daily average T_{app} for the entire region of Puducherry. This average daily T_{app} was the one included in our model. Comparative figures of the data from individual weather stations is shown in Appendix A Figure S11 and S12.

4.3.4. Statistical model

Our model consisted of the self-matched case-crossover design using dlnm, as described in [109, 110] to capture the non-linearity and delayed association between T_{app} exposure and risk of in-hospital CVD mortality (hereon referred to only as CVD mortality). By design, this allows for the estimation of the average 'within-case' risk while controlling for between subject time-varying factors [44]. As our dataset consisted only of patients who died in hospital, we chose to use the day of admission as our main 'event' since there was no way to determine environmental exposure (presence or absence of air conditioning), medical treatments administered prior to death or other prognostic factors that might have differed between out-of-hospital and in-hospital days. Our study therefore focussed on the association between T_{app} and the risk of 'fatal CVD admission' following hospitalisation.

We used a time-stratified approach in which each case of mortality served as its own control, with the comparable control days being matched by the same day of the week within the same month to generate a total sample size of 17,352 (3,960 cases and 13,392 controls) used in the final model. We chose to model the T_{app}-CVD mortality risk over 21 days to capture long term lags as well as any short term harvesting effect. We constructed the crossbasis by creating a lag matrix over 21 days using the whole T_{app} series, which was matched with the cases and bi-directionally sampled controls. We modelled the exposure-response association using binomial likelihood regression with a natural cubic spline with 2 internal knots placed at the 25th and 75th percentile of the T_{app} range. For modelling the lagged-response, we used a natural cubic spline with 3 internal knots placed equally on the log scale to allow for consistency and comparability with similar studies done previously [68]. A time-stratified design was adopted to regulate potential time-invariant confounders (e.g., age and sex) using self-control and limit bias from temporal confounders (e.g. secular trends, seasonality, day of the week effects, etc.) and exclude long-term impact of air pollutants.

We expressed risks in relation to the minimum mortality temperature (MMT). The MMT was derived from the point on the cumulative exposure-response curve with the lowest associated risk of mortality. This value was used to centre the overall cumulative exposure-response and also considered to be the optimal temperature. We have reported our findings as the fraction of CVD mortalities that can be attributed to temperature, or the attributable fraction (AF). The total number of deaths attributable to non-optimal temperatures, both hot and cold was calculated using the MMT as a reference with a backward direction. The AF is derived as a ratio of the number of deaths attributable to non-optimal temperatures and the total number of deaths [111]. We feel this measure is better suited to show the general trend for how temperature affects CVD mortalities in Puducherry. Empirical confidence intervals have been calculated using Monte Carlo simulations with 1000 replicates. Additionally, to limit spurious values at the extremes we have restricted plots and analyses to the central 95th percentile of the T_{app} distribution.

4.3.5. Subgroup analysis

4.3.5.1. Age-and-sex

We performed subgroup analyses with stratifications for age and sex combined. The age categories used were above and below 60 years of age to account for post-menopausal women. Three cases were missing information on age and were thus excluded from the stratified analysis. A total of 17,338 cases and controls were included in the age-and-sex stratified analysis, out of which 6030 and 11,308 were below and above the age of 60 years respectively.

4.3.5.2. CVD class specific

We stratified the analyses by type of CVD using 3 main classes: (i) IHD; (ii) CVA; and (iii) all other CVDs. Many cases presented with multiple classes of CVDs and since the dataset did not contain ICD-10 codes, there was no way to know the primary cause of death. Such cases were considered in all the CVD classes they presented with and therefore, this cause-specification is patients who died with the particular CVD as opposed to from.

4.3.5.3. Sensitivity analysis

Sensitivity analyses were performed to explore the impact of different numbers and placement of knots, changing the regression to quasi-Poisson, excluding patients who stayed in hospital for longer than 10 days and also using only 5 years of data (2016-2020). The results are presented in Appendix A figures S1 to S4 and S7.

All data were analysed using a combination of Microsoft Excel 2016 and the R software (version 4.0.3, The R Foundation for Statistical Computing Platform 2020). The main packages used were ‘dlnm’ to fit the dlnm model and ‘attrdl’ for the attributable fraction [109]. The methodology used in this project abided by the principles laid out in the Declaration of Helsinki.

4.4. Results

4.4.1. Descriptive statistics

As seen in Table 2, out of the 3,960 cases of in-hospital mortality with a CVD involvement between 2011 and 2020 that were included in this study, the average patient spent 4 days in hospital. There is no data on whether these were emergency visits or planned visits. More than half (54%) of patients died within 48 hours of being admitted to the hospital.

Table 2: *Table of descriptive statistics showing the distribution and characterization of the meteorological data and patient data. N/A denotes missing information. Additional information on climate variable distribution by patient characteristics is presented in Table S2*

		Apparent Temperature (°C)	Average Temperature (°C)	Humidity (%)
Climate variables	**Mean ± SD**	33.5 ± 8.6	28.6 ±2.5	76.6 ± 3.4
	Min, Max	22.9, 41.9	19.6, 36	43, 100
Patient characteristics			***n* (% of total)**	**(Mean ± SD, Min, Max)**
	Gender	**Male**	2366 (59.7)	
		Female	1591 (40.2)	
		Missing	3 (0.1)	
	Age (Years)	**<20**	24 (0.6)	65 ± 14.2, 1, 104 (Years)
		21-40	236 (5.9)	
		41-60	1371 (34.6)	
		61-80	1937 (48.9)	
		>81	389 (9.8)	
		Missing	3 (0.07)	
	State	**Puducherry**	3064 (77.4)	
		Tamil Nadu	879 (22.2)	
		Andra Pradesh	7 (0.2)	

		Other/Missing	10 (0.3)	
	Time spent in hospital	**<48 hours**	2121 (53.6)	4 ± 4.95, 1, 82 (Days)
		>48 hours	1839 (46.4)	
	Comorbidities	**Yes**	2176 (54.9)	

The mean dry bulb temperature and humidity for Puducherry was around 29°C and 76%, respectively. The mean T_{app}, which takes both of these into account along with VP and WS was slightly higher in Puducherry between 2010 and 2020, around 33°C. Two thirds of the patients were older than 60 years (65.2%). More males than female patients died of a CVD related mortality. Over 50% of patients in this study also had at least one co-morbidity associated with CVDs, namely hypertension, diabetes or alcoholism.

4.4.2. Cumulative exposure-response association and attributable fraction

Figure 9 shows the relative risk (RR) estimates for the association between T_{app} and CVD mortality, cumulatively across the 21-day lag period, with the corresponding T_{app} distribution, MMT and heatwave threshold as defined by the Indian Meteorological Department (IMD) [112].

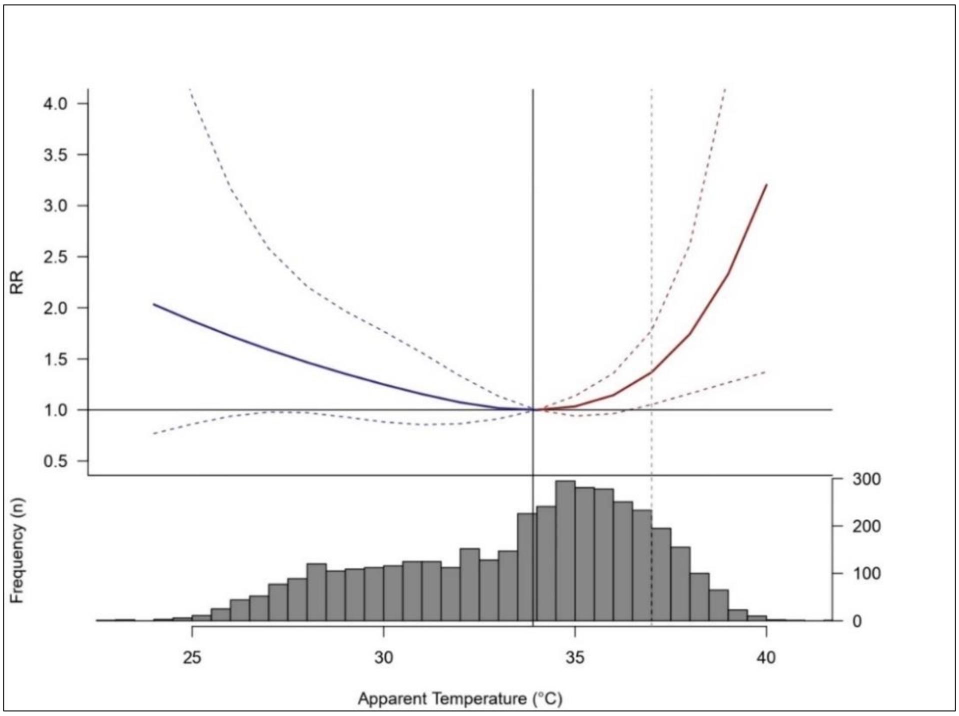

Figure 9: *Cumulative apparent temperature (T_{app})-CVD mortality RR with a 21-day lag (dotted lines show the 95% CI) with a histogram of the T_{app} distribution for Puducherry between 2011 and 2020. The black solid vertical line represents the minimum mortality temperature (MMT), while the dotted grey line represents the heat wave threshold at 37 °C. The blue line and red line represent the exposure–response curve for cold and hot temperature relative to the MMT respectively.*

The cumulative association shows a distinct U-shaped curve with temperatures below and above the MMT showing an increased RR of in-hospital CVD mortality. The MMT itself is 33.9°C and occurs at around the 60^{th} percentile of the T_{app}. The temperature distribution shows that the MMT is close to both the median and mean T_{app} (34.25°C and 33.5°C, respectively). In the 10 year period, the T_{app} was between the MMT and heatwave threshold temperature for 1506 days, representing a total of 41.3% of all days.

The optimal temperature corresponds to the MMT and can be thought of as the temperature with the least associated risk of in-hospital CVD related mortality. Here, all temperatures below and above 34°C will be considered 'cold' and 'hot', respectively. While the RR increased rapidly and non-linearly above heatwave threshold temperatures, there are fewer days (496 days) with extremely hot temperatures above the heatwave threshold.

Overall, 17.4% (95% CI 6.4-26%) of the in-hospital CVD related deaths can be attributed to non-optimal temperatures within the study period (Table 3). Out of these, colder non-optimal temperatures, consisting of 1645 days, have a higher burden with 8.3% of deaths (95% CI -2.5-16.6%) attributable to cold as compared to 9.1% (95% CI intervals 0.9-15.8%) of deaths being attributable to heat, representing 2002 days in the study period.

***Table 3**: The overall attributable fraction (AF) for overall non-optimal apparent temperature (T_{app}), cold T_{app} and hot T_{app} in Puducherry with the 95% CI.*

	Attributable Fraction (%) (95% CI)
Non-optimal T_{app}	17.4 (6.4, 26)
Cold T_{app}	8.3 (-2.5, 16.6)
Hot T_{app}	9.1 (0.9, 15.8)

4.4.3. Lagged association

Figure 10 represents the lagged response association for the 5^{th} (27.3°C) and 95^{th} (38.0°C) percentile of the T_{app} distribution over a 21-day period.

Colder temperature has an almost immediate response or increase in RR, while hot temperatures show a delayed association. The cold effect peaks at day 1 before gradually decreasing to a protective risk at lag day 5 (with no statistical significance). The cold-CVD mortality association risk then increases slightly again from around day 7 to day 16 where it peaks around day 11, as seen in Figure 10a. Hot temperature related risk of CVD-mortality is only seen after a 5-day lag period, with an initial protective effect, and persists for 16 days, although the confidence intervals are quite wide as shown in Figure 10b. This risk is relatively lesser compared to the cold-CVD mortality risk.

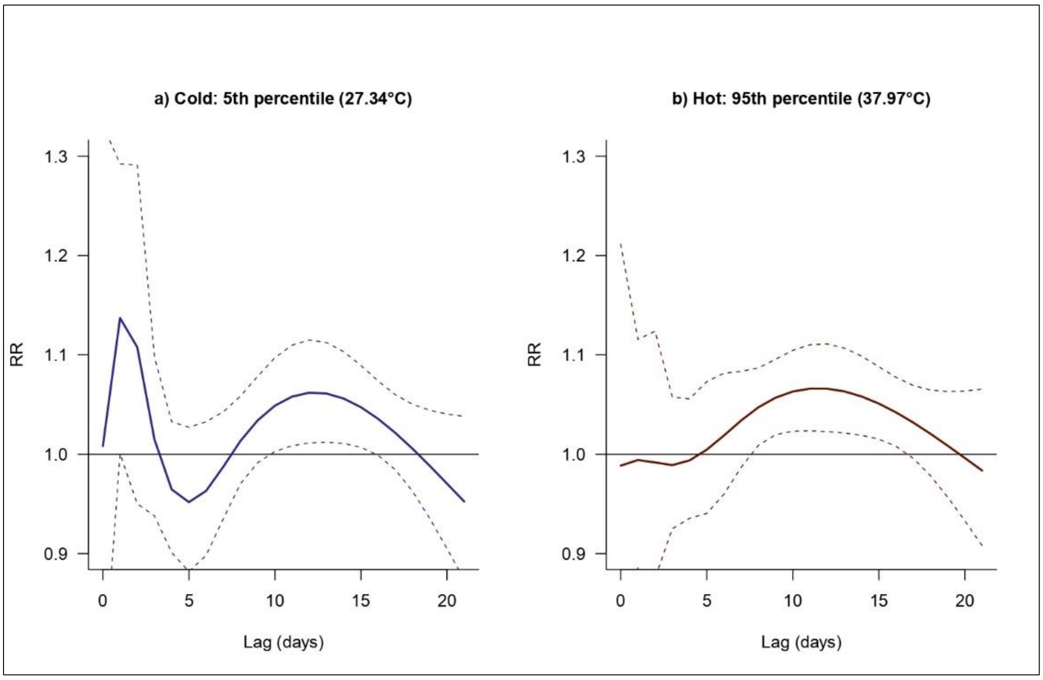

Figure 10: *The RR for the lagged apparent temperature (T_{app})-CVD mortality association at the 5th and 95th percentiles of the T_{app} range. (a) The blue line represents the cold temperature at 27.3 °C and (b) The red line represents the hot temperature at 38.0 °C. The dotted lines represent the 95% CI*

4.4.4. Age-and-sex stratification

In order to better understand this association in different groups, we performed age-and-sex stratified analyses. Sex and age group both seem to be a contributing factor to the risk temperature related CVD mortality, as seen in Figure 11

Males both above and below 60 years of age seem to be largely unaffected by heat (Figure 11a and b). Females below 60 years of age are affected by both heat and cold, although the heat effect is predominant (Figure 11c). Females over 60 years are more likely to be unaffected by cold and have a higher risk from heat on average (**Figure 11**d).

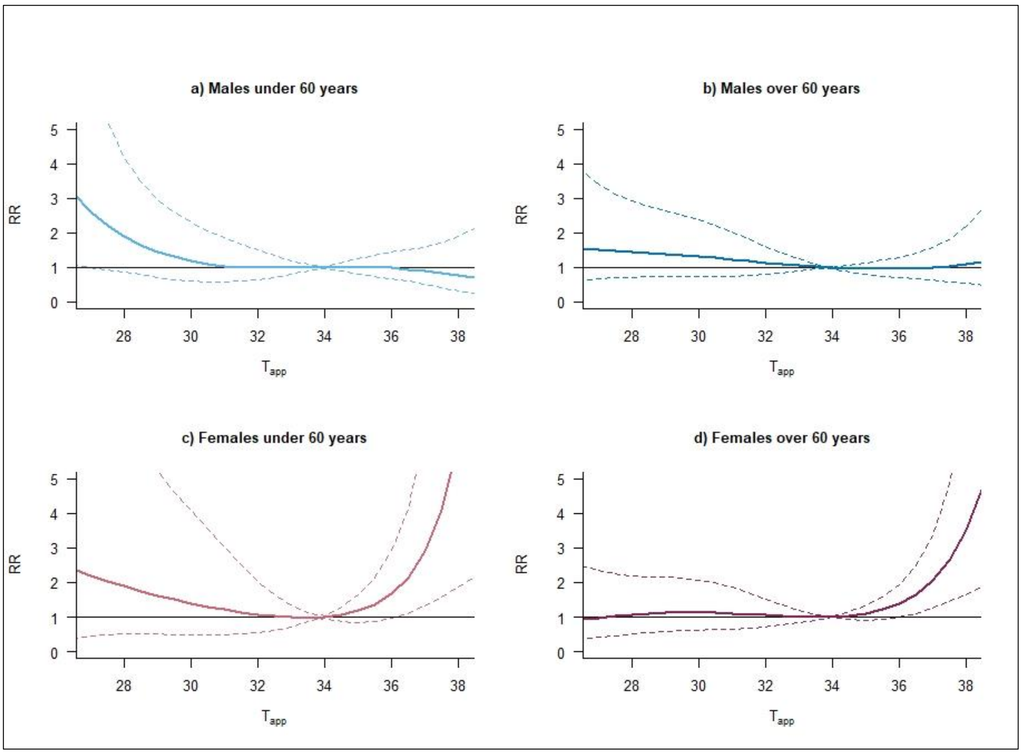

Figure 11: *The RR of apparent temperature (T_{app}) attributable CVD mortality among males under 60 years, b males over 60 years, c females under 60 years and d females over 60 years. Graphs are restricted to the central 95% of temperature due to wide CIs at the extreme ends.*

We found that males of all ages are at a relatively similar risk for temperature attributable CVD mortality (Table 4). Females below 60 years have a higher AF to non-optimal temperatures compared to older females, primarily since they are also sensitive to cold. Females over 60 years have a lower risk from cold and their AFs are mainly heat related.

Table 4: *The fraction of CVD mortality attributable to overall non-optimal apparent temperature (T_{app}) cold and hot non-optimal T_{app} for males and females above and below the age of 60 years with the number of cases and controls for each category*

Sex and age (years)	AF% (95% CI)	Cold AF% (95% CI)	Hot AF% (95% CI)
Males below 60 (*n*=4139)	4.4 (-19.3, 19.5)	6.8 (-15.9, 20.7)	-2.4 (-21.8, 12)
Males over 60 (*n*=6222)	7.3 (-10.6, 20.3)	8.3 (-10.1, 21.4)	-1 (-15.1, 9.8)
Females below 60 (*n*=1891)	28.4 (-4, 43.3)	8.8 (-28, 27.2)	19.8 (1.5, 31)
Females over 60 (*n*=5086)	16.3 (-4, 28.1)	2.5 (-22, 17.4)	13.8 (3.7, 22.1)

4.4.5. CVD type stratification

Stratified analyses for the type of CVD revealed that IHDs do not seem to be particularly affected by heat and minimally affected by cold, as shown in Figure 12a. For CVAs, cold temperatures affect the risk of mortality less than heat, as can be seen in Figure 12b. All other forms of CVDs seem to display the same U-shaped association seen in the cumulative association and are affected by both heat and cold (Figure 12c). As such, the results shown here are of patients who died with that particular CVD as opposed to from that particular CVD.

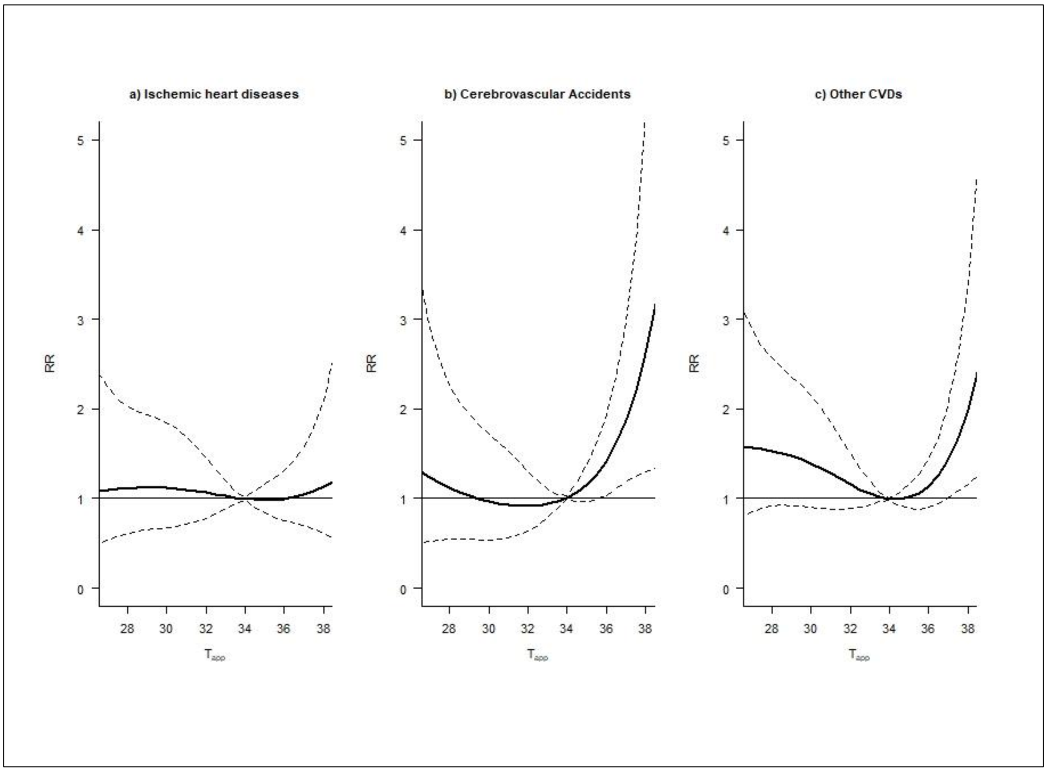

Figure 12: *Cause-specific apparent temperature (T_{app})-mortality association for patients who died with (a) ischemic heart diseases, (b) cerebrovascular accidents and (c) all other types of CVDs. The graphs have been restricted to the central 95th percentile of the T_{app} range.*

4.4.6. Sensitivity analysis

The findings from the sensitivity analyses are presented in Appendix A (Figures S1 to S4 and S7). Briefly, the associations identified in our main analysis were insensitive to changes explored, though there was some sensitivity of predicted associations at more extreme temperatures, where data available for estimation was more limited.

4.5. Discussion

Our findings show that despite having generally high T_{app} throughout the year, both cold and hot non-optimal temperatures are responsible for contributing to excess CVD deaths in Puducherry. The overall AF we found was 17.4%, with an almost equal burden attributable to cold (8.32%) and hot (9.1%) non-optimal temperature. A review spanning 750 locations across 43 countries found that out of 9.4% of all-cause excess deaths attributable to non-optimal temperatures, 8.5% were cold related while 0.9% were heat related, thereby supporting our findings, especially related to cold [29]. In inherently hot regions like Puducherry, it thus becomes important to consider cold exposure as an important contributor to temperature-related mortality.

We found that cold exposure had a bi-level lagged response with a sharp, immediate increase in mortality risk followed by a protective effect over a short time period before a second peak of increased risk in CVD mortality, most likely due to the long-term effects of cold. On the other hand, heat exposure showed a delayed CVD-response. This differs from other studies, which found an immediate effect due to heat and a more lagged cold response [40, 44, 68, 113]. The harvesting effect or mortality displacement, when the most vulnerable people are affected earlier than the healthier members of the population, thereby bringing mortality forward in time, could explain the immediate increase in cold related mortalities followed by the slightly reduced risk till about lag day 7 [114, 115]. Since the average T_{app} in Puducherry is around 34°C, the population is likely more adapted to temperatures above 30°C. Repeated exposures to temperatures above 30°C could induce a form of thermal pre-conditioning. This sub-lethal, frequent heat exposure could help to build tolerance and confer protection against further lethal thermal stress brought on by extremely high temperatures [55]. The thermal pre-conditioning effect has been found to set in within hours of exposure and can last up to 5 days, potentially explaining the 5-day lag seen for hot temperatures in Puducherry [116].

Additionally, there is a greater proportion of 'cold' days compared to 'hot' days or 'extremely hot' days. For the coastal regions, a heatwave is declared when the maximum temperature rises above 37°C and is a departure of 4.5°C or more from the normal temperature, as per the IMD [112]. There are relatively few consecutive 'extremely hot' days in Puducherry, while there is often a 'cold spell' lasting for several days, especially during the winter months, which could affect the population negatively, especially if they are unaccustomed to it. Indoor heating systems are also uncommon in the southern part of India where temperatures rarely drop below 20°C. However, the IMD definition of a cold wave in coastal areas is when the minimum temperature is <15°C or a departure of 4-5°C from minimum temperature, meaning that there has been no official cold wave recorded in Puducherry for several years [117, 118]. Puducherry is one of the most urban territories in India with 68.3% of the population considered as urban according to the 2011 Census [106]. Typical urban characteristics that modify the temperature effect on health, such as tightly packed spaces and living quarters, population density, air pollution and green spaces, might contribute to the overall relatively high heat AF we found [119]. Thus, our results also highlight the importance of regionally defining cold and heat from a health perspective using the MMT.

The MMT percentile also seems to vary by region, with tropical and subtropical regions having a MMT around the 60th percentile of the temperature distribution compared to the 80th or 90th percentile as seen in temperate regions [120]. Therefore, a one-measure-fits-all approach cannot be used to describe the temperature-CVD mortality or all-cause mortality relationship [121].

We were able to identify the differences in the temperature-CVD mortality association between sexes and age simultaneously, which to our knowledge has not been studied yet in the Indian context. Our results demonstrate that age and sex together act as effect modifiers. All males were more likely to be susceptible to cold compared to heat. Males aged above 60 years were more vulnerable to cold non-optimal temperatures than females in the same age bracket, who were more susceptible to hot non-optimal temperatures and seem to withstand cold better, as a whole. Meanwhile, females below 60 years were affected by both hot and cold non-optimal temperatures. We postulated several possible explanations for this phenomenon. Overall, age is a common risk factor for CVD mortality with older people, especially women, being more susceptible [55, 122-125]. Most women over the age of 50 years have undergone menopausal transition, which has long been associated with decreased cardio-protection and an increase in the risk of developing CVDs and vulnerability to heat [126]. Sex differences in thermoregulation could also be a factor for these findings. For example, the temperature threshold, above which sweating is induced, is higher in women than in men while their overall sweat output is lesser, resulting in reduced heat tolerance [127, 128]. On the other hand, men have found to have a greater decrease in core body temperatures when exposed to cold compared to women, leading to a higher cold intolerance or sensitivity [129, 130]. A study by Achebak *et al.,* in Spain reported a similar relationship between older females and males being more susceptible to CVD mortality from heat and cold respectively [45].The context of Puducherry might also play a role in this association. Manual outdoor labour including agriculture and construction are common occupations for many men, potentially helping them build tolerance to higher temperature. Traditionally, females, especially older females, are more likely to spend a larger part of the day indoors where the urban island effect, inadequate air conditioning and physiological factors could make them more vulnerable to heat [131].

The findings from our cause-specific analysis compare to a recent study by Schulte *et al.,* in Switzerland which found limited risks of mortality from myocardial infarction (part of IHD in our study) associated with temperature [124]. They also found the risk of mortality from strokes (CVA in our study) increases with heat. The findings are also similar to the Fu *et al*., study from India, which found smaller cold-attributable risk in addition to a U-shaped curve for CVAs as we confirmed [68].

Many studies look at the temperature-mortality association, but few look at CVDs in particular. The MMTs for all-cause mortality are derived as a function of disease-specific MMT [97]. In fact, temperature-CVD mortality associations have been found to be U or J-shaped while various patterns including the inverse U or reverse-J shape have been associated with infectious diseases [44, 132-134]. The association between temperature-CVDs also varies by region and latitude, with different regions within a country reporting different relationships [44, 97, 121, 135]. While most studies have found an increase in CVD events due to heat exposure, a study done across China found that the bigger burden of CVD mortality can be attributed to cold temperatures [44].

As of 2016, 28.1% of all deaths in India were due to CVDs as compared to 15.2% in 1990 and this burden is projected to increase along with the level of epidemiological transition (ETL) [136]. Puducherry falls in the higher-middle ETL bracket with 53.1% of deaths below 70 and 46.9% of total deaths above 70 years due to CVDs, making it a severe public health issue [136].

We found few studies that looked at the temperature-mortality association in India; however, none were from Puducherry or the surrounding states. The findings from these studies are instrumental in highlighting the differences in regional temperature distribution ranges within India and the corresponding MMT for all-cause mortality, which ranged from 28.6°C (temperature range 15.3°- 33.2°C) to 30°C (pan India temperature range 0.4°C - ~40°C) [68, 69]. Further studies are needed to characterize the micro-climatic, demographic and socio-cultural differences in temperature attributable, cause-specific mortality.

While there are relatively fewer "heat wave" days in Puducherry, if the warming trend continues as projected, the temperatures for Puducherry could increase or lead to erratic extreme temperatures. It could lead to either a potential right-shift of the optimal temperatures, if this occurs gradually, or a significant increase in the AF for CVD mortality due to hot temperatures if there are more erratic extreme days. For example, a study from Hyderabad, a city with higher mean temperatures than Puducherry, found an increase in all-cause mortality by 16% and 17% for maximum temperatures above 40°C and heat index > 54°C respectively [72]. The pattern of anthropogenic climate change over India is a complex one. Mean temperatures in the South Asian region have been decreasing in the past decades and India has not seen an increase in the maximum temperature trends since the 1970s [29, 137]. From a health perspective, T_{app}, which accounts for humidity, is better at measuring the health effects. The increase in humidity in India has led to T_{apps} increasing in India and thereby the severity and occurrence of heat has increased [137]. In the future, pollution control measures and a slower pace of irrigation expansion will likely counter the present cooling effects being seen and as humidity is projected to increase, the net effect will be a gradual rise in hot temperatures, especially during heat waves [137]. It is difficult to assess whether the rise in temperatures might be accompanied by a decrease in the AF for cold-related mortalities or whether only the severity and frequency of heat waves will increase. The absolute number of CVD mortalities attributable to non-optimal temperatures are likely to increase, however, since more people will be at risk or have CVDs in the future.

A recent multi-country, multi-community study found that most excess deaths occur in eastern/southern Asia, especially in coastal cities, highlighting the difficulties to protect, react and reduce adverse temperature effects in these regions, partially due to the large and dense population [29]. As there are several large cities both within this region and along the extensive coastline of India, it is imperative that further research is done on how temperature affects the health of the local population. There is also a need to develop a tailored temperature-health impact management and adaptation plan to reduce the burden of CVD mortalities due to non-optimal temperatures that accounts for regional demographics. These preliminary estimates can be used as a basis to support further detailed research on this topic in Puducherry or elsewhere.

4.5.1. Strengths

Our study has several strengths. First, it demonstrates how both relatively cold and hot temperatures affect CVD mortality in the tropical region of Puducherry. The high quality of patient level data allowed for examining the effects of age-and-sex grouped together, which has not been explored in the Indian context. It highlights the added vulnerability of older women to extreme heat. Second, the case-crossover approach adjusted for stable within subject and residual individual confounders, particularly from variables that may not have been recorded, by design and allowed us to preserve individual characteristics. We could thus conduct individual-level and inter-individual analysis through subgrouping. Third, this is the first study of its kind in this region; we were able to show how regional and demographic variations play an important role in determining the fraction of CVD mortalities attributable to non-optimal temperatures over a relatively long time period. Additionally, the small size of Puducherry coupled with a single multi-speciality state government hospital and robust health system means that we were able to capture the general trends from the main state government hospital, which caters to majority of the population within Puducherry. Finally, we were able to demonstrate that cold temperatures have a large AF consistent with other Indian studies as shown. Overall, our study is comparable to global studies from different climate zones and areas, implying a greater contribution of population, genetics and acclimatization to the temperature-CVD mortality relationship. The results from our sensitivity analyses using only 5-year data from the whole hospital, or changing the knot placement were all insensitive to the changes in the model, supporting the robustness of our findings about the association in Puducherry.

4.5.2. Limitations

The study has several limitations that we offer for consideration. The small sample size which we managed to obtain and the variability in daily in-hospital mortality reduces the certainty with which we can draw inferences, particularly regarding subgroups. This is also shown by the wide CIs, especially at the extreme ends. Since the data stems from a state-run government hospital, we cannot account for patients who might have chosen to seek treatment in a private hospital or travelled to neighbouring states, however as mentioned above this is likely to be minimal. We also did not include air pollution in our study due to lack of suitable data. Thus, we cannot evaluate whether air pollutants are correlated to temperature in our study area, as seen in some studies. This implies that our association with temperature may also include air pollution effects to the extent temperature affects air pollution levels. However, it must be noted that temperature has been shown to have a relationship that is independent from the effects of air pollution [138, 139]. Owing to its geographical location, with ventilating effects from the sea and land breeze, and relatively low population density, Puducherry levels of air pollutants are relatively low with an average mean of about 30-49 µg/m³ for PM10 and a declining trend since 2016 [140]. This study assumes that the effects of temperature on CVD mortality are through an acute exposure (the effect on CVD is assumed to only happen over the 21 day-lag that was modelled) as opposed to the chronic nature of temperature exposure. One of the key assumptions of this study was that temperature changes recorded at weather stations affected the entire population in the same way. Different parts of the district may have been more insulated from these changes. As we did not have information on the specific location of individuals prior to admission it was not possible to explore this in more detail, but we felt as though differences were unlikely to be sufficiently systematically different to confound the association between temperature and CVD admissions as shown in Figure S11. Finally, as there is no way to separate the temperature effects on the cardiovascular system from the medical interventions or hospital conditions that might counter the actual effects and work to prolong life, used the outcome of 'fatal admission' as opposed to simply mortality, as is commonly used. This allowed us to assume that exposure lasted only until hospital admission, following which treatments and climate control in the hospital could be expected to modify the exposure-mortality association, especially since patients who were admitted for more than 48 hours spent an average of 7 days in hospital before dying. We have performed sensitivity analysis including only those who spent a maximum of 10 days in hospital (Appendix A Figure S7). While we tried to assess the cause-specific risk of morality, there were some limitations, for example as most of the patients presented with multiple CVDs, the overall risk from individual CVDs cannot be confidently assessed and there is likely a mixed effect.

4.6. Conclusion

Our study highlighted the burden of CVD mortality within hospitals attributable to cold and hot non-optimal temperatures in Puducherry. We found the MMT for Puducherry differs from the MMT reported at the national level, pointing towards a need to follow up with larger, regional studies. There are also age-related sex differences in the vulnerability of the population to non-optimal temperatures If the warming trend over India continues, heat will likely become a bigger challenge for public health, particularly increasing the vulnerability of females. As such, public health interventions need to be contextually and gender tailored for the local population and need to address the cold-impacts as well as the heat-impacts, even in tropical regions. In addition, our findings suggest the importance of considering optimal temperatures as the measure against which 'cold' and 'hot' are refined for a region.

Finally, we feel that there needs to be an increased awareness about the health impacts of climate change. Research is one of the main ways to raise awareness and ensure measures such as healthcare system preparedness, early warning systems, climate resilient infrastructural developments and urban planning are taken. It can also contribute to the development or enhancement of climate informed health policies. There is also an urgent need to have central, individual level, health registers which can be accessed for research.

Overall, our findings contribute to understanding how climatic conditions can affect CVD outcomes in India.

4.7 Declarations

Author contributions

S.S, M.R, M.A.D, J.U and G.C conceptualized and planned the study. S.S and R.L acquired and provided access to the data. S.S, H.P and A.G designed and carried out the modelling and statistical analysis. S.S wrote the main manuscript with inputs from H.P. The manuscript was revised by all authors. The authors read and approved the final manuscript.

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Ethics declaration

Informed consent was not required for the study, as it deals with de-identified secondary data. This study was approved by the Institute Ethics Committee (Human Studies) of the Indira Gandhi Medical College and Research Institute (A Govt of Puducherry Institution); No. 318/IEC-31/IGM&RI/PP/2021 and by the Ethics Committee Northwest and Central Switzerland (EKNZ); Statement ID- AO_2020_00034. The methodology used in this project abided by the principles laid out in the Declaration of Helsinki.

Availability of data and materials

The meteorological data used in this study is available from the Indian Meteorological Department, upon request, from their Climate Data Service Portal (https://cdsp.imdpune.gov.in/).

The health data that support the findings of this study are available from the Puducherry Department of Health following their prescribed procedures and ethical approval as this data is not publicly available. A sample of the dataset can be available from the authors upon reasonable request and with permission of the Puducherry Department of Health with ethical permissions from an Indian ethics review committee.

R codes are available from the corresponding author upon request.

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Chapter 5. The association between apparent temperature and hospital admissions for cardiovascular disease in Limpopo Province, South Africa

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Article

The Association between Apparent Temperature and Hospital Admissions for Cardiovascular Disease in Limpopo Province, South Africa

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Abstract: Cardiovascular diseases (CVDs) have a high disease burden both globally and in South Africa. They have also been found to be temperature-sensitive globally. The association between temperature and CVD morbidity has previously been demonstrated, but little is known about it in South Africa. It is important to understand how changes in temperature in South Africa will affect CVD morbidity, especially in rural regions, to inform public health interventions and adaptation strategies. This study aimed to determine the short-term effect of apparent temperature (T_{app}) on CVD hospital admissions in Mopani District, Limpopo province, South Africa. A total of 3124 CVD hospital admissions records were obtained from two hospitals from 1 June 2009 to 31 December 2016. Daily T_{app} was calculated using nearby weather station measurements. The association was modelled using a distributed lag non-linear model with a negative binomial regression over a 21-day lag period. The fraction of morbidity attributable to non-optimal T_{app}, i.e., cold (6–25 °C) and warm (27–32 °C) T_{app} was reported. We found an increase in the proportion of admissions due to CVDs for warm and cold T_{app} cumulatively over 21 days. Increasing CVD admissions due to warm T_{app} appeared immediately and lasted for two to four days, whereas the lag-structure for the cold effect was inconsistent. A proportion of 8.5% (95% Confidence Interval (CI): 3.1%, 13.7%) and 1.1% (95% CI: −1.4%, 3.5%) of the total CVD admissions was attributable to cold and warm temperatures, respectively. Warm and cold T_{app} may increase CVD admissions, suggesting that the healthcare system and community need to be prepared in the context of global temperature changes.

Keywords: climate change; cardiovascular diseases; apparent temperature; distributed lag non-linear model; rural setting; South Africa; time-series analysis

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5.1. Abstract

Cardiovascular diseases (CVDs) have a high disease burden both globally and in South Africa. They have also been found to be temperature-sensitive globally. The association between temperature and CVD morbidity has previously been demonstrated, but little is known about it in South Africa. It is important to understand how changes in temperature in South Africa will affect CVD morbidity, especially in rural regions, to inform public health interventions and adaptation strategies. This study aimed to determine the short-term effect of apparent temperature (T_{app}) on CVD hospital admissions in Mopani District, Limpopo province, South Africa. A total of 3124 CVD hospital admissions records were obtained from two hospitals from 1 June 2009 to 31 December 2016. Daily T_{app} was calculated using nearby weather station measurements. The association was modelled using a distributed lag non-linear model with a negative binomial regression over a 21-day lag period. The fraction of morbidity attributable to non-optimal T_{app}, i.e., cold (6–25 °C) and warm (27–32 °C) T_{app} was reported. We found an increase in the proportion of admissions due to CVDs for warm and cold T_{app} cumulatively over 21 days. Increasing CVD admissions due to warm T_{app} appeared immediately and lasted for two to four days, whereas the lag-structure for the cold effect was inconsistent. A proportion of 8.5% (95% Confidence Interval (CI): 3.1%, 13.7%) and 1.1% (95% CI: −1.4%, 3.5%) of the total CVD admissions was attributable to cold and warm temperatures, respectively. Warm and cold T_{app} may increase CVD admissions, suggesting that the healthcare system and community need to be prepared in the context of global temperature changes.

5.2. Introduction

Cardiovascular disease (CVD), the leading cause of death globally, is a major threat to human health and well-being. CVD is a broad term used to encompass a group of multi-factorial diseases affecting the structure and function of the heart and the vasculature system. In 2019, CVDs were estimated to account for 32% and 15% of the global mortality and morbidity, respectively [32]. Non-modifiable (age, sex, and genetics), modifiable behavioural risk factors such as physical inactivity; unhealthy dietary patterns; tobacco; and alcohol consumption as well as external determinants, including stress, noise and air pollution, and socio-economic status are known contributors to CVD incidences [31, 32, 55]. CVDs are a public health issue, especially in low- and middle-income countries (LMICs), with over 75% of global CVD deaths occurring in these regions, partially due to inequitable healthcare services and insufficient awareness of early intervention programmes [32].

Over the years, a growing body of research has found temperature to be an environmental factor affecting CVD mortality [29, 55, 120, 121, 141]. The risk of severe illness or morbidity due to CVDs increases at very high or very low ambient temperatures, although this is context-dependant [93, 97]. The thermoregulatory response of the cardiovascular system is thought to play a role in driving the temperature-CVD association. As a response to heat stress, the superficial blood vessels dilate, increasing blood flow to the skin, and which increases cardiac workload. With prolonged heat exposure and inability to lose bodily heat by sweating an increase in core temperature occurs. The inability of the cardiac output to compensate for this leads to a cardiovascular event, usually through heat intolerance. A core body temperature above 38°C results in heat exhaustion with impaired physical and cognitive functions and higher than 40°C leads to heat stroke and increased risks of organ damage and mortality [55, 95, 96]. In contrast, exposure to cold causes an increase in the cardiac workload and a sustained increase in systemic blood pressure resulting in cardiovascular dysregulation, through vasoconstriction that reduces blood flow to the heart [55, 59]. Further, altered blood constitution and consequent increase in haemo-concentration and fibrinogen as a response to cold, favours coagulation and increases the risk of thromboses [142]. This response is also driven by the cold-related autonomous nervous system activation, occasionally leading to arrhythmias [143].

There are several studies showing the effects of temperature on mortality and morbidity, although fewer tend to focus on the latter [29, 121, 144-147]. Studies have shown an increased short-term effect of temperature on CVD mortality; some have shown a V-, U- or J-shaped relationship, which suggests an increase in the risk for CVD above and below an optimal temperature [40, 42, 43, 148]. Optimal temperature is defined as the temperature with the lowest risk for CVD mortality and temperatures above and below this are referred to as warm and cold temperatures, respectively [42, 44]. However, with respect to CVDs, optimal temperature and the extent to which temperatures affect them, varies by climate, region and population [42, 44].

Taken in the context of anthropogenic climate change, global mean surface temperatures are largely projected to increase, with an increase in temperature extremes, i.e., days of extreme heat and cold, intensifying in frequency and duration [149]. The rapid pace of this global warming has emerged as a major threat to human health and is a developing public health challenge [141]. Non-optimal temperatures are now among the top 10 leading causes of mortality worldwide, according to a recent Global Burden of Disease study [91]. Given the large burden of CVDs and associations between temperature and CVD, there is reason for concern that the prevalence of CVD and short-term effects, such as hospital admissions, may increase in the future with frequent extremes of temperature [145-147, 150]. The impacts are likely to have the greatest effect in vulnerable communities and in LMICs [98, 99]. Physical factors such as rural settings, low educational attainment, and air pollution have been recognized to increase the susceptibility to temperature-related CVDs [151-154].

South Africa is facing a double burden in this context; warming over South Africa is happening at twice the global rate and ischaemic heart diseases (IHDs) and related co-morbidities such as diabetes are the only diseases that have seen an increased prevalence over the past decade [76, 80]. In 2019, CVDs accounted for 16% of all deaths and 7% of all disability-adjusted life years (DALYs) in South Africa [80]. People from low socio-economic groups and those living in remote or rural areas are at increased risk for poorer CVD outcomes, partially due to inadequate access to medical facilities compared to their urban counterparts [32, 155, 156]. Few studies have considered the relation between temperature and mortality or morbidity in South Africa. Using data for 1997 to 2013, a study found that 3.4% of the nation-wide mortality was due to non-optimal temperature, with 3% attributable to cold and 0.4% attributable to warm temperatures [42]. Two studies considered CVD morbidity using hospital admissions data and the effect modification of temperature on the association between air pollution and CVD admissions for different regions of South Africa and reported contrasting findings [153, 157]. As the average temperature projections for South Africa suggesting between 4 to 6°C increases in temperature by 2100, the risk of hospital admissions for CVD-related illnesses attributable to temperature requires further investigation for improved prevention and preparedness [158, 159].

Given the variation in findings across and within countries, the aim of this study was to perform an exploratory analysis investigating the short-term association between apparent temperature (T_{app}) and CVD hospital admissions in Mopani District Municipality, Limpopo province, South Africa and the proportion of CVD admissions attributable to non-optimal T_{app}.

5.3. Materials and Methods

5.3.1. Study Setting

Mopani district is located in Limpopo province in north-eastern South Africa. Mopani district is predominantly rural with high levels of unemployment, with approximately 55% of the population living below the upper poverty line of ZAR 1227 (equivalent to ~73 USD) per month [160]. Climate studies suggest that this region is vulnerable to the health impacts of heat exposure due to projections predicting significant increases in temperature and heatwave events [158, 161, 162]. Daily hospital admission data was collected from two large hospitals, namely Nkhensani Hospital and Maphutha L. Malatjie (Figure 13) which are two out of six secondary level health-care facilities in the district.

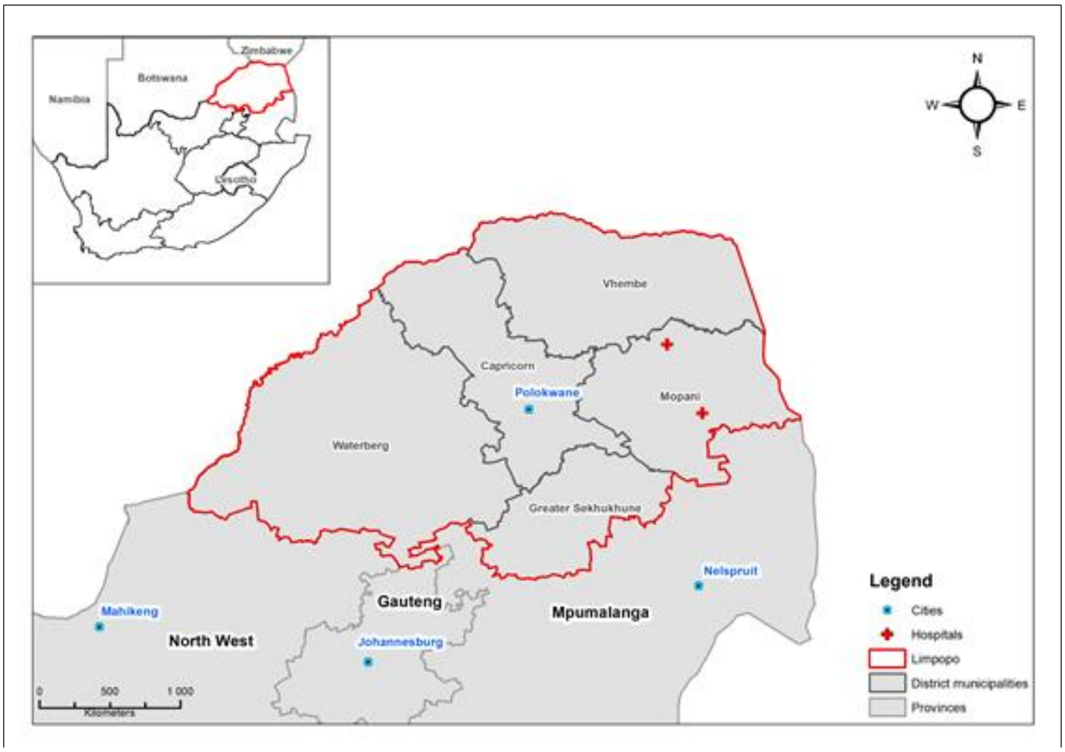

Figure 13: *Location of the two hospitals in the study site of Mopani District, Limpopo province, South Africa.*

The dataset has been used in previous studies to consider diarrhoeal disease [163], respiratory disease [164], malaria and asthma [165] but not CVD hospital admissions.

5.3.2. Data Sources

5.3.2.1. Health Data

The variables in the hospital admission data included date of admission and discharge, time spent in hospital, age and sex. The dataset was not classified using the International Classification of Disease-10 (ICD-10) codes and only the initial diagnosis on admission was available. Therefore, the ICD-10 IX (diseases on the circulatory system) classification list was employed to identify CVD cases for all ages in consultation with a general medical doctor from South Africa. The list with the broadly classified CVDs used in this study is included in the Appendix B (Table S3). While the dataset covered the period of 2002 to 2016, we chose to include only the cases from 2009 to 2016 owing to a high amount of missingness for the period prior to that, partially due to misplaced admission books.

There was a total of 37,090 all-cause admissions from 2009 to 2016. Of that, a total of 4097 CVD admission cases were included in this study, from which 1726 cases were missing the date of admission. As the date of admission was considered to be the outcome date, we imputed the missing information by subtracting the average length of hospital stay (17 days) from the date of discharge (if reported). A total of 43.6% of the cases could be imputed and the remaining 56.4% of the cases with neither date of admission nor date of discharge available were excluded from the analysis (23.6% of the overall sample). From the CVD admissions without missing information on those variables, 51.57% and 48.43% were males and females, and 21.07% and 78.93% were <45 years and ≥45years of age, respectively.

A final sample of 3124 CVD admissions occurring in the study period between 1 June 2009 and 31 December 2016 was included in the analysis. All admission records were aggregated to daily counts and merged with daily T_{app} data (see below). 147 days with no hospital admissions were treated as missing data and excluded from the model.

5.3.2.2. Weather Data

Meteorological data were obtained from Thohoyandou where a weather station was located approximately 40 km outside of the Mopani district. Data on mean daily temperature (°C) and relative humidity (%) were directly extracted from the dataset. In a previous study, temperatures measured at the Thohoyandou weather station and in dwellings in Giyani (the location of the hospitals) were well correlated ($R = 0.98$, $p < 0.001$), suggesting that meteorological conditions did not vary substantially between the station and the communities under study [164].

Missing meteorological variables were imputed with chained equations followed by predictive mean matching. Variables used to predict missing weather variables were average temperature (T_{avrg}), relative humidity (RH), wind speed (WS) and total rainfall. For days where no weather data was available, T_{app}, was calculated using an exponential rolling average of the three days before and after, where more weight was given to T_{app} of more recent days. Out of the 2771 days in the study period, T_{app} was imputed for 19 days with the predictive mean matching method and for two days with the rolling average. T_{app}, a metric that combines temperature and relative humidity, was chosen as the exposure variable, as it ought to represent the 'real-feel' of temperature. T_{app} was calculated using the Steadman equation shown below, where hPa is the vapour pressure [108].

$$T_{app} = \text{Tavg} + 0.33 * \text{hPa} - 0.7 * \text{WS} - 4$$

$$\text{hPa} = \frac{\text{RH}}{100} * 6.105 * \text{e}\frac{(17.27 * \text{Tavg})}{(237.7 + \text{Tavg})}$$

5.3.3. Statistical Analyses

5.3.3.1. Statistical Model

Following Vicedo-Cabrera et al. [110], we conducted a time-series analysis to quantify the short-term association between T_{app} and the proportion of admissions due to CVDs. The daily share of admissions due to CVDs was modelled with negative binomial regression in the distributed-lag non-linear modelling (DLNM) framework. The negative binomial regression model allowed for overdispersion of daily CVD counts, while DLNM allowed simultaneous modelling of non-linear exposure–response relationships and delayed effects. The model equation is as follows:

$$\begin{aligned} \text{Log}\,(\text{CVD admissions}_t) \\ &= \alpha + \log(\text{total admissions}_t) + f(t_t, \beta_1) + \beta_2 \text{ns}(t, 8\text{df}) \\ &+ \eta_1 \text{DOW}_t + \epsilon_t \end{aligned}$$

where α is the model intercept, $f(\text{Tappt}_t, \beta_1)$ is a delayed lag non-linear function incorporating a cross-basis matrix that defines the relationship between T_{app} and $\log(\text{CVD admissions})$ at time t, $\beta_2 \text{ns}(t, 8\text{df})$ is a vector of coefficients β_2 for a natural spline function of t with 8 degrees of freedom to account for long-term trends, η_1 is a coefficient for DOW_t (day of the week at time t and ϵ_t is the residual. $f(\text{Tappt}_t, \beta_1)$ is modelled by a crossbasis matrix which consists of the exposure–response (T_{app}-CVD) and lag-response (lag-CVD) functions.

The exposure–response relationship was modelled with a natural cubic spline with two internal knots at 15°C and 26°C. The knot placement was based on how frequently the T_{app} occurred during the study period. The best set of knots in a range of frequent T_{app} were then chosen from among a few candidate specifications using Akaike Information Criterion (AIC) (Table S4).

The lag-response relationship was modelled with a natural cubic spline with three equally spaced internal knots on the log scale, because this allowed for more flexibility at shorter lags in the model where we expected the most pronounced effects. A lag period of 21 days was motivated by previous studies and is considered as the short-term effect of T_{app} on CVD [41, 42, 44].

The model was adjusted for the log of daily counts of total hospital admissions to reduce the imprecision that could have arisen as a result of the digitization of handwritten admission data. We also adjusted for day of the week (DOW) and time. DOW was modelled as a categorical variable with seven categories while time was modelled as an integer variable using a natural cubic spline with 8 degrees of freedom.

As the interest of this study was to investigate the short-term (21 days) association between T_{app} and CVD admissions, long-term patterns such as hospital access and seasonality, were likely to obscure the short-term association [166]. Hence, by adjusting the model for time, only the short-term variations of CVD admissions caused by T_{app} were investigated.

5.3.3.2. Relative Risk and Optimal Temperature

The bi-dimensional (exposure-lag-response) relationship was reduced to a one-dimensional (exposure-response) relationship by calculating overall cumulative risk ratios (RR). For each T_{app}, the RR cumulated over the whole 21-day lag period was calculated. The RRs were calculated using the optimal T_{app} as the reference. The optimal T_{app} was derived from the overall cumulative exposure-response curve over the 21-day lag period, as suggested by a previous study [167]. It is the lowest point of the overall cumulative curve in a range of frequently occurring T_{app}, where the risk for CVD admissions is lowest. T_{app}, which occurred infrequently during the study period, were not chosen as the optimal T_{app} even if they had the lowest risk for CVD admissions from the cumulative curve, as cumulative risks at more extreme temperature ranges were imprecisely estimated and likely to be sensitive to the choice of exposure–response function. This means that extreme T_{app} was not chosen as the optimal T_{app}, due to their infrequent occurrence during the study period. T_{app} above and below the optimal T_{app} are referred to as warm and cold T_{app}, respectively. Non-optimal T_{app} is defined as all cold and warm T_{apps} together.

5.3.3.3. Attributable Fraction

The share of CVD admissions due to non-optimal T_{app} was calculated by summing up the CVD admissions from all days of the series, relative to the optimal T_{app}. The ratio with the total CVD admission resulted in the attributable fraction (AF). The AF for cold and hot T_{app} was calculated by summing up the contributions from days colder or hotter than the optimal T_{app}, respectively. Empirical 95% confidence intervals (CI) were conducted using the Monte Carlo simulation over 1000 repetitions. All of those calculations were done using the *attrdl.R* script developed by Gasparrini [111].

5.3.3.4. Sensitivity Analysis

Sensitivity analysis was performed to check the robustness of the model by changing the duration of the lag period and using the datasets without imputed dates of admissions from 1 June 2009 to 31 December 2016 and from 1 January 2002 to 31 December 2016. As studies often use a quasi-Poisson regression model instead of the negative binomial regression model, an additional sensitivity analysis was conducted to compare these two models. In this study, a negative binomial model was chosen over a quasi-Poisson regression model so that AIC is available to discriminate between candidate models, and because it allows for a more flexible relationship between the variance and the mean.

5.4. Results

5.4.1. Descriptive Results

There were 3124 admissions for CVD during the study period. Figure 14 shows an overview of the distribution pattern of daily CVD hospital admission counts during the study. Figure 14a shows the pattern of daily counts of total and CVD admission during the study period. Seasonal trends were not observed in the daily hospital admissions counts. However, high admission counts were observed between the years 2015 and 2016. Figure 14b shows the distribution of the 37,090 total admissions and 3124 CVD admissions over the T_{app} range. It is visible that, towards the warm T_{app} extremes, the number of total as well as CVD admissions decreased. Seasonal trends of T_{app} ranged from 6 °C to 32°C, with the 50th percentile at 21°C (Figure 15). Yearly averages ranged from 19°C to 21°C with an overall mean of 20°C.

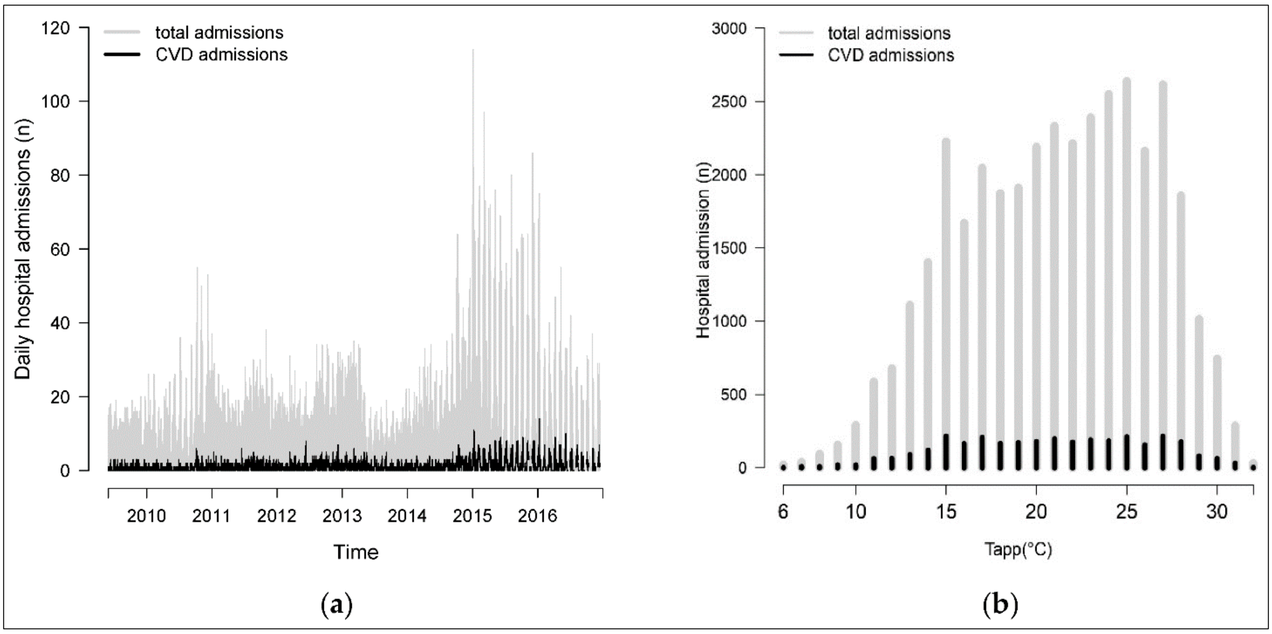

Figure 14: *(**a**) The distribution of daily total (N = 37,090) and CVD (N = 3124) hospital admission counts during the study period, and (**b**) the distribution of total and CVD hospital admission counts in relation to T_{app}.*

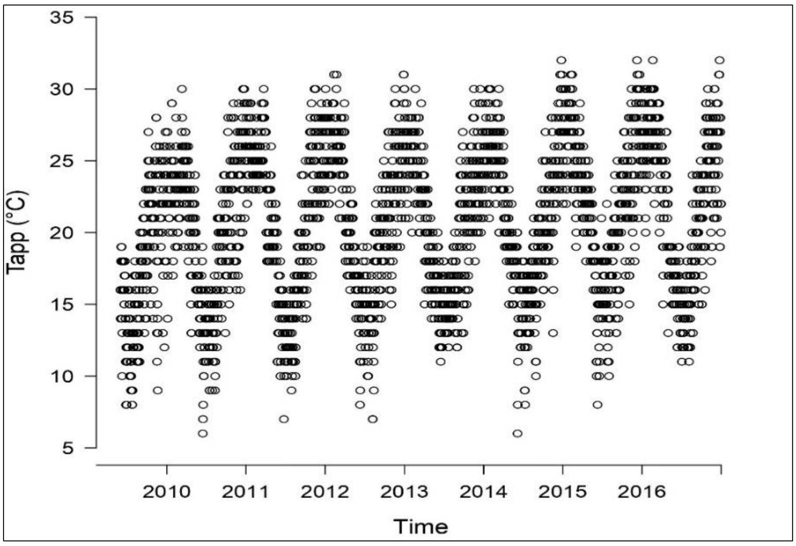

Figure 15: *Trends in calculated T_{app} during the study period. Each dot represents the daily T_{app} calculated with weather data from the Thohoyandou weather station.*

5.4.2. Exposure-response association and attributable fraction

Figure 16 shows the effect of T_{app} on the risk of CVD admissions cumulated over 21 lag days. The optimal T_{app} is identified at 26°C (corresponding to the 83rd percentile of T_{app} distribution) and is used as the reference value against which the risk for other T_{app} is compared.

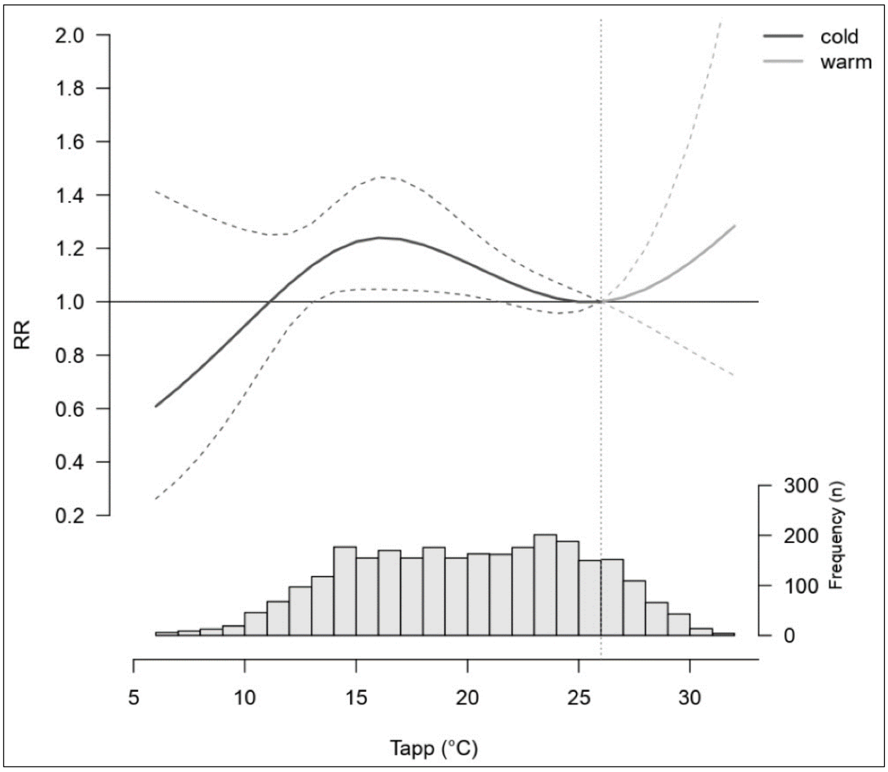

Figure 16: *The relative risk (RR) of CVD hospital admissions from apparent temperature (T_{app}) accumulated over 21 days of lag. The grey vertical dotted line marks the optimal T_{app} of 26 °C, against which the risk for other T_{app} was compared. The graph represents the RR for cold (dark) and warm (grey) T_{app}. The dotted lines represent the 95% confidence interval. The histogram shows the frequency of each T_{app} during the study period.*

The histogram shows that most days have a T_{app} below the optimal T_{app} of 26°C. The cumulative curve displays that the risk for CVD admissions increases steadily from 27°C–32°C, with 32°C showing a 33% (95% CI: 0.75, 2.36) increased risk for a CVD admission compared to 26°C. However, wide 95% CIs reveal the uncertainty of those findings.

Cold T_{app} from 12°C–24°C showed an increased risk in CVD admissions relative to 26°C, with an increase between 14°C–21°C (Figure 16). The cold T_{app} with the highest risk for CVD admissions was 16°C, which showed a 25% (95% CI: 1.05, 1.48) higher risk for CVD admissions cumulated over 21 days compared to 26°C. On the other hand, cold T_{app} between 6°C–11°C seemed to be protective towards CVD admissions accumulated over 21 days, relative to 26 °C. However, the 95% CIs were wide in this T_{app} range due to fewer data points, rendering these particular findings non-significant.

The cumulative graph in Figure 16 also shows that RRs for 25°C and 26°C were approximately one, which indicates a 'comfort zone', rather than one optimal T_{app} (see extracted RRs and 95% CIs in Table S5). The lag-response structure analysis was conducted for 9°C, 16°C, 28°C and 30°C relative to the optimal T_{app} of 26°C (Figure 17).

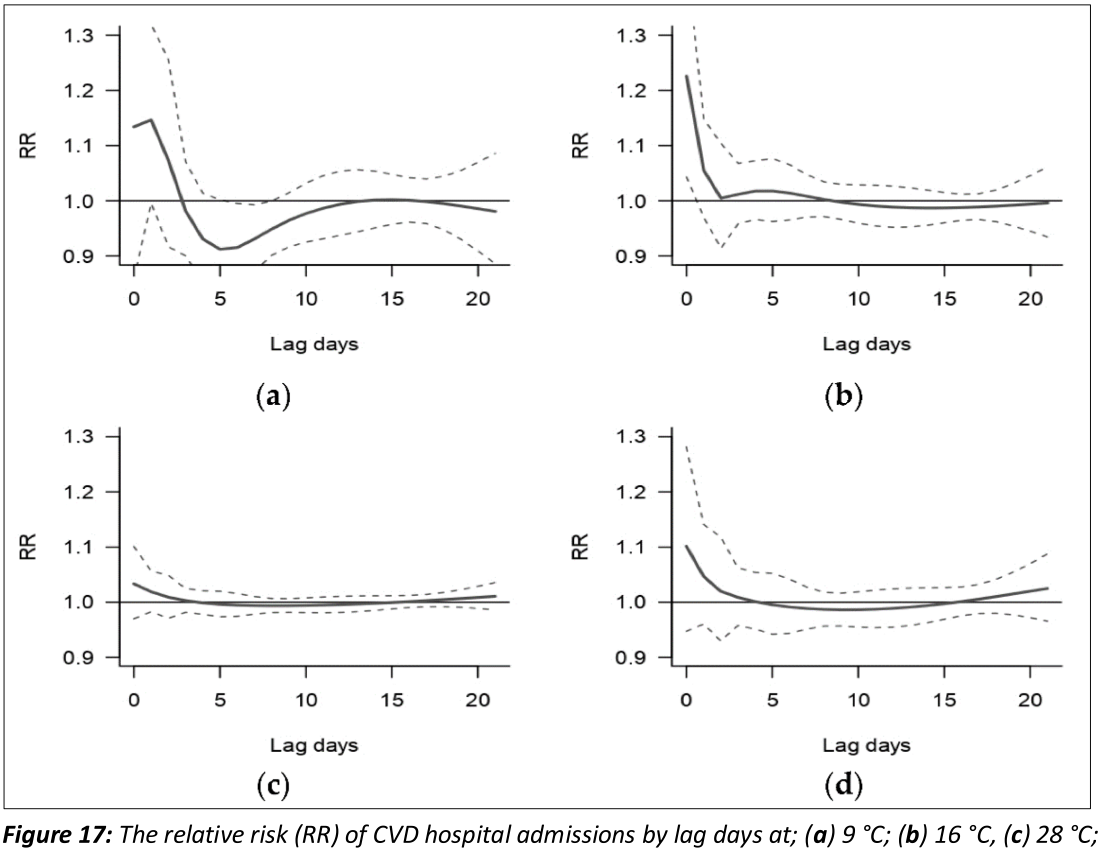

Figure 17: *The relative risk (RR) of CVD hospital admissions by lag days at; (**a**) 9 °C; (**b**) 16 °C, (**c**) 28 °C; and (**d**) 30 °C in Limpopo, South Africa. The dotted lines show the 95% CI. The RRs are compared to an optimal T_{app} of 26 °C.*

We observed a reduced risk for CVD admissions at 9 °C after five lag days, however there were few days with this temperature. At 16 °C, 28 °C and 30 °C, there was an immediate peak in the risk for CVD admissions at lag zero. The risk for CVD admissions is the highest for 16 °C, with a significant 23% (95% CI: 1.04, 1.44) increased risk for CVD admissions compared to 26 °C at lag zero. The increase in risk of 28 °C and 30 °C lasted for two and four days relative to the effect of 26 °C, respectively (see Table S5 and S6 for the extracted RRs and 95% CIs).

Our sensitivity analyses, presented in Appendix B, changing knot placements, lag durations and regression models showed that our final model was insensitive to these changes. Further detailed summary of the chosen model is presented in Table S7.

Table 5 shows the AF for CVD admissions attributable to non-optimal T_{app} during the study period. 9.5% (95% CI: 3.4%, 15.7%) of the CVD admissions to the two hospitals in Limpopo were

	AF	Lower 95% CI	Upper 95% CI
Non-optimal Tapps	9.54%	3.47%	15.73%
Cold Tapps	8.5%	3.16%	13.72%
Warm Tapps	1.16%	−1.43%	3.51%

attributable to non-optimal T_{app} (

Table 5). Cold T_{app} account for most of the total CVD admissions with an 8.5% (95% CI: 3.1%, 13.7%) AF, whereas warm T_{app} account for 1.16% (95% CI: -1.43%, 3.51%) of the total CVD

	AF	Lower 95% CI	Upper 95% CI
Non-optimal Tapps	9.54%	3.47%	15.73%
Cold Tapps	8.5%	3.16%	13.72%
Warm Tapps	1.16%	−1.43%	3.51%

admissions.

Table 5: *The attributable fraction of CVD hospital admissions (N = 3124) from the two hospitals during the study period due to non-optimal cold and warm T_{app}. The lower and upper 95% confidence intervals (CI) are also presented.*

	AF	Lower 95% CI	Upper 95% CI
Non-optimal T_{app}s	9.54%	3.47%	15.73%
Cold T_{app}s	8.5%	3.16%	13.72%
Warm T_{app}s	1.16%	−1.43%	3.51%

5.5. Discussion

We found an association between T_{app} and the share of hospital admissions due to CVDs at both warm and cold non-optimal temperatures. Warm (i.e., 27 °C to 32 °C) as well as cold T_{app} (i.e., 12 °C to 24 °C) had the potential to increase the share of CVD hospital admissions cumulated over 21 days, with cold temperatures being responsible for the biggest fraction of CVD admissions. The effect of warm T_{app} was found to be immediate and short-lived for around two to four days after exposure. Cold T_{app} between 14 °C and 25 °C showed an immediate but long-lasting (5 to 9 days) increased risk while very cold T_{app} between 6 °C and 9 °C showed a delayed (one day) and short-lived (2 days) increased risk for CVD admissions. The seemingly 'protective' effect seen at very cold temperatures after the short period of increased risk could potentially be attributable to the harvesting effect, where increased risk of CVD admissions for the most vulnerable population is brought forward in time [114, 115]. The initial increased risk of CVD admissions could be attributed to findings that performing physical activity during cold temperatures has been shown to trigger angina pectoris and myocardial infarction and cold temperatures have been found to lead to thrombosis [168]. However, given the wide CI intervals and less days with very cold temperatures, this could also be a statistical artefact. Therefore, more studies are needed from this region to elaborate the findings.

We found a longer lasting cold effect of around 5 to 9 days for T_{apps} between 14 °C and 25 °C was found, which is in accordance with other studies on this topic [169]. Cold temperatures in South Africa have been shown to be responsible for 3.0% of the national mortality proportion and warm temperatures for only 0.4% [42]. Hence, if other diseases are exacerbated by cold temperatures, hospitals might easily be overburdened and can no longer admit patients. This situation could be further complicated by the fact that Limpopo province is one of the provinces with the least established healthcare infrastructure in South Africa [170]. The immediate and short lived effect of warm T_{app} on the risk of CVD hospital admissions found in this study was also observed in other studies conducted in the United States [168], Vietnam [48], Australia [171] and Denmark [172].

In terms of CVD morbidity, our study suggests that the optimal temperature is in the range of 25℃ to 26℃. The AF from cold T_{app} was found to be responsible for the biggest fraction of the total CVD admissions. This is in accordance with findings of other studies, where cold temperatures were responsible for most of the temperature-related CVD morbidity [53, 173, 174]. The cold effect might be of greater magnitude compared to the warm effect because housing and lifestyle in a usually warm climate does not adequately protect against cold temperatures. A significant proportion of residents in Mopani district live in poverty and would therefore lack the resources such as electric or gas heaters to protect themselves from cold weather and the associated health impacts on CVDs [170, 175, 176].

Our study had several strengths. First, we investigated the association between T_{app} and CVD mortality over a long time period and few missing data points, while accounting for environmental confounders such as humidity in the model. Second, the sophisticated modelling approach allowed us to flexibly examine this association by considering both temperature and lag duration at the same time. Third, we were able to demonstrate the burden of both cold and hot non-optimal temperatures, which, to our knowledge, was hitherto not investigated in this region.

This study considered several limitations. Data quality of hospital admission records was inconsistent due to handwritten data reporting systems, leading to potential missing information. To counter this, we modelled the proportion of admissions due to CVDs rather than their absolute number. There is a chance of non-differential outcome misclassification since the CVD data were only classified by a physician's first clinical assessment upon admission and not medically confirmed. The prevalence of CVDs might be underestimated because the hospital admission records only captured hospitalized CVD cases, thus discounting cases that did not need hospitalization or sought traditional healers. Imputing missing data might have introduced non-differential exposure misclassification. However, sensitivity analysis showed the methods to be robust and the conclusions drawn from the findings to be unaffected. The daily exposure to T_{app} was assumed to be the same for everyone in Limpopo. Potential confounders such as age, sex, socioeconomic status or different types of CVDs, which have been shown to respond differently to temperature, could not be taken into consideration [124]. There may have been some patients who passed away before arriving at the hospital and this would contribute to a possible underestimation. Private hospitals were not considered in this study, potentially excluding a proportion of higher socio-economic status individuals assuming they are more often treated in private hospitals, where access is dependent on affordability [177]. Nevertheless, this concerns a small proportion of the population of the country since the private sector serves only 16% of the entire population of South Africa [177].

To strengthen the findings of this study on the associations between T_{app} and CVD morbidity in Limpopo, further research should gather additional variables to identify the most vulnerable groups, based on factors such as age, sex, type of CVD and socio-economic status. Such studies are important for surveillance systems of population health and for health-care planning. Factors such as gender differences play a major role in the association between temperature and CVDs, especially in conjunction with age. Men and women have different physiological and thermoregulatory responses following heat and cold exposure, with men generally being able to tolerate heat better and females being more vulnerable to heat [45, 126, 127, 129]. The information would better inform interventions, e.g., to develop early warning systems of the effects of cold and heat to prepare health professionals and the communities to encourage them to take precautions based on their predisposed vulnerabilities. There is a need to improve surveillance systems to track diseases such as CVD and especially those likely to be influenced by climate change. Hospital admissions data collection systems should be digitized, and physicians and hospital staff should be trained to record patient details and diagnosis in a uniform manner. Such systems will not only benefit tracking within the healthcare systems but will also be invaluable for research purposes to generate evidence for decision and policy making.

5.6. Conclusion

In this study, the non-linear association between T_{app} and the relative frequency of CVD admissions in Limpopo province of South Africa was characterised. We demonstrated that both cold and hot non-optimal T_{app} is associated with an increase in the risk of CVD morbidity, with cold non-optimal T_{app} attributable to a larger fraction of cases. The warm effect was immediate and short lived while the cold effect had a delayed presentation and lasted longer. Our study provides a more nuanced glimpse into the temperature attributable CVD issues facing Limpopo in the coming decades in light of climate change.

5.7. Declarations

Author Contributions

Conceptualization: G.C., C.Y.W., S.S., T.K., Z.K., A.M. and N.P.; Data curation: C.Y.W.; Formal analysis: J.L.B., H.P., M.K., S.S. and T.K.; Funding acquisition: G.C. and C.Y.W.; Investigation: J.L.B.; Methodology: J.L.B., M.K., H.P., S.S., T.K. and Z.K.; Project administration: G.C.; Supervision: G.C., Y.L. and C.Y.W.; Writing—original draft: J.L.B., S.S. and C.Y.W.; Writing—review & editing: All authors. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The South African Medical Research Council Ethics Committee approved the study (EC005-3/2014).

Informed Consent Statement

Informed consent was obtained from the Provincial Department of Health and Hospital Management. Patient consent was waivered since data provided to the research leader were anonymised.

Data Availability Statement

Weather data can be obtained from the South African Weather Service and the codes used in this study are available upon request from the authors.

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Conflicts of Interest

The authors declare no conflict of interest.

QUALITATIVE STUDIES

ASSESSING STAKEHOLDER PERCEPTIONS AND RESEARCH BARRIERS ON CLIMATE CHANGE AND HEALTH

Chapter 6. “Climate change and health?”: Knowledge and perceptions among key stakeholders in Puducherry, India

International Journal of *Environmental Research and Public Health*

MDPI

Article

“Climate Change and Health?”: Knowledge and Perceptions among Key Stakeholders in Puducherry, India

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Abstract: Climate change has far-reaching impacts on human health, with low- and middle-income countries, including India, being particularly vulnerable. While there have been several advances in the policy space with the development of adaptation plans, little remains known about how stakeholders who are central to the strengthening and implementation of these plans perceive this topic. We conducted a qualitative study employing key interviews with 16 medical doctors, researchers, environmentalists and government officials working on the climate change agenda from Puducherry, India. The findings were analysed using the framework method, with data-driven thematic analysis. We elucidated that despite elaborating the direct and indirect impacts of climate change on health, there remains a perceived gap in education and knowledge about the topic among participants. Knowledge of the public health burden and vulnerabilities influenced the perceived health risks from climate change, with some level of scepticism on the impacts on non-communicable diseases, such as cardiovascular diseases. There was also a felt need for multi-level awareness and intervention programmes targeting all societal levels along with stakeholder recommendations to fill these gaps. The findings of this study should be taken into consideration for strengthening the region’s climate change and health adaptation policy. In light of limited research on this topic, our study provides an improved understanding of how key stakeholders perceive the impacts of climate change on health in India.

Keywords: cardiovascular disease; climate change; health; India; key informant interviews; low- and middle-income countries; qualitative study; stakeholder perspectives

Publication:

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6.1. Abstract

Climate change has far-reaching impacts on human health, with low- and middle-income countries, including India, being particularly vulnerable. While there have been several advances in the policy space with the development of adaptation plans, little remains known about how stakeholders who are central to the strengthening and implementation of these plans perceive this topic. We conducted a qualitative study employing key interviews with 16 medical doctors, researchers, environmentalists and government officials working on the climate change agenda from Puducherry, India. The findings were analysed using the framework method, with data-driven thematic analysis. We elucidated that despite elaborating the direct and indirect impacts of climate change on health, there remains a perceived gap in education and knowledge about the topic among participants. Knowledge of the public health burden and vulnerabilities influenced the perceived health risks from climate change, with some level of scepticism on the impacts on non-communicable diseases, such as cardiovascular diseases. There was also a felt need for multi-level awareness and intervention programmes targeting all societal levels along with stakeholder recommendations to fill these gaps. The findings of this study should be taken into consideration for strengthening the region's climate change and health adaptation policy. In light of limited research on this topic, our study provides an improved understanding of how key stakeholders perceive the impacts of climate change on health in India.

6.2. Introduction

To paraphrase an environmentalist we interviewed for this study, "*Climate change is like a ticking time-bomb that is going to blow up in the near future in a way we cannot even imagine.*" Across the globe, evidence of the changing climate and its far-reaching impacts on our world, including peoples' health and well-being, have been reported, with the Lancet Commission declaring it to be the biggest threat to global health [25, 90, 178].

As an added factor, climate change compounds on top of existing health vulnerabilities for several climate-sensitive outcomes, including vector-borne diseases, water-borne diseases and non-communicable diseases (NCDs), such as cardiovascular diseases (CVDs) [25]. Given the trends projected for climate change, these risks are expected to increase in the future. By 2050, an excess of 250,000 deaths per year are projected to be attributable to climate change, through several exposure pathways, ranging from heat stress and changes in vector-breeding patterns to malnutrition caused by changes in agricultural productivity [25, 179].

The impacts of climate change are region specific, with unequal distribution both within and between countries, regions and even communities [180]. There is evidence of effective and timely adaptation practices reducing or potentially avoiding several climate associated health risks [25]. A growing number of countries have committed to developing national climate adaptation or action plans, especially after the Paris Agreement in 2015 [181, 182]. However, the regional differences in vulnerabilities and subsequent impacts remains a key challenge for developing these plans. National and regional indicators like socio-economic factors, access to healthcare, infrastructural developments and even awareness determine individual vulnerability to climate change, especially in resource limited low- and middle-income counties (LMICs) such as India [99, 183]. While there have been several advances in this sphere in India, there remains great scope to comprehensively enhance and strengthen health adaptation strategies and health determinants, thereby improving public health [184-186]. These efforts are often undermined by ineffective climate adaptation policies and strategies [187].

In light of these vulnerabilities and gaps, there is a need to explore the perceptions of key stakeholders, such as policy makers, researchers, environmentalists and medical staff, on the health impacts of climate change in India. Policy makers, including ministerial officers and scientific researchers play a key role in generating evidence, designing, implementing, monitoring and evaluating climate change-health-related policies and plans. Although there is limited research on this topic, the knowledge, perceptions and awareness among these groups of people have been shown to influence political prioritisation of climate change adaptation [188, 189]. Another group of key stakeholders includes public health professionals. A recent literature review showed that public health experts, despite being aware of the consequences of climate change, lack sufficient knowledge on its health impacts [190]. As first responders, healthcare providers play a key role in identifying climate impacts on health, recognising opportunities for health-in-climate actions, advocating for policy support to address climate impacts on health and building climate resilient healthcare systems [86]. However, the extent of their work is largely dependent on public health policies or adaptation frameworks in place to support them [191].

India is characterised by a high disease burden and climate change is thought to further exacerbate vulnerabilities [192-194]. There is a need for multi-factorial studies on this topic, including qualitative studies, as little is known about the perceptions of stakeholders with regard to the nature, magnitude and urgency of climate change impacts on peoples' health in India. Hence, it is important to examine this nexus in order to facilitate a region-specific understanding of how key stakeholders involved in the field of climate change and/or health perceive these impacts. This exploratory study has the potential to contribute towards addressing policy gaps and tailoring specific interventions to reduce the health burden attributed to climate change in India. Against this background, we aimed to understand how the health impacts of climate change are perceived by two key stakeholder groups in Puducherry, namely those working in the health sector and those involved in environmental planning and policy development. We also chose to include questions that focused specifically on CVDs, the diseases with the largest burden in India, along with other health impacts [67]. The findings from this research feed into a larger project examining the impacts of climate change on CVDs in Puducherry. The objective was to identify the knowledge and awareness, the perceptions of climate change health links, key gaps in knowledge and services, and scope for improvement of future climate change health policies and plans.

6.3. Materials and methods

6.3.1. Study Setting

Puducherry is a unique Union Territory (UT) in India, comprised of four erstwhile French colonies (i.e., Puducherry District; Karaikal; Mahe; and Yanam region) in the south-eastern part of India (Figure 18A). The total area of the UT is 492 km^2.

This study focuses on Puducherry district, which itself covers an area of 294 km^2 spread out over four non-continuous sub-districts or 'Taluks' (Figure 18B). As per the Government of India census of 2011, the population ofPuducherry is 950,289 with an almost equal distribution of males and females [106, 195]. Puducherry falls within the tropical savannah with a dry winter climate type as per the Köppen-Geiger classification, with a mean annual temperature around 30°C and a temperature range from 23 to 41°C. A study describing the causes of death in Puducherry for the first time found that 31% of deaths were attributed to CVDs followed by external causes, digestive diseases, respiratory illnesses and infectious diseases, respectively, providing a glimpse into the health profile of the region [107].

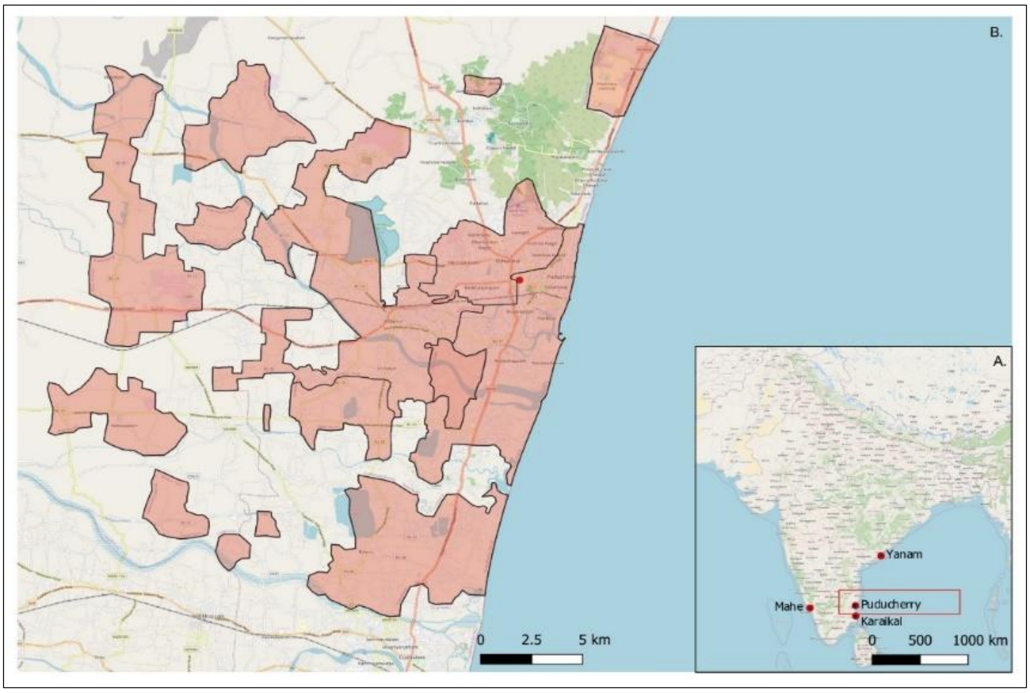

***Figure 18**: Map of Puducherry. (**A**) Location of the four districts that make up the Union Territory of Puducherry, namely Puducherry, Karaikal, Mahe and Yanam, spread out on either side of the coast of India. (**B**) Puducherry district, which is nestled within the state of Tamil Nadu with Andra Pradesh to the north (inlaid map). The shaded area highlights the non-continuous geographical area of Puducherry district.*

6.3.2. Study Design and Participants

We conducted key informant interviews (KIIs) with medical professionals (both in practice and research) and officials from the Department of Science, Technology and Environment (DSTE) involved in the Puducherry State climate change action plan.

Participants were initially selected using purposive sampling based on professional relevance to the topic and prior connections. To that end, the sample included in this study consisted of interviewees with either a medical or an environmental professional profile. Further interviewees were invited through snowball sampling [196]. We specifically chose this method to ensure that we were able to elucidate the perspectives of professionals working closest to this field and those who would be able to provide us with the most granular information. We continued to recruit key informants and carried out interviews until saturation was reached in the information provided. In the case of the DSTE representatives, we interviewed all possible relevant participants. Informant recruitment was also carried out with practical considerations, bearing in mind COVID-19 restrictions and schedules of the medical professionals.

Out of the informants, all but five were medical professionals either actively practicing medicine or working in academia. For the medical professionals, we focused mainly on trained cardiologists, emergency medicine and general medicine doctors with varying levels of experience. The majority of doctors interviewed were male, with only one female informant. The entire sample only contains three female participants. The participants' profiles are shown in Table 6.

__Table 6:__ Descriptive characteristics and participant profiles of the key informants interviewed in this study.

Sector/Background	*N* (%)	Females (%)	Males (%)	Age Range (years)	Range of experience (years)
Medicine (in-practice)	8 (50%)	0 (0%)	8 (50%)	32–51	3–20
Medicine (research/academic)	3 (18.8%)	1 (6.3%)	2 (12.5%)	40–44	11–20
Environment/governmental	5 (31.3%)	2 (12.5%)	3 (18.8%)	28–53	4–30
Total	16	3 (18.8%)	13 (81.3%)	28–53	3–30

6.3.3. Data collection

A total of 16 interviews were conducted in Puducherry between January and March 2022 with stakeholders working in this region. Participants were invited for an in-person interview at their place of work at a convenient time. For two participants, who were unavailable for an in-person interview, virtual interviews were conducted over Zoom. Interview questions were based on an a priori, developed, semi-structured interview guide based on the objectives and analytical framework. It included general questions on climate change and health asked to all participants, as well as profession-specific questions. The conceptual framework for climate change risk perceptions developed by van Eck et al. [197] and the framework for health inequalities proposed by Rudolph et al. [198] was used as a base for our analytical framework shown in Figure 19. This paper focuses on the themes of ‘systems knowledge’ and ‘socio-cultural dynamics and public engagement’. Findings pertaining to the theme of ‘institutional determinants’ are discussed in Chapter 7.

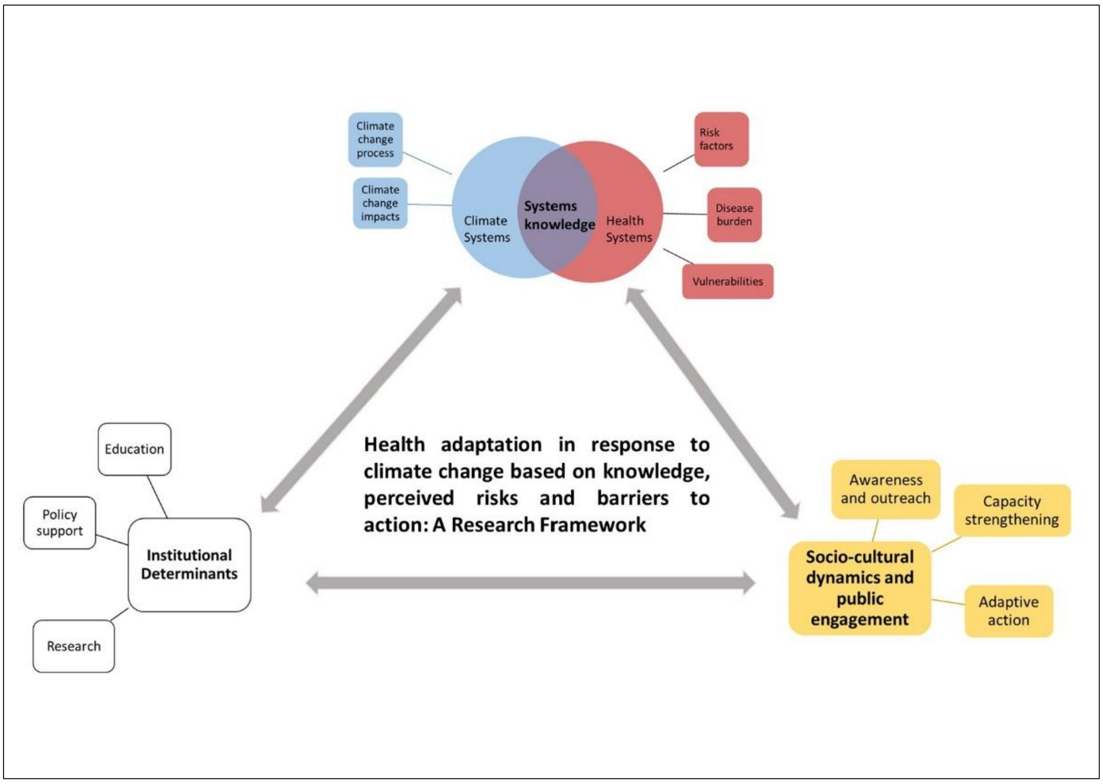

Figure 19: *A framework for health adaptation action in the context of climate change based on knowledge and perceived health risks, policy and institutional support and public engagement. The coloured parts highlights the thematic areas we focus on in this paper. The three main components have been shown in bold text.*

The guide was finalized following three pilot interviews, but was purposefully kept flexible depending on the responses of the participant. The interview guide is presented in the Appendix C Table S8. All the interviews were carried out in English by the first author (S.S.S.), while another author (R.L.) facilitated the interviews and was present for three interviews as a passive observer. There was no prior relationship between the interviewer and interviewee. At the start of each interview, the interviewer gave a brief personal introduction and explained the informed consent form (ICF), which included a detailed description of the study objectives, the role of participants and planned output. A copy of this form was provided to all participants with contact details of the study team. Interviews lasted for approximately 15 to 50 min, with the average interview lasting around 30 min, and were audio recorded using a simple voice recorder. Field notes were also taken during the interview to aid the optimisation of the interview guide, for key issues and themes that emerged.

Broad and open-ended questions were asked to allow participants to freely express thoughts and perspectives and discuss about any issues on their mind not explicitly asked through questions. The structure and order of questions varied based on discussion points but roughly covered the same key topics. Every effort was made to minimise the impact of potential biases throughout the study by keeping note of and reflecting on them throughout the interview, analysis and write-up phases. Participants had an option of requesting a recording, which was requested by one participant. The final question included participants' comments about the study, which were taken into consideration while adapting the questionnaire.

6.3.4. Data Analysis

The recordings were assigned a number before verbatim transcription by the first author (S.S.S.) to ensure anonymity. Transcription and analysis were completed using MaxQDA software version 2018.1 (VERBI Software, Berlin, Germany)).

We used a combination of deductive and inductive thematic analysis following the framework method developed by Gale et al. [199]. We first developed broad codes and themes based on our framework and interview guide. Further codes were developed inductively through open coding during the analysis to identify emerging themes and additional categories, which were then clearly defined in our framework.

After familiarisation with the transcripts, the interviews with the richest data quality were used to develop the initial codebook and analytical framework. These included one interview from a medical doctor, a medical researcher and an environmentalist. The codebook was validated by two authors (S.S.S. and T.L.) in an effort to address discrepancies and agree on the final coding system, which was then applied to the remaining transcripts. The codebook was updated to include any themes not covered in the initial three interviews during the inductive coding to develop a final framework matrix. All transcripts were re-read at the end of the first round of coding to cover any missing or additional codes. Summary sheets were developed by code to better understand the themes that emerged within and across interviews. Relevant quotes were then directly charted into our framework matrix covering two themes and nine categories. The structural codebook and framework matrix is presented in the Appendix C Table S9. This was further elaborated using a cross-matrix, also developed using MaxQDA.

6.3.5. Ethical Considerations

Written informed consent was obtained through the ICF prior to the interview, which included the participant's rights to withdraw from the study at any stage without further obligations. The participants were provided with contact details of all the researchers involved in the project. All quotes form stakeholders presented here are assigned a serial number to further ensure anonymity. Additional relevant quotes are presented in Section 3 of Appendix C.

This study was approved by the Institute Ethics Committee (Human Studies) of the Indira Gandhi Medical College and Research Institute (a Government of Puducherry Institution); reference no. 318/IEC-31/IGM&RI/PP/2021 and by the Ethics Committee Northwest and Central Switzerland (EKNZ); statement ID- AO_2020_00034. The methodology used in this project abided by the principles laid out in the Declaration of Helsinki and the COREQ checklist.

6.4. Results

We presented our findings based on two main thematic areas, namely the understanding of climate change and health (systems knowledge) and socio-cultural factors that influence public awareness and engagement on this topic (sociocultural dynamics and public engagement).

6.4.1. Systems Knowledge

6.4.1.1. Climate Change Is an Acute and Growing Problem for India

All participants were aware of, but had varying understanding of climate change. Extreme heat, increase in urban flooding, changes in monsoon patterns and air pollution were some of the terms most commonly associated with climate change, along with plastics, global warming, climate refugees and droughts. One participant also mentioned how "*climate refugee is going to be the word of the century".* Many participants also directly associated climate change with "*reducing the quality of life"*, mainly through extreme weather events, and expressed concern about the growing burden of climate change-related issues. Participants understood the within- and between-country differences in climate impacts and thought of it as an acutely and disproportionately growing burden, especially for the future.

" …climate change is extremes of weather in many cities across the world, including Delhi and other parts of India which is making human beings suffer" (#15, practicing physician).

Participants also described dystopic views about the future due to a rapidly changing climate.

"When I think of climate change, it gives me a very gloomy picture about the future" (#7, Environmentalist).

"In 20 years, or by the end of the century, it is going to create a huge problem that by then nobody could tackle or could come over" (#9, Environmentalist).

Participants cited diverse sources of climate knowledge and awareness, including media and international organizations as well as personal observations. Some of the environmentalists also backed up their thoughts with results from climate change-related studies they conducted. The most strongly stressed observation by the environmentalists was the relatively recent acceleration of climate change. This sentiment was echoed by almost all participants, who described a remarkable change in weather patterns over the past two decades. Phrases such as "*as the years passed, climate has changed so much*", and "*what I saw as a child in the 1980s, like there we used to get, uh, showers fed throughout the* *monsoon season. But now it's all sudden downpour on a single day*" were used to describe the change over recent time. Participants described observing dramatic changes in weather patterns, especially over the past 10 years.

"I'm in Pondicherry since 1989, the initial 10 to 15 years things were very stable. For the past 15 years, things have been much worse. The things are becoming more severe. So, temperatures are becoming higher in Pondicherry and we are having a lot of cyclones and everything in the past 10 years compared to the first 20 years I was in Pondicherry" (#15, Practicing physician).

The unpredictability of seasonal patterns and heat were also mentioned multiple times to support the severity of the problem. Many mentioned the prevalent heat throughout the year, transcending the erstwhile seasonal boundaries, along with harsher and irregular monsoons.

"Pondicherry, it's not hot season- cold season, it's hot, hotter, hottest. So that's the change, so we cannot tell it's cold season…Even during the rains or other things, we feel that the background heat is there and it looks like summer throughout" (#4, Medical doctor/researcher).

6.4.1.2. Climate Change Ultimately Affects Health through Domino Effects

The awareness of the impacts of climate change were largely informed by day-to-day experiences and observations for most participants. Several participants described the interconnected chain of impacts they attributed to climate change. Quality of life and agricultural impacts arising from changes in monsoon patterns were frequently mentioned. Regardless of the sector directly impacted, most participants perceived health to ultimately be impacted through a chain of cyclical or downstream effects of climate change.

"Because, you know, ultimately, all sectors will lead to health of the individual. Let it be financial, let it be agriculture, let it be electricity, let it be road, whatever, it's going to affect the health of the people" (#2, Medical doctor/researcher).

An example of this domino effect was unseasonal weather patterns causing agricultural disturbances and leading to other problems, such as unemployment, economic problems, disruption of the biological natural cycles and eventually health, including malnutrition. Overall, health was mentioned by almost all participants as being directly or indirectly affected by climate change. One Health as a concept was also mentioned by a medical researcher and described by a doctor and environmentalist with the belief that climate adaptation strategies needed to be framed from a One Health lens.

"I strongly believe in the concept of One Health. So there's like this impact on everything. So if one gets tilted, it's like a domino effect. It affects every part of it…So starting from agriculture or animal health, human health, everything gets largely affected" (#4, Medical doctor/researcher).

6.4.1.3. Knowledge of the Public Health Burden and Vulnerabilities Influenced Perceived Health Risks from Climate Change

Vector-borne diseases, such as malaria, dengue and chikungunya, were considered to have the greatest burden from a public health perspective in Puducherry. These were also the most commonly mentioned group of diseases perceived to be affected by climate change, largely based on local experiences, observations and public health experiences in dealing with them.

"Primarily, we deal with a lot of VBDs [vector-borne diseases]. What we say is, as the global warming is going to affect more and more areas, the mosquitoes and other vectors are going to breed horizontally and vertically, they're going to expand horizontally as well as vertically" (#2, Medical doctor/researcher).

Altered breeding patterns of mosquitoes in recent years and new reported incidences of malaria in hilly regions not prone to outbreaks were examples given to support the view of climate change increasing the breeding window for mosquitoes. Changes in monsoon patterns and increased incidences of flooding were also considered to foster new suitable breeding grounds for mosquitoes.

While there was some awareness on other climate-sensitive diseases, such as NCDs, most considered them to be primarily affected by other risk factors, predominantly lifestyle. A few participants thought of respiratory illnesses such as chronic obstructive pulmonary disease and asthma as climate sensitive. Mental health, seasonal and heat-related illnesses such as dehydration, skin diseases, allergies, CVDs and heat stroke were mentioned by a few participants, mainly doctors, as climate-sensitive.

Factors such as gender and occupation were considered important drivers of climate vulnerability and its subsequent health impacts. An interesting observation made by one of the medical researchers, pointing to an often underrepresented gender-based occupational hazard and vulnerability is described:

"Working women actually will be a problem because many of these construction workers and people who are working in this sector, even shops and other things you know, they have a difficulty-they don't have a privacy for using the restroom. So they don't drink water much thinking that if they drink water, they have to search for the restroom, which is not available. So they don't hydrate themselves" (#4, Medical doctor/researcher).

Across the board, the aged and socio-economically disadvantaged populations were thought to be most vulnerable to adverse health outcomes associated with climate change. There was no consensus on different vulnerability levels between urban and rural populations, with several participants considering socio-economic factors as more important determinants of vulnerability. The majority of respondents mentioned those engaged in outdoor work and the unorganized sector such as agriculture, fishing and construction as those being more vulnerable to climate impacts. Socio-economically disadvantaged people were thought more likely to disregard health concerns, especially in the early stages, often delaying treatment. Health complaints were also thought to likely be brushed off as occupational hazards, with livelihood coming at the cost of well-being.

"A lot of research has shown that you know, health seeking behaviour depends on the felt need. So we have seen that you know, the lower economic strata may assume many things to be normal because they're more of manual labourers. So they may not be very much worried about a fever or a headache" (#2, Medical doctor/researcher).

6.3.1.4. Indirect Health Impacts of Climate Change Experienced

Some respondents described feeling powerless in the face of climate-related damages, which have long-lasting impacts on life, including on mental health. Extreme weather patterns and changes were perceived to be an important driver for unemployment in the agriculture sector. One environmentalist discussed the difficulties workers have in being motivated to re-join the workforce or finding gainful employment due to lack of demand, thus affecting their mental health. This was also linked to laid-off workers becoming increasingly prone to NCDs through a sedentary lifestyle.

"For some (because of) the climate change, they don't have agricultural work… and they become sedentary" (#6, Practicing physician).

In conjunction with easily accessible and relatively cheap fast food, several participants mentioned the changes in food patterns, ranging from downstream effects of insufficient harvests, lifestyle modifications and increased prices of food. This was also largely perceived to contribute to the development of health issues.

Most of the environmentalists and a few medical professionals also mentioned the impacts on water quality, from an increase in salinity to groundwater depletion. Salinity seemed to be considered as a problem for Puducherry, being a coastal region, with one of the medical researchers describing ongoing studies on the association between salinity and hypertension. Other participants, particularly the environmentalists, also described health issues they had faced due to contaminated groundwater and flooding. The challenges in ensuring a continued adequate supply of clean water were also highlighted, with one environmentalist expressing concern about competition for water in the future.

Air pollution, while thought of as a factor affecting health overall, was not seen as a cause of concern for Puducherry. Multiple participants stressed on the relatively clean air in Puducherry, with one environmentalist describing the results of DSTE study on air pollution. Some participants also highlighted air pollution monitoring displays in the city as their source of awareness on air quality in Puducherry.

"The only thing that we are not facing an issue, unlike Delhi or Mumbai or other places is that this sea breeze is taking away things. The dispersion is quite good here; I have also carried out the air pollution studies for the last 15 years data…Not even close to an alarming situation, because of our geographical gift or whatever" (#9, Environmentalist).

6.4.1.5. Scepticism about Climate Change Affecting CVDs

As part of a larger study, we wanted to focus on the participants' views on the impacts of climate change on CVDs. We found divergent opinions on whether and how climate change, especially temperature, affects CVDs. Although some mentioned CVDs to be temperature sensitive, especially to extreme heat, others also voiced the belief that the scientific community does not know much about the association between climate change and CVDs. Most environmentalists believed temperature, mainly heat, to be a risk factor for CVDs, but believed vector-borne diseases to ultimately be more affected.

While CVDs are mentioned as one of the heat-sensitive diseases in the National Action Plan for Climate Change (2008) [200] and the National Action Plan on Climate Change and Human Health (2018) [201], almost all participants felt they did not have enough data to confidently inform their opinions. The prevalent belief is that CVDs are largely a multifactorial, lifestyle-linked group of diseases; the long development time, and subsequent difficulty in isolating the environmental risk factors were thought to contribute to this uncertainty. Some participants proposed the indirect link between climate change and CVDs through changing food habits and stress caused by climate uncertainty.

Other participants expressed scepticism about the association between climate change and CVDs at large or within Puducherry, partially due to insufficient knowledge or awareness about current research on the topic.

"For example, hypertension, dyslipidaemia cause heart disease. There is direct evidence, multiple meta-analysis and everything was there. But there is no…say like no study categorically saying that climate change will cause cardiac disease…as of now, I'm not convinced about the cardiovascular disease and the climate" (#13, Practicing physician).

"At the present point, we cannot tell whether increase in temperature will cause so and so heart disease. Without that link, we cannot prepare now. See high temperature—if at all I'm correct, like it can cause a heat stroke. But I have not read anywhere, like sudden rise in temperature causing a cardiac disease" (#14, Practicing physician).

This was supplemented by an expressed difficulty by doctors in identifying temperature-attributed CVD cases in hospitals, partially due to the relatively stable temperatures in Puducherry without extreme heat or cold.

"See I don't think such things will happen in Pondicherry. We don't have extreme climates out here. See all these things. Maybe north. In the south nothing" (#5, Practicing physician).

Interestingly, a few of these same participants classified CVDs as being heat sensitive. This could point to a gap in associating temperature with climate change, as most medical professionals were able to describe thermoregulatory changes in response to heat or cold. However, this finding was limited to the cardiologists, with other participants not displaying much knowledge about the burden of CVDs or their association with environmental factors.

Another perspective was that the focus was on more 'explicit' diseases from a public health perspective, such as vector-borne and communicable diseases. While NCDs such as CVDs have an extremely high disease burden, they are seen as the "silent" disease commonly associated with personal lifestyle choices, as opposed to external risk factors. One medical researcher also described the overwhelming onus on individual choices when it came to

CVDs as opposed to external influences, leading people and policies to not prioritise them. As one cardiologist put it:

"Awareness regarding cardiovascular diseases is the number one cause of death itself is not there…..nobody in India knows that in 2020, [approximately] 2 million people died of COVID across the world, but 10 times that died because of cardiovascular disease. That is 20 million. Everybody thinks that the most common cause of death in 2020 was COVID. … And before that everybody thinks of cancer, or accidents and terrorism, all these things kill more people, but actually cardiovascular disease kills maximum number of people" (#15, Practicing physician and cardiologist).

6.4.2. Socio-Cultural Dynamics and Public Engagement

6.4.2.1. Perceived Credibility and the Societal Role of Information Communicator Are Important for Uptake and Public Awareness

The relative lack of awareness of climate change and health among the population combined with the perceived need to mobilize the medical community to engage in environmental health literacy was a point of discussion. The lack of awareness among the scientific community on climate change and health was brought up several times. The scientific community, especially the medical community, were seen as leaders and there was a felt need for them to lead the charge on climate change and health-related outreach. The need to train the medical fraternity to recognise climate sensitive diseases was also mentioned, especially as doctors in Puducherry were ranked high on diagnostic skills.

"It is more of, you know, making the medical fraternity as advocates for this issue. So I think diseases we are very good, you know, we will treat the patients we will do this thing. But the awareness level, you know, even for a scientific community as doctors there is very less regarding climate change" (#2, Medical doctor/researcher).

When it came to information sources, the credibility and perceived role in society were considered paramount to how the information would be received by the population and their reaction to it. The more credible a source was deemed to be, by virtue of professional title, education or celebrity, the more likely the audience was thought to able to absorb or trust the information. Doctors, for example, were thought to a trusted source of information through their education and standing in society, leading people to accept the message easier.

"The same thing the two people can say, but when the doctor says it, they (people) will easily take it. But if I'm saying that (the reaction will be) "Okay, someone is talking" and (people will) leave it. So those who are working in that (area) will connect it easier. If I'm telling you about health, (you) won't understand and if the working people like doctors or those who are in the research—if they tell, they can easily connect and you will easily understand" (#10, Environmentalist).

In line with this, famous personalities such as Narendra Modi and Greta Thunberg were mentioned in relation to climate change, although here political inclinations of the participants influenced how credible they perceived the source to be.

Finally, several participants mentioned newspapers and other media channels, including the daily news, as their primary source of information. Some even mentioned how they turn to these sources for guidelines on issues such as climate change and consider mass media to be a potential medium to spread awareness on climate change and health impacts or preventative measures.

6.4.2.2. Need for Alternate Solutions and Incentivized, Targeted Programs on All Societal Levels

One of the participants, when speaking about awareness and measures to counter climate change, emphasized the need to provide alternative solutions to everyday behaviours to improve health. This was accompanied by the perceived need for a legal framework or mandate to support public health initiatives, policies and encourage behaviour change. Climate actions in the form of popular campaigns, such as tree plantations, were seen by one participant as a temporary fad with little practical longevity. Issues in maintaining these programmes in the long term were also mentioned.

"We are advising the people to do this, do this. But the problem is we are not providing an alternative solution for that. …When you're advising for avoiding use of plastics (for example) what is the alternative we are providing. Without providing alternative, we can't ask the people to change" (#13, Practicing physician).

This was somewhat echoed by another participant when talking about vulnerable populations prioritising economic needs at the cost of their health and thus lacking the incentive and interest to back climate action. This highlights the need to consider the health needs of vulnerable population groups and creating provisions for them when developing climate adaptation guidelines or plans. There were concerns that despite being warned, the most vulnerable population would disregard risks, which needs to be taken into consideration.

"Even when you give them awareness, they will not be ready to follow all those because they have to take care of their daily living. So, when you say that or 'do not work more number of hours outside' or even during any severe heat waves IMD [Indian Meteorological Department] gives warning. As a State, we can give warnings. Severe heatwave is not more than two days a month, but even then, we cannot make people or we cannot compel them to, you know, take care of themselves. We can just give warning" (#9, Environmentalist).

The need to tailor adaptation plans, awareness campaigns and programmes to be relevant and accessible to different types and groups of the population was also stressed by several participants. The need for programmes to start from "grassroot level" was especially perceived to be imperative by most of the participants. There was a perceived disconnect in the needs of the most vulnerable population and the planned programmes at a higher level.

One participant also highlighted having sub-committees focused on the needs of different population groups. The environmentalists also mentioned holding webinars or information sessions tailored to children or farmers, for example, which could also be used as a means to communicate climate change-health awareness in the future.

6.4.2.3. Integrating Climate Change Impacts in Schools, Universities and Continuing Education Curricula

Nearly all participants were of the opinion that the curriculum needed to be adapted for all educational levels. Participants especially stressed the need to include climate change as a separate module in the medical curriculum. The underlying feeling was that medical students need to be taught about climate impacts on health in order for them to be able to effectively treat and spread awareness among their patients. Topics such as climate impacts on health and health system management in light of resilience were thought to be of importance for inclusion in the medical curriculum. Some participants, who were parents of young children, also expressed a desire to see more content specifically focused on climate change in schools. One even spoke about teaching their child about the importance of climate change from home to make up for the lacunae felt in the primary school curriculum.

Another option discussed was adding a climate component in continuing education courses, especially for those planning to work in climate change or health-related fields. Open access lectures or webinars on climate impacts on health were recommended as a potential solution in order to increase awareness on the topic among the general public. Climate change and health as a topic in scientific conferences were also considered a good way to disseminate current research within the scientific and medical community.

"Once in six months, some courses of some continuous medical education, like that. If it is conducted for conferences, medical conferences it will be beneficial at present state, once the real burden is more than we can implement in the medical curriculum also" (#16, Practicing physician).

Not all participants were open to taking courses, especially doctors, thinking it to be more beneficial for the younger generation; however, all were willing to engage in information sessions or seminars of a short duration.

6.4.2.4. Seasonal Workplace Guidelines

Related to the aforementioned finding on considering the needs of different population groups in adaptation guidelines, a few participants also mentioned the need to include temperature or season-related workplace and school guidelines. Schools and outdoor workers were especially thought to be the targets for these interventions. Heat in particular was seen as the exposure which people needed protection from. One participant even drew comparisons to similar programmes already practiced elsewhere in India as a benchmark.

"Policies in the sense that change in the workplace guidelines. Especially people who are working in the open area like road workers and agricultural labourers and other things. So they should bring in some policy change in the sense that when the temperature goes above one particular limit and below one particular level, they should avoid working during daytime and night-time. For example, extreme temperatures, high temperatures, they should not be working between let's say 11 am and 4 pm. And even schools and colleges and all they close during that period. Same thing with low temperature. … So same thing should be practiced across all offices so that it becomes more bearable for the people" (#15, Practicing physician and cardiologist).

A participant also brought up the need for improved early warning and dissemination systems for temperature levels and warnings. On the other hand, contextual challenges in implementing early health warning systems were mentioned by one participant, which require further investigation.

6.5. Discussion

To date, little is known about the perceptions, knowledge and attitudes to health impacts of climate change in Puducherry and elsewhere in India. By focusing on two interlinked groups of stakeholders, namely medical professionals and officials from the DSTE, we attempted to understand the fundamentals of how this topic is perceived from a medical practice and policy lens. Our findings focus on the system's knowledge about climate change and its health impacts, socio-cultural dynamics, public engagement and recommendations.

Consistent with findings from large-scale, global studies and reviews, all medical professionals were aware of climate change [190]. As was also seen in a study by Sheffield et al. from Harlem, New York, the feeling that 'things are changing' in Puducherry was prevalent amongst the participants, especially over the past two decades [202]. This can be supported by evidence of a steady rise in temperatures across southern India in the past few decades with more records of extreme temperatures along the eastern coast in addition to changes in rainfall patterns and increases in cyclonic activity [203].

In line with several other studies on this topic, perceptions and beliefs about health impacts of climate change were shaped by personal experiences and direct observations [202, 204-206]. This could potentially explain why participants deemed common and easily observed climate risks and health impacts, such as agriculture and vector-borne diseases, greater than others, such as CVD impacts. Vector-borne diseases are commonly considered to be highly climate-sensitive, partially due to their explicit nature and monsoon climate, which fosters stagnant water [206, 207]. There have also been reports of increased flooding along the eastern coast of India in recent years [203, 208, 209]. This flooding and water stagnation were mentioned by many participants as affecting their day-to-day life, including health. However, some participants mentioned that Puducherry is not severely affected by diseases such as malaria, with a study finding a declining trend in malaria transmission in Puducherry between 2015 and 2021, with no observed seasonal trends [210]. Government-supported mass vector-borne disease awareness campaigns and vector control programmes over many years might have also contributed to cementing the stagnant water and vector-borne disease association in India, thereby lead to the strong interlining of climate change, floods and vector-borne diseases seen here [211, 212].

We found a perceived need by participants to target interventions on multiple levels, taking into account the specific needs based on vulnerabilities, including socio-economic factors. The most economically disadvantaged are also the most vulnerable to exposure, which is likely to exacerbate in the coming decade primarily through health impacts, and as also affirmed by the participants, there is a need to target interventions at this group [213]. Climate-sensitive health risks disproportionately affect the most disadvantaged and vulnerable fractions of society, including women, the elderly and economically disadvantaged communities [187]. As highlighted by one of the participants, their needs have to be taken in account, especially when developing public infrastructure such as toilets, which are an important part of the political agenda of the Indian government [214].

Given the scale of recent agricultural damages due to extreme climate events in India, their widespread coverage and importance in the region, this was high on the list of perceived climate impacts. This included downstream effects of agricultural impacts on health through food systems, as was also seen in other multi-stakeholder studies from other settings, pointing to the interlinked nature of climate impacts [188, 206, 207]. As was also discussed by participants as an indirect impact of climate change, reduced agricultural yield due to climate change has been linked to a loss of work hours, which in turn can potentially lead to sedentary lifestyles, causing further risk of ill health and malnutrition [215, 216].

Heat and season-related diseases including skin diseases, CVDs and respiratory illnesses, mentioned by few of the participants, are also commonly linked to climate change [190, 207, 217]. When it came to CVDs in particular, not all participants were convinced of the association. We found a gap in participants making the climate change-temperature-CVD connection, implying a need to improve awareness of the CVD or NCD impacts of climate change, which was also echoed by a participant. CVDs are mainly thought of as multifactorial and lifestyle-linked by all professionals, although several doctors appeared aware of how temperature affects the cardiovascular system. This was perhaps due to the tendency to disconnect temperature from climate change making it difficult for participants to connect it to the broader climate change manifestations, despite the growing number of studies conducted on the topic [215, 218, 219]. All participants also described being disconnected from the current climate-health research, and not having awareness of research and new developments by other national and international institutes. The need to improve inter-departmental communication and science dissemination in Puducherry is pronounced through the general dearth of awareness on the CVD impacts, compounded by the silent nature of the disease.

A need for improved awareness on climate change and health impacts emerged as a key finding, along with considerations on who delivers the message. Participants described a need to mobilize medical professionals in light of their emerging roles as trusted sources of information on health impacts of climate change and supporting public health policies, as has been observed in other global studies [86, 220]. The high levels of public trust in physicians or perceived experts allows them to exert their influence and convince people easier than other professions, as was also alluded to by a participant in this study [220-223]. Celebrities as a source of knowledge, which we found in this study, have similarly been reported in another study from Puducherry [224]. Given that we found the political inclinations of information sources a contributing factor in their level of credibility, we can imply that the perceived 'neutrality' of the source is an important factor in how the information is received. However, based on our results, there is a need for doctors to receive more education and awareness on the topic, especially about CVDs and other non-explicit health impacts in order to confidently integrate climate change into their practice and disseminate information to the public [86, 218, 223]. Continued medical education courses are potential opportunities for the medical fraternity to recognise the health impacts of climate change and consciously implement it in their practice [86, 225]. As a critical aspect of adaptation, education can serve as a major area through which to implement behavioural change, especially if started at a young age [226]. With respect to that, there is also a need to assess the level of knowledge, misconceptions and confidence in explaining climate change concepts among teachers, as also demonstrated in a Canadian study [227].

We found that there remains a need to provide alternate solutions and target design interventions specific to different groups in Puducherry, starting from the ground level, which has been shown to increase public support for actions [228, 229]. Targeting the most vulnerable groups, such as farmers or those exposed to the external environment for an extended time was considered to be important among study participants. According to the participants, the DSTE has already made first steps in this direction with their tailored programmes to specific groups like farmers and children. However, there remains scope to include health impacts of climate change in these programmes which serve as an important mode of accessible science communication. The media has been proven to be another powerful source of information, one which most people trust and consider reliable [190]. In fact, participants in this study mentioned it as being the most common and influencing source, showing the great scope for utilizing it to further the agenda and spread the message among common people.

Participants also mentioned the need for occupational health protection measures as a response to climate change, especially among those engaged in outdoor and manual labour. Exposure to heat is a major driver of occupational vulnerability due to heat stress and it affects worker health through increased vulnerability to diseases such as CVDs, and productivity [230]. In India, common reasons for reduced work capacity included exhaustion, hospitalization and lost wages, which also greatly reduce the economic and development pace and capacity of the country [231]. Worker productivity decreases when the Wet Bulb Global Temperature (WBGT) is above 26 to 30 °C [232]. Puducherry, with an average temperature of 30 °C, has an apparent temperature range between 23 and 41 °C, meaning it is especially important to protect the health of outdoor workers such as farmers, fishermen, construction and manual labourers [233, 234]. Policy measures to reduce workplace heat exposure in the context of climate change and improve occupational health are imperative to protect the working population, as has also been recommended by WHO [230, 235]. Similarly, it is essential to plan actions with the aim of protecting children's health in the context of exposure to heat in schools [236, 237].

This study has some limitations, which we present here for consideration. First, our study was small in scale and was of an exploratory nature, restricted to Puducherry. Second, despite the saturation reached in the information, further studies with a larger sample size might prove to be advantageous. Third, there was a gender imbalance in the study, with only very few female participants, especially regarding medical professionals. Fourth, our study was limited only to health professionals and environmentalists in the policy sphere, and hence, it did not include the views of the broader public. In particular, we recommend future studies on the topic to include the perspectives of the most vulnerable and marginalized population to gain a deeper understanding of the climate risks they face as well as areas for improving interventions.

6.6. Conclusion

There are limited data on how climate change and its health risks are perceived by key stakeholders, especially in the LMICs. Our study sheds new light on this topic among medical professionals and environmentalists in the Puducherry region as well as some perceived gaps and recommendations. While there was awareness on the impacts of climate change, including on health, we found a disconnect when it came to diseases not conventionally associated with climate, such as CVDs. There is scope for education and training, especially among healthcare providers, on climate-sensitive diseases. We also report a high perceived need for more education and awareness on climate change and health, not only among the scientific community but also among the general population, along with recommendations for adaptation measures. It also highlights the need for studies in other regions of India and elsewhere. These findings can be used to strengthen the region's climate action plan through targeting key areas identified in this study such as education and awareness building on health impacts of climate change, not only among the local population but also among key stakeholders.

6.7. Declarations

Author Contributions

S.S.S., M.R., M.A.D., J.U. and G.C. conceptualized and planned the study. S.S.S. and R.L. acquired and provided access to the data. R.L. facilitated the interviews. S.M. and S.S.S. designed the study. T.L. validated the codes and codebook. O.C., S.S.S. and S.M. conceptualized and structured the framework. S.S.S. wrote the first draft of the manuscript with inputs from all authors. The final manuscript has been revised by all authors. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

This study was approved by the Institute Ethics Committee (Human Studies) of the Indira Gandhi Medical College and Research Institute (a Government of Puducherry Institution); no. 318/IEC-31/IGM&RI/PP/2021 and by the Ethics Committee Northwest and Central Switzerland (EKNZ); statement ID- AO_2020_00034. The methodology used in this project abided by the principles laid out in the Declaration of Helsinki and the COREQ checklist.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. All participants were verbally explained the project and its objectives as well as being provided information sheets. All participants were made aware of their right to refuse participation at any point without further obligations. Signed informed consent was obtained from all participants prior to the interviews, with participants retaining one copy.

Data Availability Statement

All relevant data from this study have been included in the Supplementary Material. As this is a qualitative study with a small number of key informants, making the full dataset and interview transcripts available to a wider audience could potentially breach the confidentiality commitment made to the participants during the process of obtaining informed consent as well as to the ethics committees that approved this study. Therefore, the data will not be made available.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

Chapter 7. Barriers to climate change and health research in India: A qualitative study

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Barriers to climate change and health research in India: a qualitative study

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ABSTRACT

Objectives Almost a quarter of the global burden of disease and mortalities is attributable to environmental causes, the magnitude of which is projected to increase in the near future. However, in many low- and middle-income settings, there remains a large gap in the synthesis of evidence on climate-sensitive health outcomes. In India, now the world's most populous country, little remains known about the impacts of climate change on various health outcomes. The objective of this study is to better understand the challenges faced in conducting climate change and health research in Puducherry, India.

Design and setting In this study, we employed key informant interviews to deepen the understanding of the perceived research barriers in Puducherry. The findings were analysed using data-driven qualitative thematic analysis to elaborate the major perceived barriers to conducting environmental health research.

Participants This study was conducted among 16 public health professionals, including medical researchers, and professionals involved in environmental policies and planning in Puducherry.

Results We identify three key barriers faced by public health professionals as key stakeholders, namely: (1) political and institutional barriers; (2) education and awareness barriers; and (3) technical research barriers. We show there is a need, from the professionals' perspective, to improve community and political awareness on climate change and health; strengthen technical research capacity and collaboration among researchers; and strengthen health surveillance, resource allocation and access to health data for research.

Conclusion Evidence informed policies and interventions are a key element in the adaptation response for countries. In the context of the paucity of data on environmental health from India, despite recognised climate change related health vulnerabilities, these findings could contribute to the development and improvement of relevant interventions conducive to a strong research environment.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study identifies crucial challenges faced in conducting environmental health research by public health professionals for the first time.
⇒ The findings draw on the experiences of respected experts who are well placed in the climate change and health sphere.
⇒ The sample was restricted to Puducherry district and not representative of the entire Union Territory of Puducherry, much less India as a whole.
⇒ The sample is restricted to the opinions of a selected group of experts and we could not include the experiences and perspectives of other public health professionals or stakeholders.

INTRODUCTION

An ever-growing body of research has irrefutably shown the global health impacts of climate change through both direct and indirect exposure pathways.[1 2] Multiple risk and vulnerability factors determine the population resilience and adaptive capacity, from sociopolitical, demographic and biological factors to infrastructure, urban planning, health information systems and health workforce.[2 3] Given the regional variations in climate systems, the health impacts of climate change differ between and within countries and communities, mediated by interconnected socioeconomic and environmental determinants of health.[4 5] Non-communicable diseases, such as respiratory diseases, cardiovascular diseases (CVDs) and mental health conditions, have been recognised as growing climate-sensitive health outcomes, in addition to other communicable diseases like vector-borne and water-borne diseases and malnutrition.[3 6]

With the rapid pace of climate change, the health impacts attributable to it are also projected to increase.[7] Strengthening the adaptive capacity of countries is therefore an essential component of the climate change response.[8] Timely public health interventions can do much to protect population health from the potential adverse health impacts of climate change.[9] Low- and middle-income countries (LMICs), such as India, remain disproportionately affected by climate impacts, with a critical need to strengthen the healthcare response to climate impacts.[10 11] One of the key steps in the regional or local

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7.1. Abstract

Objectives: Almost a quarter of the global burden of disease and mortalities is attributable to environmental causes, the magnitude of which is projected to increase in the near future. However, in many low- and middle-income settings, there remains a large gap in the synthesis of evidence on climate-sensitive health outcomes. In India, now the world's most populous country, little remains known about the impacts of climate change on various health outcomes. The objective of this study is to understand the challenges faced in conducting climate change and health research in Puducherry, India.

Design and setting: In this study, we employed key informant interviews to understand the perceived research barriers in Puducherry. The findings were analysed using data driven qualitative thematic analysis to elaborate the major perceived barriers to conducting environmental health research.

Participants: This study was conducted amongst 16 public health professionals, including medical researchers, and professionals involved in environmental policies and planning in Puducherry.

Results: We identify three key barriers faced by public health professionals as key stakeholders, namely: (i) political and institutional barriers; (ii) education and awareness barriers; and (iii) technical research barriers. We show there is a need, from the professionals' perspective, to improve community and political awareness on climate change and health; strengthen technical research capacity and collaboration amongst researchers; and strengthen health surveillance, resource allocation and access to health data for research.

Conclusion: Evidence informed policies and interventions are a key element in the adaptation response for countries. In the context of the paucity of data on environmental health from India, despite recognised climate change related health vulnerabilities, these findings could contribute to the development and improvement of relevant interventions conducive to a strong research environment.

Strengths and limitations of this study:

- This study identifies crucial challenges faced in conducting environmental health research by public health professionals for the first time.
- The findings draw on the experiences of highly relevant experts, well placed in the climate change and health sphere.
- The sample was restricted to Puducherry district and not representative of the entire Union Territory of Puducherry, much less India as a whole.
- The sample is restricted to the opinions of a selected group of experts and we could not include the experiences and perspectives of other public health professionals or stakeholders.

7.2. Introduction

An ever-growing body of research has irrefutably shown the global health impacts of climate change through both direct and indirect exposure pathways [25, 238]. Multiple risk and vulnerability factors determine the population resilience and adaptive capacity, from socio-political, demographic and biological factors to infrastructure, urban planning, health information systems and health workforce [25, 187]. Given the regional variations in climate systems, the health impacts of climate change differ between and within countries and communities, mediated by interconnected socio-economic and environmental determinants of health [215, 239]. Non-communicable diseases (NCDs), such as respiratory diseases, cardiovascular diseases (CVDs), mental health conditions, have been recognized as growing climate-sensitive health outcomes, in addition to other communicable diseases like vector- and water-borne diseases and malnutrition [187, 240].

With the rapid pace of climate change, the health impacts attributable to it are also projected to increase [241]. Strengthening the adaptive capacity of countries is therefore an essential component of the climate change response [242]. Timely public health interventions can do much to protect population health from the potential adverse health impacts of climate change [243]. Low- and middle-income countries (LMICs), such as India, remain disproportionately affected by climate impacts, with a critical need to strengthen the healthcare response to climate impacts [244, 245]. One of the key steps in the regional or local adaptation response is assessing the true burden of the health impacts within the population of that location [183]. However, owing to the complexity of the relationship between climate change and health, identifying and estimating this association remains one of the biggest global and environmental health challenges, especially in LMICs [245].

In India, the existing health and social disparities within the population make it one of the most vulnerable to climate change impacts, compounded by climatic diversity [205, 246-248]. There have been recent efforts from the Government of India to focus on climate change and health, as evinced by the recent addition of a health mission to the National Action Plan on Climate Change (NAPCC). This led to the formulation of the National Action Plan on Climate Change and Human Health (NAPCCHH) and the drive for State Action Plans for Climate Change and Human Health (SAPCCHH) [200, 201]. The government recognizes several diseases as climate-sensitive in these official document., However, public health engagement, action and research on health impacts of climate change are limited in India, especially given the magnitude of climate impacts to which it is vulnerable [194, 249].

Medical and public health professionals, hereafter referred to as health professionals, play an important role in researching, managing and responding to climate change impacts on health. Along with being considered credible sources of information, these groups of professionals also have the capacity for scientific inquiries into the climate change attributable impacts of health [221, 223, 250, 251]. Globally, there is an acknowledged need to train health professionals to engage in, study and manage health impacts of climate change. There are few studies assessing stakeholder perceptions on climate change and health [190, 205, 252], and even fewer studies looking at specific barriers to research on this topic [86, 253]. Given the present gaps in this domain, especially in LMICs, it is particularly important to understand what research barriers and needs are perceived by health professionals [86, 190, 252, 254].

The aim of this study is to understand some of the contextual barriers to environmental health action and research amongst two relevant professional groups in Puducherry, India. We focused our study on: (i) medical professionals, both in active research and practicing; and (ii) members of the Department of Science, Technology and Environment working on climate change in Puducherry. As this study is a part of a larger project on CVDs and climate change in India, we also highlighted the specific challenges and barriers to conducting research on CVDs.

7.3. Methods

7.3.1. Study setting

This study employed key informant interviews following a semi-structured interview guide. The methods have been described in detail elsewhere. Briefly, the focus of our study was Puducherry district, which lies on the south-eastern coast of India, with a population of 950,289, as per the Government of India 2011 Census [105]. Puducherry has one main State government run tertiary care hospital and medical college, along with several private clinics and primary care health centres. It is also home to the Central Government Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER), an 'Institute of National Importance' and tertiary care referral hospital. Within the Department of Science, Technology and Environment (DSTE), there also exists a specialized Puducherry Climate Change Cell with the aim to integrate knowledge about climate change and facilitate the NAPCC implementation, including the state specific Action Plan [255].

7.3.2. Data collection and analysis

16 semi-structured interviews were conducted between January and March 2022 with participants from Puducherry. 14 interviews were conducted in-person and 2 were conducted virtually over Zoom. Using purposive sampling based on prior connections followed by snowball sampling, we invited medical professionals (research or practicing) and DSTE staff working on the Puducherry State Action Plan for Climate Change (hereon referred to as environmentalists). Interviews continued until information saturation was reached in the interviews or we had interviewed all the relevant target participants, as in the case of the DSTE staff. The full interview guide and framework with the main categories has been given in the Supplementary Table S10.

Eleven of the participants had a medical background and were working as either practicing physicians or researchers. Within the doctors, we mainly targeted cardiologists, emergency medicine or general medicine physicians who were involved in areas relevant to our study. The majority of the participants was male, with only three females, out of which only one had a medical background. Half of the participants were practicing physicians while the other half were researchers. The participant profile is presented in Table 7 and further described in [6].

Table 7: *Profile of participants interviewed in this study.*

Sector/background	***n***	**Females (*n*)**	**Males (n)**	**Age range (Years)**	**Range of experience (Years)**
Medicine (in-practice)	8	0	8	32-51	3-20
Research (Medical)	3	1	2	40-44	11-20
Research (Environment/governmental)	5	2	3	28-53	4-30

The interviews, conducted by S.S, lasted between 15 to 50 minutes and were audio recorded with informed consent using a voice recorder. Field notes taken to optimize the interview guide and note key topics. R.L was a passive observer and facilitator for 3 interviews. We used an *a priori* developed interview guide with broad and open-ended questions to allow participants to freely bring up and discuss relevant topics. All interview recordings were assigned a number prior to transcription to ensure anonymity throughout the analysis process. Verbatim transcription and analysis was done using the MaxQDA software version 2018.1 (VERBI Software, Berlin, Germany) by S.S.

For the analysis, a combination of deductive and inductive thematic analysis was used as described by Gale et al [199]. Broad themes were developed based on the aim, framework and interview guide, as discussed below. During analysis, major themes were inductively developed for emerging topics, which we then clearly defined. After familiarization with the transcripts, an initial codebook was developed from coding the three interviews with the richest data; the remaining interviews were indexed and coded further. The codes were classified into categories, sub-themes and themes. The final analytical matrix included three themes. S.S. and T.L. independently validated the codebook with the 3 main interviews and agreed on the final framework matrix that considered all relevant codes. The matrix was then used to chart relevant quotes supporting our findings and draw comparisons between participants.

The conceptual framework for climate change risk perceptions developed by van Eck *et al* [197] and the framework for health inequalities proposed by Rudolph *et al* [198] were used as a base for our analytical framework, shown in Figure 20. While there are three major themes, this paper focuses only on the theme of 'Institutional determinants'. The findings from the two other themes have been elaborated in chapter 6. Within the context of this paper, 'institution' is used as a broad term covering all governmental structures including policy, education, and occupation. We identify how these determinants can be perceived as barriers to environmental health research. The framework matrix with relevant themes and categories has been provided in Supplementary Table S12. Additional supporting quotes have also been provided in the Supplementary material.

7.3.3 Ethical consideration

There was no prior relationship between the researcher and participant. Before the interview, the researcher went over the informed consent form, which was then signed by both parties. S.S, the main researcher is an Indian PhD candidate supervised by a team of international experts based mainly in Switzerland. R.L is also Indian national based in Puducherry. Additionally, all the quotes presented in this analysis have been assigned only by serial number to ensure anonymity.

This study was approved by the Institute Ethics Committee (Human Studies) of the Indira Gandhi Medical College and Research Institute (A Govt. of Puducherry Institution); No. 318/IEC-31/IGM&RI/PP/2021 and by the Ethics Committee Northwest and Central Switzerland (EKNZ); Statement ID- AO_2020_00034. The methodology used in this project abided by the principles laid out in the Declaration of Helsinki and the COREQ checklist.

7.3.4. Patient and public involvement

As we employed a combination of purposive and snowball sampling, some participants were involved in helping us identify suitable participants to interview. Beyond that, no members of the public were involved in the design, conduct, reporting or dissemination plan of our research.

7.4. Results

Overall, there are 4 main themes that emerged from this research, which are presented in Figure 20. We first report participants' knowledge regarding climate change and health policies, followed by their perceived institutional barriers to research, namely political, educational and technical barriers. As this study is part of a larger study examining climate change impacts on CVDs, we also highlight barriers specific to climate change and CVD research.

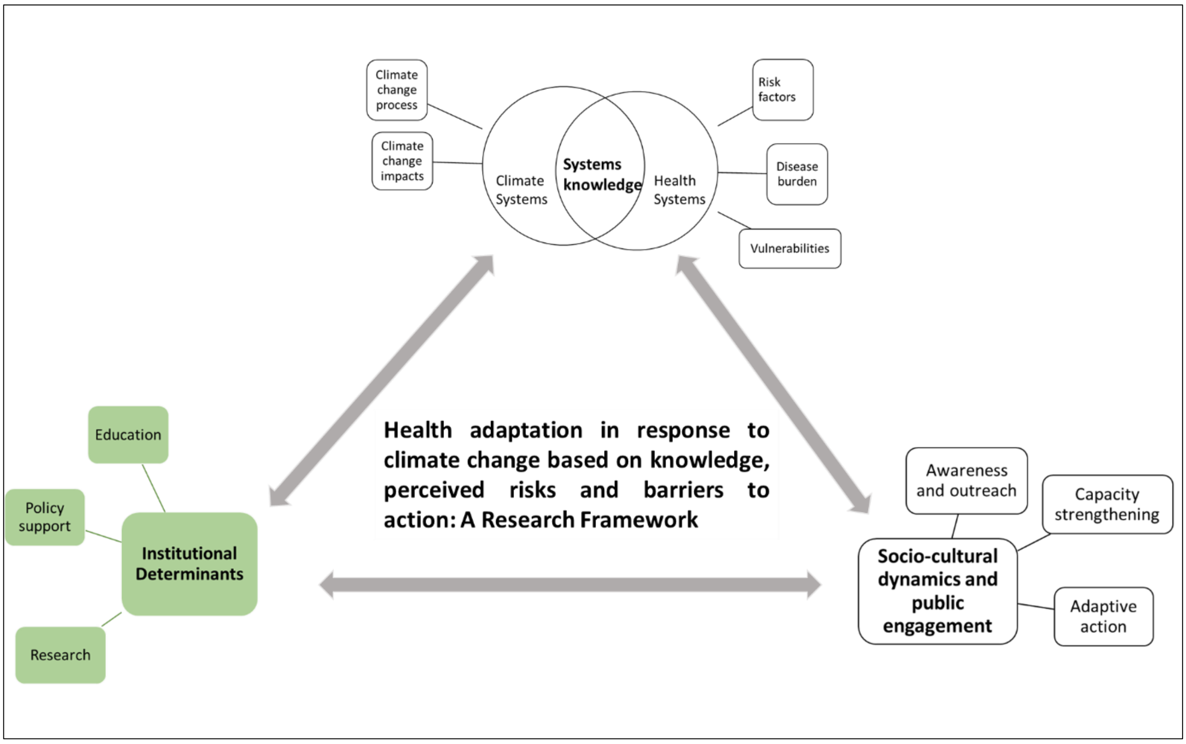

Figure 20: *A framework for health adaptation action in the context of climate change based on knowledge and perceived health risks, policy and institutional support and public engagement. The coloured parts highlights the thematic areas we focus on in this paper. The three main components have been shown in bold text.*

7.4.4. Institutional framework: knowledge on policies

7.4.4.1. Limited knowledge and awareness on climate change and health related policies

We found limited awareness among the participants about climate change and health related policies, such as the NAPCC, NAPCCHH and SAPCCHH. Aside from the environmentalists, who worked on it, only three medical professionals who worked on one of the Action Plans were aware of it. Four participants expressed belief about the non-inclusion of climate change in disease specific policies and the lack of integrated climate change and health policies and guidelines.

"Our country has different policy, environmental policy, health policy. But I have doubt whether health policy has any component of climate change. So, it needs to be incorporated in a health policy of national importance as well as the state, but currently, this element is not in place, that is my feeling." #8, Environmentalist.

One of the environmentalist also mentioned challenges in integrating climate change in development plans. These were thought to be made primarily from a socio-economic development perspective, although there were ongoing efforts to include the economic co-benefits of climate change adaptation in the development plans.

"The challenge is that the government sectoral officers are not aware of how the climate adaptations need to be integrated into their developmental plans. Because they, whenever they plan for a project, they plan it from the socio economic development perspective." #7, Environmentalist.

7.4.5. Political and institutional barriers

7.4.5.1. Disengaged leadership and low political prioritization of climate change and health

Political leadership that did not consider health impacts of climate change as a pressing matter was perceived as one of the barriers to conducting research on the topic.Several participants mentioned how climate change was seen as future concern by policy makers and the general public, rather than viewed as a cause for immediate concern. A few participants also mentioned the slim likelihood of decision makers actually being aware of it. One participant described the issue as being "*not mainstream enough*" to warrant focused work, contributing to the perceived low priority assigned to environmental health research.

Many participants felt that the governmental focus was inclined towards non-health impacts of climate change. The most pressing climate change impacts, which also influence research focus, were thought to be pollution, coastal sensitivity and natural resource depletion and degradation, especially in the context of Puducherry as a coastal region. Additionally, existing sectoral programs already running were seen as a hindrance to focusing on climate change related programs by one participant.

"The problem is everybody has to understand at the level of the minister or the secretaries. So many programs are there. Not only about climate change, other programs are there so they do not focus much on (climate change) programs… Actually, what I have seen for the past 2-3 years, they don't care much about climate."#1, Practicing physician/policy advisor.

Despite climate change being recognized as a health risk factor, there was a clear disconnect between on-paper government plans and practice when it came to environmental health research. The challenges India faces from other vulnerabilities, including unmet nutritional and economic needs were perceived to outrank climate risks to health..

"I'm an adviser to government of India on health related research. We did discuss a lot of things but we also touched upon climate and the effects of climate on health…That was considered as an important topic, but we didn't dwell much upon how to take it forward because there are more pressing problems." #15, Practicing physician/academic.

7.4.5.2. Weak inter-departmental integration and co-ordination for climate change and health

The compartmentalization of topics within institutes or sectors was seen as a barrier to conducting inter-disciplinary research by the participants. One participant discussed the newly formed Puducherry Climate Change and Health Action Plan (2022), which aims to bring together a multi- sectoral team, under the leadership of the health ministry, to focus on health impacts of climate change.

However, apart from one participant, most others voiced a perceived need for an independent, coordinating body focused on environmental health, incorporating a research agenda. Partially, this was due to climate change being thought of an added responsibility for health professionals and vice versa for environmentalists, especially for those working in the government. As highlighted by a few participants, officials were likely to prioritize their primary work profile over the added responsibility of climate change and health research. Another concern in the existing scenario was inter-sectoral, collaborative research being dependant on higher officials being receptive to their junior employees researching a topic not entirely within the scope of their respective department.

"Especially government departments, they are loaded with a lot of work. Today, an officer comes in, he has to do his own work, not the work that other departments asks us to do…" #9, Environmentalist.

Several participants mentioned the Puducherry Climate Change cell created in response to address climate change impacts. However, despite that, one medical researcher mentioned the current difficulties in collaborating on climate change and health. Several participants also mentioned the need to improving coordination between the sectors, with a dedicated head of climate change and health.

"Intersectoral body and there should be one decision maker. So now, everybody is like the leader in the particular sector, but if they need the support from other one, that coordination may be lacking…There won't be any one dedicated person for the climate change. So they will be in charge of multiple departments. For example, somebody's going to be in charge of immunization or the child health. So their priority will be child health obviously." #3, Medical doctor/academic.

7.4.6. Educational and informational barriers

7.4.6.1. Gaps in climate change and health in higher education curricula

One of the strongest emergent themes, referred to by most participants, was the need for environmental health education, either by incorporating climate change in the health curriculum or health impacts of climate change in the environmental curriculum in universities and schools. The prevalent feeling was the source of climate change and health literacy needs to be from multiple sources, with formal education being the most important one. Most participants also felt that at present there was a disconnect between environmental and health education, as a result of which there was a relatively low level of awareness on climate change impacts on health.

"Education system need to be addressed from beginning…Even the medical college students who are completing five years courses, I do not see any syllabus which contains impact on health by the climate change even though it is very important…my son is studying medical-medicine, but I guess I just go through the syllabus, but nothing is there." #8, Environmentalist.

All the environmentalists professed to never having specifically studied health impacts of climate change during the course of their education. On the other hand, the health professionals expressed incongruent views on climate change-health education. While one mentioned having studied climate sensitive diseases in medical school, another denied ever having been taught the link between climate change and various diseases.

Continuing education courses specific for health impacts of climate change were suggested by a few participants as potential options to bridge the gap between the environment and health. Two participants also suggested including short courses on this topic for all people working on topics related to climate change, health, adaptation and resilience.

7.4.6.2. Weakness in inter-sectoral information dissemination

Many of the participants mentioned having little to no awareness on climate change-health related research unless actively searching for it, pointing to the scope for improving related education and science dissemination, especially among the scientific community. Environmental risk factors were not commonly associated with health inherently, partially attributed the low scientific exposure on the topic.

CVDs were seen as a 'silent' disease, with many people are not trained to look for symptoms, much less correlate them to weather conditions, all suggesting the need for improved CVD literacy and awareness on the topic. On the other hand, many participants were open to changing theirs current schools of thought on risk factors for health to include climate change, conditional to being informed by global research on the topic.

"If there is research or it's already proven in other countries, 'so this is a risk factor it is a good idea to add' but [before adding anything], I think some data or there should be some routine surveillance or monitoring system should be there. … even within the medical circle, people may not be aware how much is the contribution of climate change to the heart disease or for any disease for that case… I don't think our administrators or even our clinicians are that much thinking about the impact of climate change, and [heart disease]." #3, Medical doctor/academic.

7.4.6.3. Scepticism and low awareness on non-conventional health impacts of climate change

As alluded to previously, health impacts of climate change are often not explicit, making it a challenge to research or focus the research agenda on for several reasons. One participant described how the slow pace of climate impacts leads people to think it will not immediately affect health, unless the impacts are drastic.

"…The problem has to become so severe, like you have air pollution in Delhi, then people will act. Climate change affects the life slowly it's not drastic…that is one of the reasons I feel. And slowly if you get some data and keep on generating awareness not only among the public, but also within the scientific community, then slowly things will be better."#3, Medical doctor/academic.

For researchers, an additional challenge of convincing funders or collaborators on the health impacts of climate change also emerged. One participant described the difficulty researchers had separating environmental risks from other common health risk factors. Scepticism when attempting to research health impacts of climate change was also encountered. Confounding from other risk factors and potential ecological bias was seen as the roots of this uncertainty.

"Maybe for six, seven years, I have been trying to do some work on climate change and environmental health. Every time I write a proposal I'm criticized largely telling that "how is it going to work?... And one other problem I see with the research with climate change or any environmental thing, it's ecological effects. So people ask "how can you attribute this to only this, why not to this?", " Why not to lifestyle, why only to climate change?" So this direct relationship is not there." #4, Medical doctor/ academic.

Diseases such as malaria, with historical links to stagnant water as breeding grounds, have been etched into public knowledge and further perpetrated through mass awareness campaigns, intervention programs and research. The slow developing nature of CVDs and the prevalent categorization of CVDs as solely lifestyle diseases was mentioned by many participants as potential barriers to research. One participant described how CVDs are commonly reduced to lifestyle diseases with the onus of risk management on the individual rather than a "*willingness to see the invisible factors*". The multifactorial nature of CVDs was thought to add to the difficulty of identifying climate attributable impacts.Another participant described how clinicians especially do not see the need to focus on environmental risk factors for CVDs, believing it ineffective in reducing the overall burden.

"Non-communicable diseases, because we are not quantifying that and because of the long latent period of the incident, you're not able to quantify directly to environment or climate change. So definitely, hypertension, cardiovascular disease, all these probably diabetes also because of the changing food pattern, but I don't think -you cannot separate climate change

from any of the health effects or any of the non-communicable diseases. Also related to stress caused by climate change." #2, Medical doctor/ academic.

The need for regional studies was also stressed upon as there seemed likely to be a disconnect in comparing national or global level problems with health impacts of climate change on a local level. Participants described the attitude of "*this does not affect us"* among the public when it came to climate change especially. A few participants expressed belief and hope that the temperature-CVD association was an upcoming topic of interest for the government and public both.

7.4.7. Technical barriers to research

7.4.7.1. Insufficient resources and workforce dedicated to research

Resource allocation, especially financial, for climate change-health research was described as a barrier, especially by researchers. Along with inconsistent funding from the government, one of the problems mentioned was lack of adequate trained personnel. This was partially linked to the need to relieve the research expectations from already over-burdened doctors. There was also a need to have trained personnel for digitalization and categorization of health data in order to create a digital state-level health database.

Some participants, referred to the low percentage of the annual budget of India allocated to health along with the need to increase this. One participant described funds earmarked for climate change-health research institutionally, along with optimism that this would lead to future research opportunities.

*"Yes, for recent years even ICMR (Indian Council of Medical Research) has called for proposals on this environment related, uh, this one. ICMR is one of the largest body which is for the research organization as well as for the academic institutes like us. So, clearly, they are given a separate block of funding for climate change and [health]. That means the funds are available."#*3, Medical doctor/academic.

However, this was countered by the notion that most of the funds are directed to Central government institutes as opposed to smaller research institutes. A participant also alluded to misappropriation of research funding at an institutional level. Another participant spoke about the need to involve university students in research along with concern that most students do not get access to funding or research opportunities. There was a feeling that most students remain unaware of opportunities for funding or that funds do not ultimately reach the students aiming to conduct research. Another participant also described the prioritization of more immediate health burdens and curative research as opposed to preventative research for the directing of funds or resources. This was supported by the opinion expressed by an environmentalist on climate change being viewed as a problem for the future as opposed to the present.

"So though we focus on vaccination and other things, but still, the budget still flows more for the curative aspects rather than the preventive part. So for instance, the climate change is more of like, you prevent this- the future heart attacks or some other diseases. You have to focus on the prevention." #3, Medical doctor/academic.

7.4.7.2. Underdeveloped transdisciplinary research capacity

Alongside education, the need to build more technical capacity among researchers was also mentioned as one of the biggest challenges by participants. Despite a potential interest and willingness from researchers, the lack of training and expertise in climate change-health research was strongly expressed. This was tied in with the expressed desire for mentorship, both to facilitate increased awareness among the scientific and medical community as well as increased regional research on health impacts of climate change.

"Yeah, more than research, I would tell it as people are aware and willing to do it, but here is more of capacity building…Let's say if I want to work on vector borne disease, I know who to approach…but when it comes to climate change, that linking is absent. …So actually, even if I'm interested and I want to work on it, there are a lot of hurdles which has to be crossed…So I have to be given an opportunity to work on it, or I feel somebody has to mentor me to work on it. So what we call as, starting trouble, you know is there. Once I think somebody starts, we will be going into it…." #4, Medical doctor/ academic.

Some participants had the belief that larger research institutes or relevant ministries could be drafted to provide training to the smaller educational institutes or local government bodies. There was a sense of "*duty*" attached to studying all aspects of climate change impacts for the environmentalists in Puducherry tied in with a search for a starting point.

7.4.7.3. Research slowed by unavailability and limited access to quality data

Participants described critical gaps in monitoring, surveillance and database development, all of which were perceived to hamper research conduction, especially for health data. First, merging health data from the many healthcare facilities within Puducherry was seen as a challenge. There was an expressed need to bring together health data for the entire UT in a single system, including public and private healthcare facilities.

Second, some participants mentioned the state-level government health-monitoring database. However, participants described this as being limited to selected diseases from all the government run primary healthcare centres, with limited information on the private sector or secondary and tertiary care hospitals. A few participants described the lack of disease-specific categorization of health outcomes, making it an added challenge in conducting health related research.

Third, participants also perceived private medical colleges and healthcare facilities as reluctant to share data with the government, with a felt need to enhance governmental efforts to work on the state wide database. Fourth, on a related note, concerns about data quality were mentioned by several participants. Part of the reason for an unwillingness to share data by healthcare facilities was thought to be due to potentially inaccurate or poor quality data.

"They're all afraid of like somebody will find a fault with that. So because they don't have manpower to look at the accurate or clean the data, okay, so somebody shares and later they find their mistake, and they will be answerable to the higher authority. So that's the usual reason we do not to share the data, the insecurity." #3, Medical doctor/academic.

Another challenge shared was the slow, ongoing effort to digitalize the data. Participants described as feeling unmotivated to start research at the cost of manually sorting through thousands of paper records, unless there was a way to guarantee research output. This was also relate to a challenge of medical professionals being overburdened with work.

"There is not even a digitalization…Many hospital doesn't have digitalized MRD [medical records department]. For example, I was doing a study, retrospective study, collecting infective endocarditis data for past 10 years, there are more than 1000 files. How can I go through the 1000 files? It's not possible." #13, Practicing physician.

Surveillance of diseases was mentioned as ongoing work. Diabetes, hypertension, cervical cancer and other 'notifiable' diseases like infectious diseases were described as being under surveillance.

7.5. Discussion

This research examined barriers faced in conducting climate change and health research by key stakeholders in Puducherry. The localized findings relatively remain relevant for India and can be extrapolated to other LMIC settings [253]. Four main themes emerged from this research, which are discussed below.

First, we found limited knowledge of relevant policies, especially amongst the participants with a medical background. In recent years, there have been a lot of strides taken in the Indian policy space with pertaining to climate change and health, such as the addition of the Health Pillar to the NAPCC and the subsequent development of the NAPCCHH and mandates for the development of the State level action plans for climate change and health [200, 201]. Although the Health Pillar is a relatively recent addition (2015), there was still a substantial lack of awareness on the NAPCC as well as the health mission in general, which we present as a key area for strengthening. Knowledge of such policies, especially if they can provide a framework to support related research, is a useful tool to advance the research agenda on climate change and health [191, 256] . Health system vulnerabilities are already being seen in Puducherry and active knowledge of such policies can also be utilized by relevant stakeholders to develop resilience focused interventions. This includes communicating the severity of the problem to the policy makers, who generally lack the political will to divert resources to non-apparent problems, alluded to by the participants in this study and identified in other studies [206, 257].

Second, participants perceived climate change and health as a topic lacking political support and prioritization. Most political efforts are thought to be focused on mitigation measures such as air pollution control, with little importance given to health adaptation and healthcare resilience. The participants believed that the health impacts of climate change were not a political priority or seen as urgent. Similar findings have been elucidated in other studies which also found public health leadership on climate change to be fragmented [86, 258]. Further efforts to inform the decision makers on the importance of health adaptation might contribute to more evidence informed climate change and health policies [259, 260]. As an added justification for health co-benefits of mitigation can be introduced through multiple pathways, including air pollution, lifestyle modification, health surveillance or research programs in development or related policies [185, 261].

Participants also highlighted weaknesses in inter-departmental co-ordination for working on climate change and health. We found almost unanimous support for a separate inter-sectoral body focused specifically on climate change and health. Methodological challenges in the light of limited technical knowledge and adequate inter-sectorial coordination and support for transdisciplinary capacity that we found have also been reported elsewhere [254, 262]. A recent study on the knowledge, attitudes and practices related to climate change and health among the Indian health workforce found intermediate or delayed health impacts of climate change less commonly identified [252]. This could also support the development of regional, national or even international research networks facilitating knowledge sharing and transfer, including research methodology support [254].

The siloed operations of 'health' and 'climate change' was also seen as a research barrier. This was partially due to the unclear division of responsibilities and fragmented institutional focus, as also seen in other studies [254, 258, 263]. A study examining the challenges for the Californian public health sector in climate change found the compartmentalization and lack of inter-sectorial coordination to limit work on inter-sectoral issues such as climate change and health [86]. Our findings point to the need to have regular national level conferences or improved science dissemination systems to communicate climate adaptation related research or plans between and across sectors.

Third, participants perceived gaps in formal education and training on climate change and health. Our respondents had varied views regarding education on climate change or its health impacts; however, the need to improve this was clearly described by participants in this study. The need for strengthening capacity and education has been a common finding in several other global studies. Globally, there is a critical gap and scope for improvement in the education on health impacts of climate change, especially for medical practitioners [86, 190, 204, 207, 225, 228, 264-267]. A study comparing medical curriculums across the world found inconsistencies between environmental changes, health and community needs, with Indian and Chinese students especially having a gap in the inclusion of planetary health in medical schools [265]. The inclusion of planetary health from an early stage for medical students leads to a more active role of physicians in educating their patients about climate risks [265, 268]. However, there is a need to validate the results in future studies given the inconsistencies in the views we found on climate change-health education. The emphasis on cure rather that prevention, which has shown to reduce long term healthcare costs, could support the need for Puducherry to focus on the preventative aspects, largely through education and awareness [223]. We also found scepticism and low awareness on the non-conventional health impacts of climate change, such as CVDs. These health impacts were thought to be viewed as 'invisible' compared to more conventional or immediate impacts, such as air pollution or extreme events. This is also a commonly identified challenge to climate change and health research, accompanied by insufficient education about climate systems during the course of school or university education [87, 252].

Fourth, technical research barriers we found included insufficient data, capacity, human and financial resources. Data barriers remain common challenges in public health research, despite efforts to facilitate improvements [269, 270]. As Puducherry has the advantage of a relatively small size and well-connected healthcare facilities, efforts need to be taken to improve a central, disease specific data collection system, incorporating all the healthcare facilities in the State [107]. Facilitating training to build local data analysis expertise and capacity would contribute to more region specific research on the topic [214]. As was also made apparent in this study, other studies have shown that health impacts of climate change are a relatively new concept and not inherently associated with climate, potentially explaining the uncertainties and scepticism expressed by our participants, especially for diseases that do not warrant a visit to the doctor [217, 218]. On the positive side, the expressed desire of participants to learn more about it and make changes to the healthcare system and policies based on robust, conclusive evidence implies a willingness to adapt and implement changes in how the region tackles health impacts of climate change [264, 271]. Resource and funding constraints are one of the most common barriers to public health research, especially in LMICs and there remains a critical need to address this gap [272].

At present, little is known on CVD impacts of climate change in India. Our related study from Puducherry found a high attributable burden of non-optimal temperature to CVD mortality, suggesting a need for similar studies from around the country [233, 273]. The CVD specific challenges we identified here are comparable to the general health challenges. Awareness among the medical community on the environmental risk factors of CVDs will be instrumental in furthering this research agenda, while awareness among policy makers will help raise the political prioritization of CVD impacts of climate change [202, 223, 229].

Limitations

First, the sample was restricted to Puducherry district and not representative of the entire Union Territory of Puducherry, much less India as a whole, although the projected population for Puducherry is 1.25 million in 2021, comparable to a few smaller countries or global regions [195]. The results might thus only reflect the studied context and participants. Secondly, while we chose to focus on the medical community and DSTE representatives working on climate change, we did not include the experiences and perspectives of other public health professionals or stakeholders. Third, we do not highlight the opportunities for increasing research on climate change and health as many of these are very often interconnected with barriers. However, we do discuss potential recommendations given by stakeholders. Nonetheless, the results of this study could be useful for the research community and policy makers alike to strengthen climate change and health research and engagement.

7.6. Conclusion

There is a great need to fill the gap in research on the impacts of climate change on various health outcomes in India, especially in light of the vulnerabilities it faces. By highlighting some crucial barriers to environmental health research faced by relevant professionals, we present potential intervention points for consideration. Insufficient awareness on health impacts of climate change and perceived need to improve research capacity through collaborative work; and challenges in data availability emerged as the largest barriers to conducting research on this topic in Puducherry. We outlined the gaps and scope for addressing these through improved policy awareness; informed leadership and evidence informed climate change and health policies; research capacity strengthening and transdisciplinary research and communication network; improved education on climate change and health on all levels; and addressing data barriers in climate change through improved monitoring and evaluation systems. The key findings could contribute to supporting and strengthening evidence-informed climate resilient healthcare systems. In addition, it would also serve to inform and strengthen the research and institutional support for environmental health research in the future both in India and globally.

7.7. Declarations

Competing interests

The authors declare that they have no competing interests.

Author contributions

S.S, M.R, M.A.D, J.U and G.C conceptualized and planned the study. S.S and R.L acquired and provided access to the data. R.L facilitated the interviews. S.M and S.S designed the study. T.L validated the codes and codebook. O.C, S.S and S.M conceptualized and structured the framework. S.S wrote the main manuscript with inputs from all authors. The final manuscript has been revised by all authors.

Informed consent

This study was approved by the Institute Ethics Committee (Human Studies) of the Indira Gandhi Medical College and Research Institute (A Government of Puducherry Institution); No. 318/IEC-31/IGM&RI/PP/2021 and by the Ethics Committee Northwest and Central Switzerland (EKNZ); Statement ID- AO_2020_00034. The methodology used in this project abided by the principles laid out in the Declaration of Helsinki and the COREQ checklist.

All participants were verbally explained the project and its objectives as well as being provided information sheets. All participants were made aware of their right to refuse participation at any point prior to publication of the study. Signed informed consent was obtained from all participants prior to the interviews, with participants retaining one copy.

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Data availability statement

All relevant data from this study has been included in the Appendix D. As this is a qualitative study with a small number of key informants, making the full dataset and interview transcripts available to a wider audience could potentially breach the confidentiality commitment made to the participants during the process of obtaining informed consent as well as to the ethics committees that approved this study. Therefore, this data will not be made available.

POLICY REVIEW

CLIMATE CHANGE AND CARDIOVASCULAR DISEASE ADAPTATION

Chapter 8. Climate change and cardiovascular diseases in the Indian policy context: A Framework synthesis

Health Policy and Planning, **00**, 2024, 1–16
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Review

A review of climate change and cardiovascular diseases in the Indian policy context

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Abstract

There is growing evidence that climate change adversely affects human health. Multiple diseases are sensitive to climate change, including cardiovascular diseases (CVDs), which are also the leading cause of death globally. Countries such as India face a compounded challenge, with a growing burden of CVDs and a high vulnerability to climate change, requiring a co-ordinated, multi-sectoral response. In this framework synthesis, we analysed whether and how CVDs are addressed with respect to climate change in the Indian policy space. We identified 10 relevant national-level policies, which were analysed using the framework method. Our analytical framework consisted of four themes: (1) political commitment; (2) health information systems; (3) capacity building; and (4) cross-sectoral actions. Additionally, we analysed a subset of these policies and 29 state-level climate change and health action plans using content analysis to identify health priorities. Our analyses revealed a political commitment in addressing the health impacts of climate change; however, CVDs were poorly contextualized with most of the efforts focusing on vector-borne and other communicable diseases, despite their recognized burden. Heat-related illnesses and cardiopulmonary diseases were also focused on but failed to encompass the most climate-sensitive aspects. CVDs are insufficiently addressed in the existing surveillance systems, despite being mentioned in several policies and interventions, including emergency preparedness in hospitals and cross-sectoral actions. CVDs are mentioned as a separate section in only a small number of state-level plans, several of which need an impetus to complete and include CVD-specific sections. We also found several climate-health policies for specific diseases, albeit not for CVDs. This study identified important gaps in India's disease-specific climate change response and might aid policymakers in strengthening future versions of these policies and boost research and context-specific interventions on climate change and CVDs.

Keywords: Climate change, cardiovascular diseases, policy analysis, policy, environmental health policy

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8.1. Abstract

There is growing evidence that climate change adversely affects human health. Multiple diseases are sensitive to climate change, including cardiovascular diseases (CVDs), which are also the leading cause of death globally. Countries such as India face a compounded challenge, with a growing burden of CVDs and a high vulnerability to climate change, requiring a co-ordinated, multi-sectoral response. In this framework synthesis, we analysed whether and how CVDs are addressed with respect to climate change in the Indian policy space. We identified 10 relevant national-level policies, which were analysed using the framework method. Our analytical framework consisted of four themes: (1) political commitment; (2) health information systems; (3) capacity building; and (4) cross-sectoral actions. Additionally, we analysed a subset of these policies and 29 state-level climate change and health action plans using content analysis to identify health priorities. Our analyses revealed a political commitment in addressing the health impacts of climate change; however, CVDs were poorly contextualized with most of the efforts focusing on vector-borne and other communicable diseases, despite their recognized burden. Heat-related illnesses and cardiopulmonary diseases were also focused on but failed to encompass the most climate-sensitive aspects. CVDs are insufficiently addressed in the existing surveillance systems, despite being mentioned in several policies and interventions, including emergency preparedness in hospitals and cross-sectoral actions. CVDs are mentioned as a separate section in only a small number of state-level plans, several of which need an impetus to complete and include CVD-specific sections. We also found several climate-health policies for specific diseases, albeit not for CVDs. This study identified important gaps in India’s disease-specific climate change response and might aid policymakers in strengthening future versions of these policies and boost research and context-specific interventions on climate change and CVDs.

8.2. Introduction

The health risks attributed to climate change have been known for decades; yet, climate change has emerged as one of the greatest and most fundamental threats to human health [25]. Acknowledging this threat to human health, several actions are being undertaken at an international and national level to address these risks. Most recently, the 28th annual Conference of Parties (COP28) held the first ever 'health day' with a climate-health Ministerial.

Climate change not only affects the physical environment through an acceleration in the occurrence, intensity and severity of extreme weather events, including extreme heat, storms and floods, but also the socioeconomic environment and health system functioning [12, 187]. Hence, climate change acts as a multiplier of threats, all of which affect health directly or indirectly through complex, interrelated pathways. The latest Intergovernmental Panel on Climate Change (IPCC) report firmly concluded that a wide range of diseases, from vector-borne diseases to non-communicable diseases (NCDs) such as cardiovascular diseases (CVDs) are affected by climate change [25, 187]. An excess of 250,000 deaths per year can be attributed to climate change and this number is projected to increase in the near future [25].

CVDs are a group of diseases affecting the heart and vasculature. Globally, they are the leading cause of death, affecting more than half a billion people and responsible for more than 20 million deaths annually [274, 275]. CVDs are largely considered to be driven by lifestyle risk factors, including unhealthy diets, tobacco use and physical inactivity, along with other underlying determinants, such as socioeconomic factors and genetics [276]. They have also been shown to be climate-sensitive and are affected by environmental risk factors, such as extreme temperature, noise and air pollution [93, 147, 277-279].

The main focus of this article is on climate change. A recent study based on the Global Burden of Diseases estimated that 597,000 deaths and 11 million disability-adjusted life years (DALYs) from CVDs could be attributed to non-optimal temperatures [27]. Another study examined this association across 27 countries and found extreme temperatures to be associated with an increase in CVD mortality [46]. A systematic review on heat and CVD mortality found an association with a 1 °C rise in temperature, with people in tropical climates and in low- and middle-income countries (LMICs) being most vulnerable [47]. However, most of the studies were conducted in Europe and North America, while only few studies focused on LMICs.

CVDs are the leading cause of death in most LMICs [280]. Most countries now have national plans for the control of CVDs, addressing various risk factors such as tobacco or obesity [281]. However, little is known about how many of these consider climate change as a risk factor or the ways to address it from a health perspective. Given the growing threat of climate change and its impact on CVDs, it is imperative to address it through policies [100, 275]. The World Health Organization (WHO), in addition to endorsing 'health in all policies' has also endorsed climate in all policies [282].

The two ways climate change can be addressed is through the mitigation of greenhouse gas emissions or adaptation to reduce the felt impacts [283]. As air pollution also affects CVDs, mitigation has CVD health co-benefits [284, 285]. However, this study focuses only on adaptation aspect. Both the impacts of climate change and the burden of diseases are disproportionately experienced in LMICs [25]. In countries with limited resources and capacity to adapt to extreme temperatures, climate change has the potential to cause a collapse of the health systems, further exacerbating social and health inequalities. It is thus especially important to strengthen the health adaptation response to address the growing and double burden of climate-sensitive diseases, such as CVDs [286].

The mechanism behind the health impacts of climate change and the response pathways to address them can be disease-specific. For example, diseases affected by flooding, such as water-borne diseases, require a different plan of action for their prevention and control than do diseases affected by extreme temperature, such as CVDs. It is therefore important to consider adaptation plans by disease groups along with general adaptation to climate change.

India is highly vulnerable to climate change, given its extensive coastline, vast geographical differences, climate zones and health and social inequities. There is limited research on climate change and CVDs, specifically in India, with most studies considering all-cause mortality. The few studies on this topic all presented a strong association between climate change and CVDs in India, which will likely increase in the future [68, 70, 287]. CVDs are already the leading cause of death in India, and unless the key risk factors are addressed, the double burden of CVDs and climate change is likely going to increase in the future [288]. The climate variations and societal diversity within the country also make it particularly challenging to estimate a national average fraction of CVDs attributable to climate change, as there are several factors which determine how people will be affected [5].

A successful adaptation response needs to be informed by scientific evidence and supported by a strong policy response. India, considering the health impacts of climate change, already has several plans that address climate change and health. Additionally, taking into account the geographical climatic variability and social diversity within the country, state-level action plans on climate change and health have also been under development, with disease specific guidance available for their development. However, to our knowledge, little is known about how CVDs are incorporated in these plans, as a climate-sensitive disease with the highest disease burden.

The main aim of this study was to better understand how CVDs are contextualized from a climate change perspective in the Indian policy space at both national and state level. Particular emphasis was placed on the National Action Plan on Climate Change and Health (NAPCCHH), which was released in 2018 in addition to the existing National Action Plan on Climate Change (NAPCC) in an attempt to address the health related aspects of climate change. Additionally, we examined a range of relevant policy documents to assess the presence or absence of a climate change and/or health and CVD elements. Finally, we scrutinized the State Action Plans on Climate Change and Health (SAPCCHH) to find out whether states have developed regional plans and whether these consider CVDs as an important public health issue.

8.3. Methods

We carried out a framework synthesis using the systematic review method as shown in [289, 290]. The main focus was on policies broadly pertaining to climate change and health, climate change adaptation, NCDs, CVDs and related determinants. Of note, in the context of this study, the term 'policy' is defined as a collection of national-level plans, guidelines, briefs, white papers and other documents released by the government of India and its affiliated institutes.

8.3.1. Data sources and search strategy

This study has included two levels of policies, namely the national and the state level. The search strategy for both levels was conducted differently, based on the stated objectives for each level.

For national level policies, the search was initiated with the NAPCC and the NAPCCHH and two other purposively selected documents, namely the National Environmental Policy (2006), hereon referred to as the environmental policy, and the National Health Policy (2017), hereon referred to as the health policy. The selection of these documents was based on the prior knowledge of the first author, supported by other relevant literature.

Other policies were searched on various repositories, such as the WHO NCD document repository; the United Nations Framework Convention on Climate Change document repository; the websites and archives of the Ministry of Health and Family Welfare (MoHFW), the National Centre for Disease Control, the National Disaster Management Authority and the Ministry of Environment, Forests and Climate Change (MoEF&CC). As this was not a literature search, we used search terms and keywords such as "CVDs", "NCDs", "environment", "climate change", "climate action", "adaptation" and "climate change and health", along with "policy", "guidelines", "action plan" and "brief" to identify polies related to CVDs and climate change. We included additional policies based on data gaps identified in our framework, which were not adequately represented, such as vulnerability assessments. We identified two vulnerability assessments based on references in the included policies conducted in India and included them in the analysis.

For the state level, the NCDC, affiliated to the MoHFW, maintains a directory to track developments on the SAPCCHHs, as a part of India's National Programme on Climate Change and Human Health. The SAPCCHHs considered in this analysis were accessed only from this directory to allow for consistency and authenticity of the material. All policies underwent a precursory reading for familiarization by the first author.

Only documents available in the public domain on the Government of India websites that were published between 1995 and July 2020 in English were included. We excluded documents that were not directly related to climate change and health, climate change and heat or air pollution or CVDs.

8.3.2. Data analysis

We used a qualitative study design to analyse the policies, which were split into two groups, each with a different analytical methodology. Policies in group 1 were analysed in depth using the framework method, as described by Gale *et al,* 2013. [291]while policies in group 2 were analysed using manifest content analysis by Krippendorff, 2018 [292].

Group 1: The framework method by Gale and colleagues was used to analyse the first group of documents to allow focussing on and analysing CVD specific data and contextualize it within the broad scope of the documents [199]. We modified the WHO Operational Framework for Building Climate Resilient Health-Systems to suit our research scope and improve coding strategies [4]. Our framework for the action and adaptation plans consists of four main themes and 11 sub-themes, as shown in Figure 21.

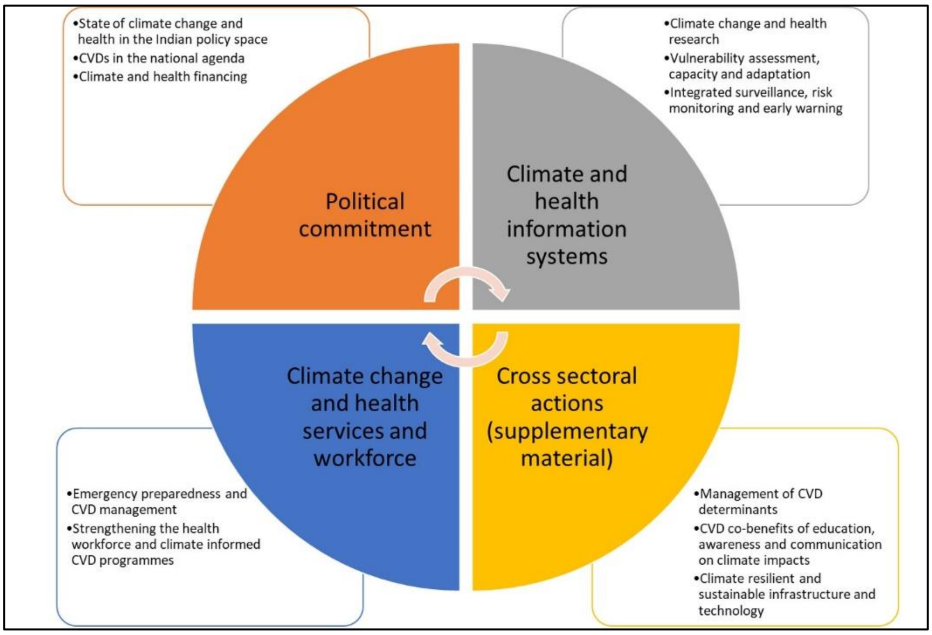

Figure 21: *Analytical framework used to contextualize India's response to climate change impacts on CVDs. Framework modified from the World Health Organization's Operational Framework for Building Climate Resilient Health-systems [4].*

Briefly, four themes were covered, namely (i) political commitment; (ii) health information systems; (iii) capacity strengthening; and (iv) cross-sectoral actions (presented in the supplementary material).

After familiarization with the selected documents through in-depth study, the documents were coded deductively based on the pre-defined framework. Additionally, as this research focused on CVDs, we also followed inductive coding to allow for the emergence of new themes. The codes were grouped into categories and mapped into the framework matrix, which was applied to all documents. Additionally, we charted relevant sections, referred to as quotes, into a spreadsheet to facilitate interpretation of the data between and within documents and themes.

The vulnerability assessments were similarly analysed by applying the six steps outlined in the vulnerability and adaptation assessment, produced by WHO, to two research relevant themes [293]. The themes, guided by the research interests, were (i) CVDs in the vulnerability assessments; and (ii) other health outcomes in the vulnerability assessments. The documents were coded deductively based on categories determined by the six steps and mapped within the two themes.

Group 2: The manifest content analysis, based on the descriptions by [292] was employed to analyse the second group of policies . This consisted of the SAPCCHH, non-action and adaptation plan policy documents related to health, CVDs, climate change and the environment. We also included relevant documents pertaining to cross-sectoral determinants of health that we identified through references in the main documents selected. Briefly, we wanted to identify (i) the mentions of “climate change and health” as an integral topic or climate change as an environmental risk factor for CVDs in the various documents; and (ii) the frequency of mentions of CVDs in the SAPCCHH compared to other health outcomes. This was in order to contextualize how CVDs were considered in these documents when compared to other health outcomes.

We used the lexical search function of MaxQDA software version 2018.1 (VERBI Software, Berlin, Germany)) to identify words and climate-sensitive outcomes, such as “health”, “cardiovascular”, “climate change”, “temperature”, “heat”, “cold”, “vector-borne diseases”, “water-borne diseases”, “malnutrition”, “mental health”, “hypertension”, “ischemic heart disease” and “extreme weather”. The mentions were then tabulated to reflect which documents covered those topics. We did not include CVD or NCD specific policies for this analysis, as there would have been a bias in terms of the mentions of CVDs, thereby skewing the results.

All analyses were done using MaxQDA software and the additional framework with relevant quotes was charted using Microsoft Excel 2016. The framework and list of policies is presented in the supplementary document. The main policy selection and analysis was done by the first author. We did not conduct a risk of bias assessment as all the documents included were national or regional policies.

8.4. Results

A total of 69 policies were assessed for eligibility, out of which 34 policies were excluded mostly for not being related to the topic, being clinical or medical guidelines. Our final sample consisted of 10 policies shown in Table 8 and 29 SAPCCHHs (Supplementary material Table S13) and the environmental policy and health policy, as shown in Figure 22. The results are presented in two parts, with the first part presenting the findings of the thematic analysis and the second part presenting the findings of the content analysis.

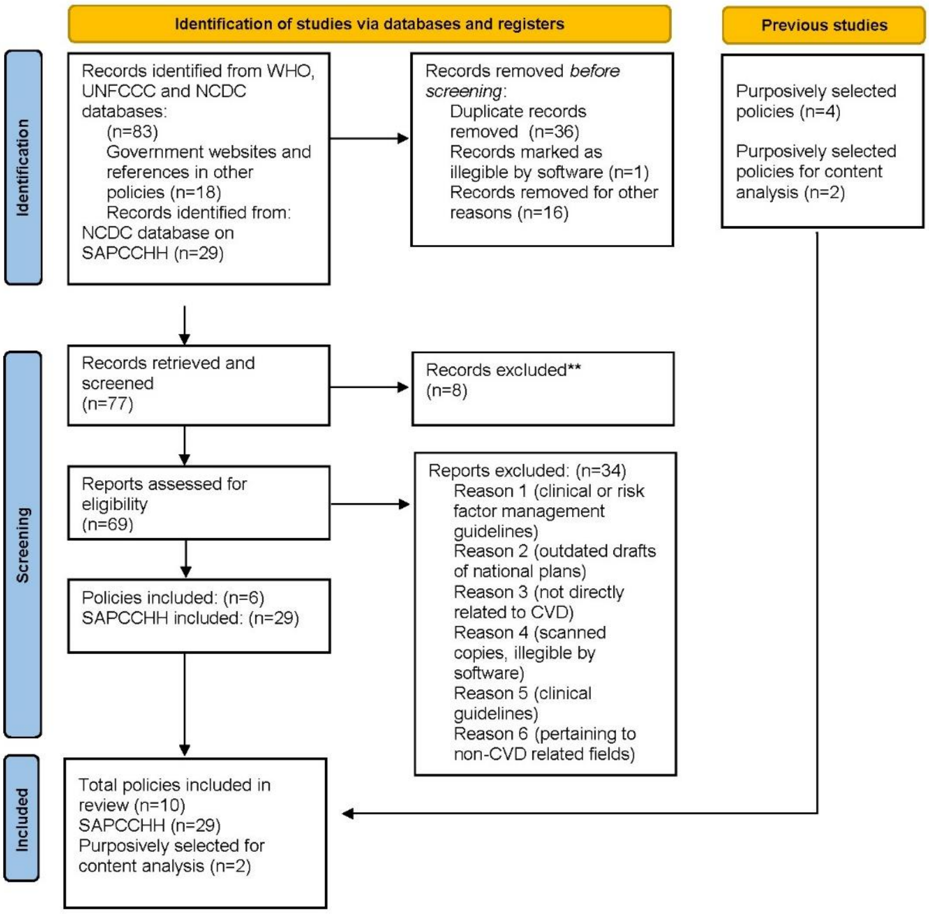

Figure 22: *PRISMA flow diagram detailing the selection process*

Table 8: *Characteristics of policies included and analysed.*

No.	Name	Abbreviation	Year	Type	Sector	Source/Department
1	National action plan on climate change [294]	NAPCC	2008	Climate change action plan	Climate change, environment	Prime Minister's Council on Climate Change, Ministry of Environment, Forest and Climate Change

2	National action plan for climate change and human health [201]	NAPCCHH	2018	Climate change adaptation plan	Climate change, health	Ministry of Health and Family Welfare
3	Health adaptation plan for cardiopulmonary diseases [295]	NAPCPD		Guidelines for development of SAPCCHH	Climate change, health	Ministry of Health and Family Welfare
4	National action plan on heat-related illnesses [296]	NAPHRI	2021	Action plan	Health	Ministry of Health and Family Welfare
5	National health adaptation plan for climate change related disasters [297]	NHAPCCRD	2019	Climate change adaptation plan	Disaster management, health	National Institute of Disaster Management
6	National action plan for diseases due to air pollution [298]	NAPDAP	2021	Action plan	Health	Ministry of Health and Family Welfare
7	National multisectoral action plan for prevention and control of NCDs [299]	NMAPNCD	2017	Action plan	Health	Ministry of Health and Family Welfare
8	National action plan and monitoring framework for prevention and control of NCDs in India [300]	NAPMFNCD	2015	Action plan	Health	Ministry of Health and Family Welfare
9	Climate vulnerability assessment for adaptation planning in India using a common framework [301]	CVAAPICF	2020	Vulnerability assessment	Climate change, vulnerability	Ministry of Environment, Forest and Climate Change and Swiss Agency for Development and Cooperation

10	Heath vulnerability assessment in context of climate change [302]	HVA	-	Vulnerability assessment	Climate change, vulnerability	Ministry of Health and Family Welfare

Part 1: Thematic analysis

Briefly, in this section, we discuss the findings from the thematic analysis pertaining to the political commitment to address climate change and CVDs, the health information system and capacity building activities related to climate change and CVDs. All findings have been placed in the context of climate change and health.

8.4.1. Political commitment

8.4.1.1. State of climate change and health in the Indian policy space

While the NAPCC did not contain a health specific section, health was mentioned as a co-benefit of the proposed activities under the missions, such as the energy efficiency mission and as part of the research plan under the strategic knowledge on climate change mission. This included research on health impacts of climate change, taking into account increased vulnerability amongst women, elderly and children. It also proposed provisions to enhance public health care services and climate sensitive disease burden assessment to model health impacts. However, this was not further defined and, aside from the general *"health co-benefits"* of other climate actions, there were some mentions of *"vector-borne diseases"* and "*water-borne diseases".* The development of a separate action plan for climate change and health, namely the NAPCCHH, further showcases the political will of the Government of India to address the health impacts of climate change. Part of the plan includes coordination with other missions under the NAPCC in a multi-pronged approach. The most predominant climate sensitive diseases have been grouped as extreme heat and heat-related illnesses, air pollution and health-related issues, vector-borne diseases, water-borne diseases, malnutrition and various NCDs. Disease groups listed as being directly climate sensitive include those affected by heat stress, droughts, storms and flood, ozone, air pollution and ultraviolet radiation. Indirectly climate-sensitive disease groups include air-borne and cardiorespiratory diseases, vector-borne diseases, water-borne diseases and food-borne diseases and malnutrition.

The NAPCCHH is the most relevant national document regarding climate change and health. While the NAPCCHH mentioned studies that emphasis how the rise in temperature relates to enhanced morbidity due to CVDs, respiratory and kidney diseases, no Indian-specific references were cited. One of the 5 main objectives of the NAPCCHH is *"strengthening the health preparedness and response through situation analyses at the national, state, district and sub-district level, including early warning systems (EWS) and monitoring and evaluation efforts"*, which led to the development of the SAPCCHHs.

To facilitate their development, there are also national level, disease specific adaptation plan guidelines, such as the health adaptation plan for cardio-pulmonary diseases (NAPCPD), aimed to serve as a guiding document for the development of the SAPCCHH. Other disease-specific plans in the series include vector-borne diseases, water-borne diseases, nutrition-related illnesses, mental health illnesses and zoonotic diseases. None of these plans or guidelines have a CVD specific section. In addition, on a regional level, the identification of the state nodal officer for climate change within the State Health Departments was encouraged, along with constituting the 'State Environment Health Cell'.

Other objectives of the NAPCCHH were listed as: (i) awareness building among the community, health-care providers and policy makers; (ii) strengthening the capacity of the healthcare system to reduce the burden of climate-sensitive diseases, including through capacity strengthening for vulnerability assessments; (iii) developing partnerships with other national missions to ensure the representation of health in the national climate agenda; and (iv) strengthening the research capacity to fill evidence gaps on climate change and health, which can be used to inform healthcare service improvement.

8.4.1.2. Cardiovascular diseases in the national agenda

In accordance with the WHO global monitoring framework for the prevention and control of NCDs, India has several programmes dedicated to NCDs, such as CVDs. In general, NCDs and CVDs are deemed a matter of urgency, with a commitment to act on them reiterated in 2011 during the joint Government of India and WHO "Call for Action on NCDs". Acknowledging the burden of NCDs both globally and nationally, India merged the National Cancer Control Programme and the National Programme for Prevention and Control of Diabetes, Cardiovascular Diseases and Stroke under a single umbrella of the National Programme for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases and Stroke (NPCDCS) in 2010. The programme was expected to be expanded to cover all districts of India during the 12th 5-year plan (2012-2017). We found two action plans dedicated to NCDs, namely the NAPMFNICD and the NMAPNCD with the goal to "*promote healthy choices, reduce preventable mortality, avoidable disability and premature mortality due to NCDs in India"* (NMAPNCD). However, neither the NMAPNCD nor the NAPMFNCD include or mention "temperature" or "climate change" as an environmental risk factor for CVDs. The four main strategic areas identified in the action plans are: (i) integrated and multi-sectoral co-ordination mechanisms; (ii) health promotion; (iii) health system strengthening; and (iv) surveillance, monitoring, evaluation and research.

One of the features of the NAPCCHH is ensuring the representation of health in India's climate change agenda through developing joint, inter-departmental action plans in view of their capabilities and synergies as well as adopting integrating and implementing environmentally friendly measures in other climate change missions (NAPCCHH). This can be used to develop feedback mechanisms of health trends to other relevant ministries, especially those related to climate change, thus "*enabling health statistics to leapfrog"* (NAPCCHH) and leveraging policies in other sectors to promote physical activity and healthy lifestyle (NMAPNCD and NAPMFNCD). While none of these contain direct actions to reduce the burden attributed to climate change, the policy actions mentioned in these plans can contribute to improving the cardiovascular health of the population. The findings pertaining to these policies have been presented in the Supplementary material along with climate resilient healthcare policies.

We found two policies related to climate change and CVDs, namely the NAPHRI and the NAPCPD, the latter being a guide for the SAPCCHH. Additionally, the NAPDAP was identified to cover a considerable portion of CVDs. CVDs are considered in the list of heat-sensitive diseases with specific mention of cardiopulmonary diseases and CVDs in the context of increase in ozone and air pollution, leading to the commissioning and launch of the NAPHRI and NAPCPD, respectively, which are explored in further detail below.

8.4.1.3. Climate and health financing

While we did not find mentions of resource allocation specifically for climate change and CVDs, we identified two policies alluding to the need to ensure funding for various programmes related to climate change and health (NHAPCCRD and NAPHRI). We also identified three policies that included references to climate action financing (NAPCPD, NAPCCHH and NAPCC). The NAPCPD has a specific climate health financing domain in its template for state-level situation analysis and stipulates the designation of climate change and health focal points, with specific programmes of action and budget allocated annually. The NAPCCHH proposes that the state earmarks a budget for climate change and health annually after the establishment of the Environment Health Cell within the Health Departments. One of the principles of the NAPCC is *"welcoming international cooperation for research, development, sharing and transfer of technologies enabled by additional funding".* Within the national mission on strategic knowledge on climate change also proposes the creation of a climate science research fund to support research activities related to climate change and its impacts.

Two policies also contained references to the need to increase budget allocation for NCDs. The NAPCCHH's 'stakeholder's intervention' recommends providing adequate and sustained resources for NCDs through increased domestic budget allocation, innovative finance mechanisms and external donors. The NAPMFNCD states the need to increase the budget allocated to NCD programmes and the need to leverage related programmes and policies to ensure financial protection for those with NCDs.

8.4.2. Health information systems: Data and evidence

8.4.2.1. Climate change and health research

We identified four action plans which cover climate change and health research (NHACCRD, NAPCPC, NAPCCHH and NAPCC), although none of them were specific to CVDs. The NAPDAP and MMAPNCD include the identified needs to improve research capacity. The NHACCRD acknowledges that community-level impacts of climate change are being poorly quantified and understood due to limitations in current health impact prediction modelling techniques from different data sources. There is also an identified need to develop research capacity to better understand how air pollution affects health outcomes and how a mechanism can be identified to fill the gap in evidence-based health policy (NHACCRD, NAPCPD, NAPCCHH and NAPDAP).

Training for relevant personnel to develop technical skills in risk assessment, epidemiology, climate modelling (main focus of the NAPCC) and related research (NAPCCHH and NAPCC), need for pilot-testing new approaches for health resilience, surveys and studies focusing on vulnerabilities in the context of climate change and health resilience (NAPCCHH and NAPCC) were features of some of the plans. We identified needs to create a database of professional researchers and institutions engaged in climate change and health, which would include a data repository platform for various research in the field as well as implementing electronic medical records to facilitate the sharing of health data and linking of individual patients across the health system (NAPCCHH and NMAPNCD). The NMAPNCD outlines the need to implement electronic medical records sharing among healthcare providers and the need to link individual patient data across the national health system, which can both be used to further climate change and health and CVD research.

The NAPCC also identified centres of excellence, where research is conducted to support policy implementation. The national mission on strategic knowledge envisages broad efforts, including research in key domains of climate science through climate modelling to improve the quality and specificity of climate projections, strengthening observatories, data gathering and assimilation to enhance the access and availability of data, creating essential research infrastructure (e.g. high computational capacity) to enable scientists to share data resources. It also mentions various databases relevant for climate impacts research, which are the responsibility of the respective sectoral agency, which includes the Department of Health Research that is responsible for compiling health data. It also proposes the concept of 'registered users' who will have easier access to climate-related data held by the respective ministries and calls on ministries and their agencies to improve digitization of data, maintenance of quality databases in addition to streamlining the process to access these.

Other relevant findings include using data on climate impacts on health to inform public health decisions, prioritizing actions and identifying research needs (NAPCPD, NAPCC and NAPCCHH), research on health impacts of climate change (NHACCRD, NAPCPD and NAPCCHH), access to meteorological and health data that can be linked through an interdisciplinary platform to better understand climate change-associated health outcomes to facilitate informed decision making (NAPCPD NAPCCHH and NHACCRD), research facilitation through multidisciplinary research partnerships, knowledge management networks and roster of local experts (suggested by the National Knowledge Commission and Principle Scientific Advisor) (NAPCPD and NAPCC), research to increase the micro-adaptive capacity, given that local impacts are poorly understood and documented, through evidence informed strategies, interventions and support to policy makers and programme planners (NHACCRD, NAPCCHH and NAPCC).

8.4.2.2. Integrated surveillance, risk monitoring and early warning systems

Seven of the action plans contained a reference to surveillance, risk monitoring and evaluation and EWS in general (NHACCRD, NAPHRI, NAPCPD, NAPCCHH, NAPCC, NMAPNCD and NAPDAP). The NAPCPD and NAPCCHH also outlined the need for regular monitoring of the action plan implementation as vulnerability re-assessment to account for current and projected climate vulnerability and its health impacts.

The Integrated Disease Surveillance Programme (IDSP), launched in 2005, was highlighted in several documents (NHACCRD, NAPHRI and NAPCCHH) as an integrated system, which has boosted disease reporting, surveillance, monitoring and data collection efforts in India in recent years for "*diseases of public health relevance*" focusing mainly on vector-borne diseases. In 2019, this was expanded to include heat related illnesses (HRI) mortalities from March to July from 23 states (NAPHRI). The NAPCC also mentions surveillance programmes with the primary objective of tracking vector-borne diseases. There have also been recent developments in revision of the surveillance formats to capture suspected or confirmed heatstroke-related mortalities, CVD mortalities, and all cause deaths instead of only HRI deaths. However, there is no information on the implementation of these changes (NAPHRI). The NHACCRD also acknowledges challenges in accuracy, timeliness of reporting and completeness of data. There is a critical need mentioned to strengthen existing surveillance systems, including surveillance in healthcare facilities and the IDSP to incorporate climate-sensitive and air pollution-sensitive diseases to facilitate logistic management by health facilities in terms of resource allocation based on requirements (NHACCRD, NAPCCHH and NAPDAP).

There were several mentions of the need for state- and district-level planning and monitoring of climate sensitive diseases, with the purpose of guiding the burden, risk, resource and vulnerability mapping. However, this was mainly in the context of cardiopulmonary diseases and air pollution, thus excluding CVDs and other environmental risk factors like temperature (NAPCPD, NAPCCHH and NAPDAP). The proposal to strengthen the role of district information officers with respect to integrating data from the environment, health and disaster sectors and strengthening monitoring systems to allow collection and analysis of key environmental, health and demographic indicators was outlined in several policies (NHACCRD, NAPCPD and NAPCCHH).

The plan to establish a state- and district-level integrated risk monitoring and early warning mapping along with tracking geographic and seasonal distribution of health risks and outcomes to move towards EWS for weather events, air quality and climate sensitive diseases such as heat stress was outlined in a few policies (NAPCPD, NAPCCHH and NAPDAP). Additionally, the NAPCC includes the plan to implement an EWS for imminent disasters to facilitate planned responses, especially in vulnerability assessments, to minimize the impact of disasters, which can also be extended to include heat and extreme weather event impacts.

Regarding NCDs, the NMAPNCD mentions the need to set up a steering committee for monitoring, evaluation and surveillance, which are integral parts of the planning and implementation of the national NCD response. It also lays out the need for periodic surveys to monitor indicator trends for the prevention and control of NCDs.

8.4.2.3. Vulnerability assessments, capacity and adaptation

A prerequisite to conducting vulnerability assessments was the assessment and availability of baseline rates of climate-sensitive health conditions, monitoring of changing climate conditions and health status (NAPCPD, NAPCC and NMAPNCD), which can also be extended to include CVDs. The NAPCC also mentioned the need for disaster-specific vulnerability assessments as well as sectoral impact assessments at district and state level to inform contingency plans. Similarly, baseline risks of health outcomes and climate conditions were deemed necessary to identify the most vulnerable and high-risk population and conducting health impact assessments or implementing strategies (NAPDPD). The HVA provides a framework for vulnerability assessments that need to be conducted in India. It lists the All India Institute of Medical Sciences as the nodal agency for cardiopulmonary diseases, along with references to heat and cold stress as risk factors for various climate-sensitive diseases. Several CVDs are listed under 'heat wave-related illnesses', including hyperthermia, heat stroke, heat exhaustion, heat syncope, heat cramps and heat rash. Cold conditions include respiratory illnesses, vector-, water- and food-borne diseases, extreme weather and air pollution diseases. It also highlights priority geographical areas that are most sensitive to various climate change-related diseases. Of note, CVDs were not listed as cold-sensitive.

The CVAAPICF included only two health outcome indicators in their sensitivity assessment of biophysical health factors, namely vector- and water-borne disease. It contained no data or references to NCDs or CVDs.

8.4.3. Health system preparedness

8.4.3.1. Emergency preparedness and management of cardiovascular diseases

All the action plans analysed contained sections on emergency preparedness and risk management from a climate change and health perspective, some of which were relevant to CVDs. The NAPCPD in particular recognised the departure of the emergency response, which traditionally was focused on communicable diseases, to now including cardio-pulmonary diseases. The NAPCC discusses the emergency response and preparedness extensively, although not in the context of CVDs.

Specifically to CVDs, there are recommendations for basic equipment and medicines for HRIs and included CVDs be part of the heat preparedness in hospitals and other healthcare centres. These include ice packs in ambulances, dedicated beds for HRI patients and cooling equipment (NAPHRI and NAPMFNCD). We also found mentions of ensuring that personnel is trained to respond to NCDs during emergencies (NAPCPD), inclusion of essential NCD medicines in the national list of essential medicines (NMAPNCD and NAPMFNCD).

Ensuring contingency plans to ensure availability of essential drugs, medication and health personnel, especially during disasters and pandemics to avoid logistical supply chain issues (NHACCRD, NAPCPD, NAPCCHH and MNAPNCD), the need for a communication network that is connected to the regional public health management body and independent of the power supply or grid (NHACCRD and NAPCC), training non-health personnel such as teachers with emergency and first-aid responses in case of extreme events (NAPCCHH and NAPCC), proactive disaster prevention and emergency programmes, which include creating awareness among the community on disaster responses (NAPCC and NAPDAP), recommendation of interventions such as demand forecasting to facilitate inventory management, back-up of cold chain and buffer stock (NAPCCRD and NAPCPD), integrating CPD in emergency management (NAPCPD), training teachers on first aid measures based on regional vulnerability and community medical preparedness, disaster and emergency response training to manage casualties during extreme events (NAPCCHH and NAPCC) were some of the other features pertaining to emergency preparedness that we identified.

8.4.3.2. Strengthening the health workforce and climate informed cardiovascular disease programs

Strengthening the technical and professional capacity of the health-aligned workforce with respect to climate-sensitive diseases was seen as an important component of the action plans and discussed in seven plans (NHACCRD, NAPHRI, NAPCPD, NAPCCHH, NMAPNCD, NAPMFNCD and NAPDAP). Other health capacity strengthening components included training of the workforce for evidence-based decisions, such as using the IDSP to interpret data and take timely actions for prevention and control of climate-sensitive diseases (NHACCRD, NAPCPD, NAPCCHH, NMAPNCD and NAPDAP), sensitizing all levels of the health workforce on health impacts of climate change (NHACCRD, NAPHRI, NMAPNCD and NAPDAP); specialized training of relevant nodal officers (NAPCCRD, NAPCPD, NAPCCHH and NAPDAP), sharing of training, knowledge and research findings among relevant stakeholders (NHACCRD, NAPCCHH and NAPDAP), implementing data sharing resources (NMAPNCD) and developing baseline information on existing human resources, technical and health service delivery capacity, identifying and providing recommendations for addressing gaps to build overall health system capacity (NAPCPD, NAPCCHH and NMAPNCD), communication of baseline NCD profiles to relevant response teams and public health management of diseases based on reported patterns, types, severity as per reports of health facilities (NHACCRD, NAPCPD, NAPCCHH, NMAPNCD and NAPDAP).

Hospital preparedness plans for preparing a baseline framework, implementing, coordinating and evaluating extreme heat response activities in health facilities in states with three seasons, namely pre-heat, heat and post-heat were also discussed. There were also mentions of the need to develop resource prioritization plans based on vulnerability assessments, community assessment with key informant interviews of patients with chronic conditions that focus on burden and access to cardiopulmonary diseases health, and recommendations for strengthening the healthcare system in the context of climate change and building capacity for the vulnerability assessments (NAPHRI, NAPCPD and NAPCCHH). The primary focus in the other action plans was on training and increasing the capacity of the health workforce to recognize and react to climate-sensitive diseases and climate-related health emergencies in general.

For specific NCD control, the NAPCCHH and NMAPNCD recommend national NCD control programmes with a component of healthcare system strengthening specific to NCDs through prevention, screening, early diagnosis and sustained management of people with or at-risk of NCDs to prevent complications, reduce the risk of hospitalization, interventions and premature deaths. Only the NHACCRD, NAPHRI, NMAPNCD, NAPMFNCD and NAPDAP mentioned CVD, CR or related NCD specific competencies, including recognition, management and notification. These included heat strokes (NHACCRD), HRI (NAPHRI), CPD (NAPCPD, NAPCCHH and NAPDAP), NCDs (NAPCPD, NAPCCHH and NMAPNCD) and CVDs (NAPMFNCD, NAPDAP). Other aspects include plans to strengthen capacity among the workforce addressing NCDs through improved management of people at risk or those with NCDs to reduce hospitalizations and risks of premature deaths (NMAPNCD and NAPMFNCD), improving the structural capacity of healthcare systems to implement health promotion guidelines in hospitals (NMAPNCD), using data on tobacco and alcohol consumption to identify pockets of high-risk individuals to target interventions and subsequent sharing of data with the MoHFW (NMAPNCD), and increased efforts in patient education through guidelines and counselling (NMAPNCD and NAPMFNCD).

Part 2: Content analysis

8.4.2. Climate change and/or cardiovascular diseases in other policies

We analysed the frequency at which climate-sensitive health outcomes listed in the NAPCCHH appear in the NAPCC, NAPCCHH, CVAAPICF, HVA, the National Environmental Policy 2006 (Environmental Policy) and the National Health Policy 2017 (Health Policy). Figure 23 shows the frequency of 16 climate-sensitive health outcomes in these policies. Vector- and water-borne diseases were the most frequently mentioned diseases across policies. The vulnerability assessments or the plan for vulnerability assessments notably did not include CVDs. The health policy shows the importance of NCDs in the Indian health agenda, however this is not reflected in the climate change and health agenda, with vector-borne diseases, allergy-related illnesses and zoonotic diseases being most frequently mentioned, followed by malaria. The environmental policy did not contain a detailed environmental health section, and only cardiopulmonary diseases and food related illnesses were mentioned.

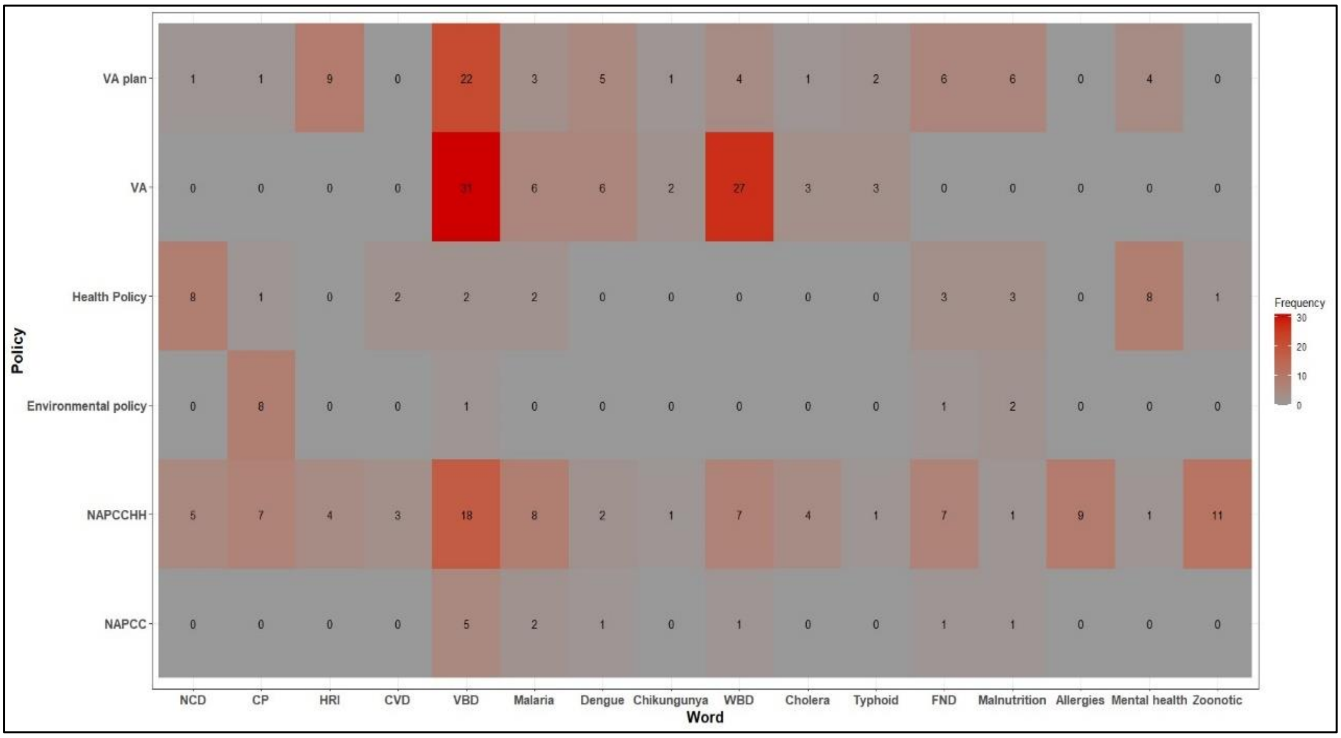

Figure 23: *Content analysis showing the frequency which climate sensitive health outcomes are mentioned in relevant policies.*

As shown in Figure 24, health was only a small section of the environmental policy, with the term "health" being referred to 12 times. On the other hand, when it came to climate change and health-related keywords, of note was the health policy having no mention of the terms "climate change", "temperature", "heat", "cold" or "environment(al)". The environmental policy also did not contain the words "heat" or "cold". While the NAPCCHH contained multiple mentions of several of these key indicators, "cold" was mentioned only five times, whereas "heat" appeared 42 times, showing the prioritization of heat-related health outcomes.

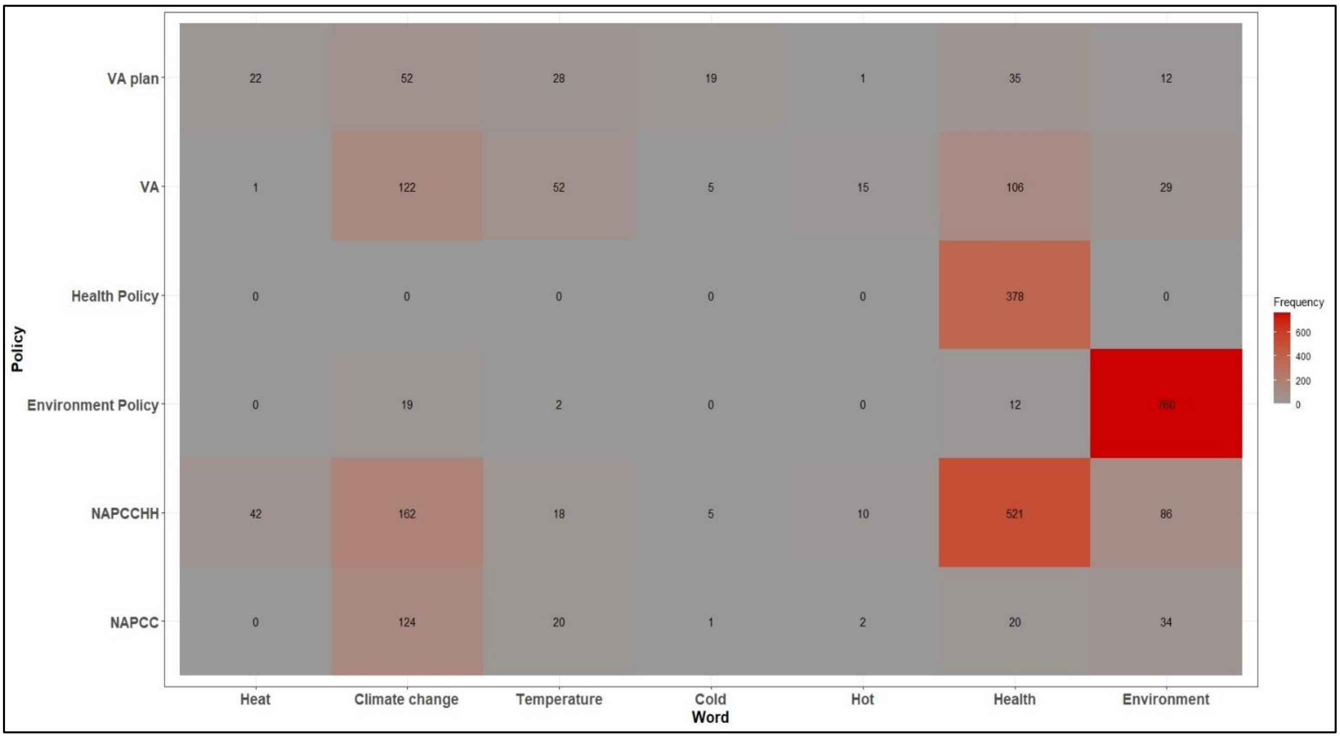

Figure 24: Content analysis showing the frequency of keywords pertaining to climate change and health are mentioned in relevant policies.

8.4.3. State Action Plans on Climate Change and Human Health

Of the 37 territories, comprising of States and Union Territories, that constitute India (Jammu and Kashmir have been split into two divisions, namely Jammu and Kashmir, for the purpose of the SAPCCHH resulting in 37 territories, instead of the formally recognized 36), the SAPCCHH was not available for eight. These are the Andaman and Nicobar Islands, Delhi, Ladakh, Lakshadweep, Maharashtra, Nagaland, Rajasthan and Telangana, as shown in Figure 25A. Only eight territories had a completed version of the SAPCCHH available, namely Arunachal Pradesh, Chandigarh, Chhattisgarh, Jharkhand, Mizoram, Odisha, Puducherry and Uttar Pradesh. For the remaining 21 territories, draft versions in various stages of completion were available. Several of these drafts were templates of the SAPCCHH provided by the Government of India with partial or no state-specific data filled in. These drafts contained sections for adaptation plans specific to air pollution linked diseases, HRIs, vector-borne diseases, water-borne diseases, food-borne diseases, nutrition-related illnesses, allergic diseases, cardiopulmonary diseases, mental health illnesses and zoonotic diseases.

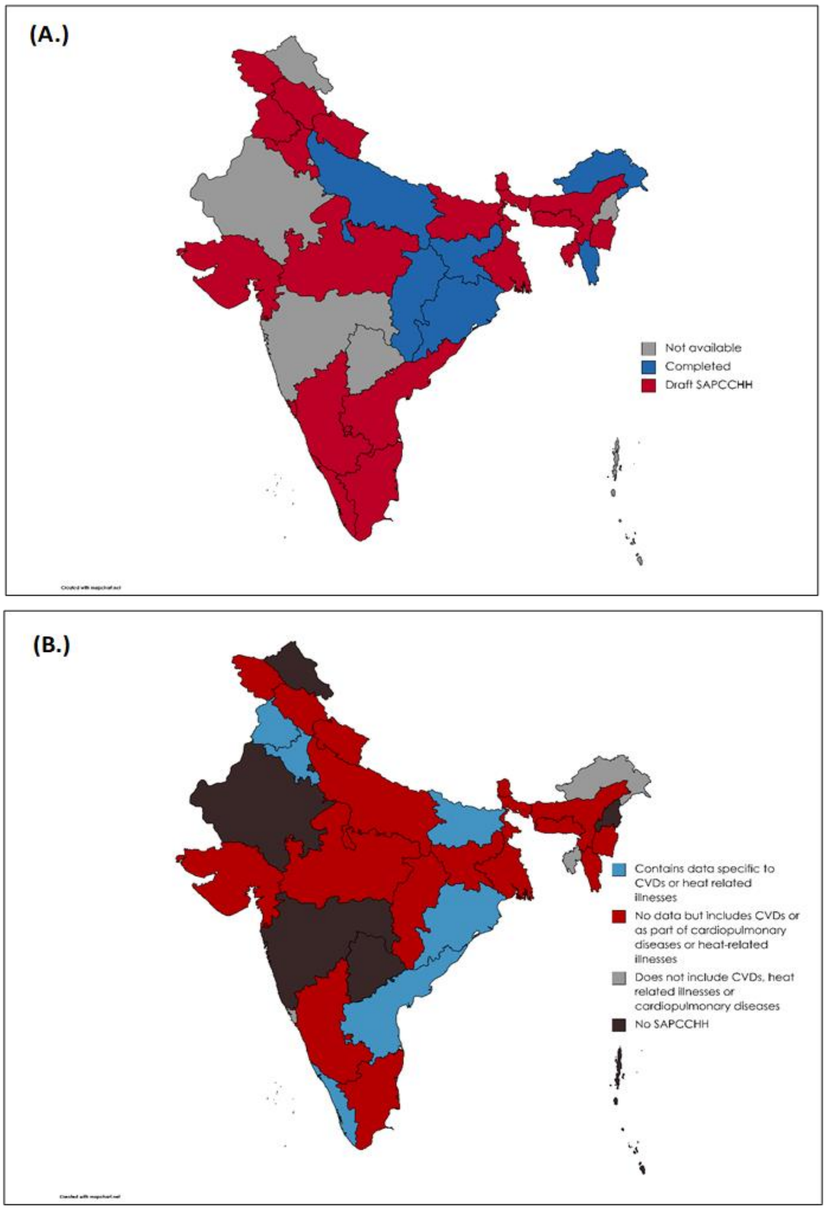

***Figure 25**: **(A.)** Map of India showing that availability and status of the State Action Plans for Climate Change and Human Health. **(B.)** Map depicting the inclusion of CVD specific data in the SAPCCHH along with an overview of the inclusion of CVDs, related HRIs and cardiopulmonary diseases in the plans.*

Twenty action plans contained health surveillance data, although it was not uniform in terms of disease representation, with data for vector-borne diseases and infectious diseases most commonly being presented. For instance, the Chhattisgarh SAPCCHH only contained data pertaining to dengue. Similarly, the time period and resolution of presented data were not comparable across the plans. Most SAPCCHHs had a section specific for cardiopulmonary diseases and HRIs, however most did not contain health outcome or disease surveillance data in the SAPCCHH, with the respective sections unfilled.

CVDs were largely considered as part of HRI or cardiopulmonary diseases due to air pollution. Only seven plans contained explicit CVD-related health outcome surveillance data, albeit not comparable across plans. For instance, Andhra Pradesh, Bihar, Kerala and Odisha contained tables with key HRI statistics, while Haryana and Puducherry only presented data for hypertension and stroke, respectively. Punjab was the only state whose SAPCCHH included key data about multiple CVDs. Chandigarh, while having no data on HRIs or CVDs, listed surveillance of temperature-related illnesses as part of its upcoming work. While the draft SAPCCHH for Karnataka included a mention of CVDs, it was not among its top five priority climate-sensitive diseases. Arunachal Pradesh, Goa and Tripura did not include CVDs, related cardiopulmonary diseases or HRIs as part of their plans. Figure 25B shows the representation of CVDs in the territories. We have highlighted states which have CVD specific data, excluding air pollution and cardiopulmonary disease data.

Not all the territories followed the recommended template. For example, Arunachal Pradesh and Chandigarh, despite having a final version of the plan, did not contain the words “cardiovascular” or “CVD”. Similar observations were made for Gujarat, Goa and Tripura. Apart from Arunachal Pradesh, Goa and Tripura, the rest of these states contained references to cardiopulmonary diseases or HRIs. A detailed table on the status of SAPCCHH and CVDs in presented in Appendix E TableS1.

8.5. Discussion

Our findings show that there is a political impetus to address climate change and health in India on a regional and national level, as shown by the development of the NAPCCHH and the supporting guidelines and SAPCCHHs. CVDs have been identified as climate-sensitive with both heat and cold acknowledged as risk factors. However, further sections on CVDs are currently not included in the NAPCCHH. While there have been several climate sensitive disease specific guidelines developed, including cardiopulmonary diseases, vector-borne diseases and mental health, a CVD specific guideline is absent. Acknowledging the growing burden of CVDs, there have also been several policies pertaining to addressing all the risk factors of CVDs, including environmental. Hence, there is a need to bridge the gap between CVD prevention and control and climate change.

Given that CVDs encompass a broad range of diseases related to the heart and vasculature, there is a need to consider the predominant ones, including strokes and ischemic heart diseases (IHD), in disease specific plans [30, 32, 100]. Indeed, strokes and IHDs are among the leading causes of mortality in India, and have been associated with air pollution and rising temperature [67, 303, 304]. A subset of climate-sensitive CVDs have been included as HRIs or cardiopulmonary diseases in some of the policies analysed. The data reporting and surveillance forms included in the NAPHRI contain comprehensive details, such as current and retrospective weather data. However, these forms are restricted to HRIs, based on the patient fulfilling a series of classical HRI symptoms.

The NAPCPD, a guide for the SAPCCHH section on cardio-pulmonary diseases, includes multiple CVDs as well as air pollution, heat and cold exposure as risk factors. However, we found data or surveillance on the national or state level on this topic to be negligible. Little is known on specific symptoms that patients present in terms of temperature-related CVD deaths, as studies on this topic include de-identified and often aggregated data.

Heat action plans, although not covered in this paper, have been successfully pushed in India with the Ahmedabad heat action plan prompting other states to develop their own [305, 306]. However, there is a need for these plans to be informed by regional evidence. Partially due to under-developed health surveillance systems that do not capture representative data, finding city- or region-specific thresholds for temperatures remains a major challenge in India [307]. Given the regional variations in these thresholds, coupled with mortality attributable to non-optimal temperature, including cold, future heat action plans need to include city-specific information. Evidence informed policies and knowledge was a feature of several policies we analysed and is an area that presents several opportunities, as they have previously been shown to be effective at addressing specific health outcomes [308]. There needs to be collaborative action with multi-level stakeholders in order to address this issue, which begins with understanding and quantifying the risk of CVDs due to climate change in various parts of India [5]. Hence, there is a need to strengthen health surveillance systems to include all climate-sensitive diseases [309].

Despite the established association between climate change and CVDs globally and the high burden of the disease in India, the link remains poorly explored in the Indian context [5, 68, 93]. Leveraging and building upon potential synergies between climate change and NCDs to facilitate more research on the environmental risk factors of CVDs would allow India to benefit from informed priority and agenda setting, interventions and CVD management, as has been previously suggested for LMIC settings [310].

We found several mentions of increased funding to research in the policies. However, this remains focused predominantly on climate change, with health research operating in separate silos. Inter-sectoral and multi-disciplinary research collaborations on environmental health would also contribute to evidence informed policies [311].

Part of the challenges in advancing environmental health both in India and globally include data access and research capacity, as well as compartmentalization between and within sectors [86]. While there are several references to databases on health, climate variables and data sharing among the policies, the research gaps and barriers should be more widely and deeply described or addressed [309]. The IDSP that was recently launched include HRI indicators for the summer months. However, the data are sparse and by not including CVDs, limits information on deaths or incidences attributable to environmental factors, including air pollution [312]. The existing databases can be built upon to broaden their scope, which might support multiple climate-sensitive disease outcomes, including CVDs, and thus galvanize environmental health research. Additionally, previous research suggests that medical professionals perceive a knowledge and training gap when it comes to identifying climate-sensitive diseases, especially CVDs [6, 190, 228]. Given that the surveillance reports are contingent on the training of the local health professionals to classify cases, this has the potential for misclassification, especially in remote rural settings [313]. Thus, collection of CVD data would not only facilitate research on the cases attributable to temperature, but and serve as a guide for the planning and adaptation process, but also CVD management actions for each region depending on the vulnerability, as there are divergent trends observed in CVD epidemiology between regions [303, 314].

Health vulnerability assessments can also be used to complement and guide the environmental health research agenda. At present, we found no health-specific vulnerability assessments based on the guidelines and the climate change VA we analysed, as they only included two health indicators, namely vector- and water-borne diseases. While a health VA has been planned, we could not find the outcome in any of the written documents [315]. The data combined with strengthened research capacity, can be used to develop and inform EWS for environmental risk factors of health, as has already been done in several countries [316-321]. They can be tailored using actual vulnerability and risk profile of the state to support the EWS. At present, the EWS related to CVDs remain restricted to HRIs and air pollution [307, 313]. Broader EWS specific to CVDs can also be a component of improving healthcare system resilience, part of the NAPCCHH. This should include actions such as hospital preparedness during non-optimal temperatures or drop in the air quality index rating.

There is a push for emergency preparedness in hospitals, but it needs to be followed up with compliance evaluations and progress reports combined with further training of healthcare professionals on awareness of climate change impacts on CVDs. This would also improve specific disease surveillance through healthcare centres. CVDs attributable to environmental risk factors can largely be preventable with the appropriate public health response [275, 322]. Part of this response includes the training and awareness among key staff, such as the healthcare workforce, on CVDs and climate change. There is limited research done on the topic globally, but the studies conducted thus far highlight that there is a perceived gap in knowledge among healthcare professionals on this topic [228, 252]. As they are an important source of health communication, there is an urgent need to train them to recognise climate attributable diseases and their monitoring and surveillance [222, 228, 229].

Policies on matters such as using the media to spread awareness can be extended in scope to include awareness on CVDs and other climate-sensitive diseases, risk factors, symptoms and preventative measures. This could also serve to foster improved acceptance and community action on policies and interventions such as green spaces in urban areas, green energy, climate friendly and sustainable architecture [261, 322-324].

Overall, vector- and water-borne diseases appear to be considered to have the highest priority in the climate change and health policies in India, as is also the case in many contexts around the world [325, 326]. This has been suggested to be a result of focusing on conventional health outcomes, which are easier to monitor [87]. While the burden of vector-borne and water-borne diseases might be more relevant, especially for the lower socioeconomic and rural segment of the population, this same population also has a disproportionate and a nationally growing CVD burden [327, 328]. Surprisingly, the environment policy did not contain any reference to human health, while the health policy did not contain any reference to environmental risk factors.

While most states have submitted the SAPCCHH, there remain incomparable and large gaps in the level of completion between states, with some plans being templates with no health profile data. Hence, there is a need to strengthen the SAPCCHH, monitor and evaluate their progress in order to have uniform, complete plans for each state. Given the paucity of health data, especially CVD data, our findings also support the need to develop or strengthen the regional health surveillance systems and strengthen regional research capacity. This is particularly salient in light of the prevailing health inequities in India, with the lower socioeconomic groups being more vulnerable to CVDs and climate change disproportionately impacting rural areas and women, all of which needs to be considered in health adaptation [273, 329, 330].

This study has some limitations. First, we focus predominantly on CVDs, and climate change and health related policies. Thus, we exclude how policies that are related to CVDs and climate change, such as in the agriculture, nutrition and energy sector could potentially address this issue. Second, as content analysis is part of the methodology, we cannot account for superfluous words or technical errors in counting mentions of various terms. Nonetheless, the content analysis provided a useful overview of the priority for several policies with reference to climate change and health. Third, the policy selection and analysis was primarily done by the first author, which might have introduced a selection bias. Efforts were made to meet the inclusion and exclusion criteria. Fourth, we did not examine SAPCCHHs in detail, nor compare health inequalities between and within vastly diverse states, since this was beyond the scope of our piece. Finally, the protocol for this review was not registered as it is not a systematic review of effectiveness and some of the methods were developed post-hoc.

8.6. Conclusion

Despite the high CVD burden and acknowledgement of the disease group as being climate-sensitive, the Indian climate change-health plans currently underrepresent CVDs, as compared to other disease groups. We identified several ways on how this situation could be improved. There is an urgent need to invest in, and strengthen the, disease surveillance data as well as research capacity to deepen the understanding of the climate change-CVD nexus. There is also a need to improve monitoring and updating of the SAPCCHHs, including an impetus for their completion by all states, which would also contribute to improving the health systems surveillance and the development of contextual EWS. Future amendments of the health and environment policy need to include environmental risk factors and health impacts, respectively. The NAPCCHH and SAPCCHHs would benefit from the inclusion sections on CVD specific impacts of climate change, readily informed by national and regional studies. An appropriate, evidence-informed response to the double burden of CVDs and climate change faced by India would contribute to drastically reducing the climate attributable CVDs.

8.7. Declarations

Competing interests

The authors declare that they have no competing interests.

Author contributions

S.S, M.R, M.A.D, J.U and G.C conceptualized and planned the study. S.S acquired and analysed the data to the data. R.L provided expert opinions and critical reviews. S.S wrote the main manuscript with inputs from all authors. The final manuscript has been revised by all authors.

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DISCUSSION AND CONCLUSION

Chapter 9. Discussion

9.1. General discussion

The overarching aim of this thesis was to contribute to the understanding of how climate change, particularly temperature, affects CVDs in India and South Africa. While there is a growing body of research focusing on climate change impacts on health, there still remains a tremendous gap in the knowledge on this topic, especially in LMICs. Disease or cause-specific studies on the topic, such as NCDs like CVDs, are few and far between. Another understudied area is the perception of local stakeholders on how climate change affects health as well as the policy response to it in various countries. Despite the growing impetus on this topic, there remains scope for a disease-specific framework integrating health and impacts of climate change allowing for a comprehensive understanding of the issue.

Given the sheer burden of diseases that can be attributed to climate change around the world, global efforts to protect community health from climate impacts through preventative and adaptive measures need to be strengthened. There is an urgent need for transformative action to reduce the exposure and vulnerability to environmental risk factors and strengthen the health system response to climate attributable diseases, at both national and sub-national (e.g., state or provincial) levels. These can be in the form of research, interventions and effective public health and environmental policies, the sphere in which there is still limited research from both India and South Africa, particularly at provincial or state level.

The research that constitutes this thesis contributes to furthering the understanding of how temperature affects CVDs in Puducherry and the Limpopo province in India and South Africa respectively. It also contributes to the understanding of how stakeholders involved in the climate change and health issue, such as doctors and environmental policy makers, perceive the topic as well as research barriers they encounter. Finally, it also analyses how climate change and CVDs are viewed, both nationally and regionally, in the Indian policy space.

By employing a multi-methods approach to address the research question, this thesis is able to present a comprehensive understanding of how CVDs are impacted by climate change in India and as well as a quantitative understanding in Limpopo. While they cannot be compared, the two study sites are good-fit illustrations of specific challenges faced by cities or regions most vulnerable to climate change impacts. As a coastal area, Puducherry is more prone to climate impacts like floods, cyclones and disrupted rainfall patterns. Limpopo, on the other hand, is a country-side rural area with limited access to healthcare in the most remote areas. It is also more prone to heatwaves and droughts, all of which are known to affect CVDs.

This chapter discusses all the major findings, presents a critical appraisal of the methodology used, the implications of the findings for India and South Africa followed by the public health relevance and research outlook.

9.2. Critical reflections on methodological approaches and key findings

This thesis can broadly be divided by methodology into quantitative and qualitative and the systematic policy analysis. In this section, the findings and methodological approaches are critically examined. For the sake of clarity, chapters 4 and 8 follow a quantitative approach, chapters 5 and 6 follow purely qualitative methods and chapter 7 is a qualitative systematic policy review.

9.2.1. Quantitative studies: assessing attributable risks

There are two studies presented in this thesis that quantified the attributable risk from T_{app} to CVDs in Puducherry, India (Chapter 4) and Limpopo, South Africa (Chapter 5).

Analytical approach

The analytical approach was guided largely by the data we had, its quality, data resolution and time period, which is why slightly different approaches were used for India and South Africa. For Puducherry, we had access to daily de-identified individual level data on CVD mortalities in hospital between 2011 and 2020. Other patient characteristics included age, sex, duration of hospitalization, type of CVD (cause of mortality), date of admission and mortality, as discussed in Chapter 4. This allowed us to perform individual level risk modelling and stratified analyses by age-and-sex as well as type of CVD. On the other hand, for Limpopo we used daily counts of CVD hospital admission between 2009 and 2016. Although we had individual level data, due to missingness in data which could not be imputed, we were unable to model individual level associations or stratify the dataset by age or sex.

In both studies, the exposure we considered was apparent temperature, which also accounts for other variables such as humidity, wind speed, vapour pressure along with temperature. T_{app} is also referred to as the 'felt' or 'perceived temperature'. The advantage of using this metric as opposed to only temperature is that meteorological variables such as humidity and pressure, which also influence the physiological response, are accounted for. Thus, T_{app} considers a holistic exposure which incorporates multiple potential variables, which determine the temperature actually felt by the body [108].

For both studies, we used a dlnm (details in the respective chapters) to model the lagged and non-linear response of the cardiovascular system to temperature exposure. In recent times, there have been significant advances in modelling techniques which take into consideration that the health impacts of environmental exposure are not always straightforward. One of these is the dlnm, a sophisticated modelling framework which allows for flexibility in accounting for effects that vary in both the space and time dimension. It thus has the power to capture the non-linear exposure-outcome association and the time lag between exposure and outcome simultaneously [331]. This model is also evolving, with newer framework being developed for specific cases in environmental epidemiology which can be used in future studies should the health data structure be suitable. For Puducherry, since we had individual data, we employed the case-cross over model following a binomial likelihood in combination with the dlnm. In doing so, we were able to account for within and between individual differences since each case was self-matched with controls occurring on the same day of the week within the same month. Thus, we were also able to control for day of the week effect and seasonality by design. On the other hand, since we had daily count data for Limpopo, we modelled the association with the dlnm combined with a negative binomial model. Factors like day of the week and seasonality were controlled for separately within the model.

Findings

Our study found that both hot and cold non-optimal T_{app} are associated with an increase in the risk of in-hospital CVD mortality in Puducherry. The T_{app} range in Puducherry is between 23 to 40° C and the optimal T_{app} is between 30 to 36°C with temperature above and below this considered hot and cold respectively. Between 2011 and 2020, 17% of CVD mortalities could be attributed to non-optimal T_{app}. Heat and cold had similar burdens, 9.1 and 8.3% respectively. We observed remarkable differences between the sexes, with males being more vulnerable to cold temperature, while females below 60 years of age were vulnerable to all non-optimal temperature and females over 60 years of age were affected predominantly by heat. Patients were more likely to be at risk from CVAs during high temps, while IHDs were not found to be particularly sensitive to non-optimal T_{app}.

On the other hand, the T_{app} range for Limpopo 6-32 degrees with the optimal T_{app} range being 25 to 27° C. 8.5% of CVD hospital admissions were attributable to heat and 1.1% to cold. The heat effect was found to be short lived and immediate, whereas the lag structure for the cold effect was inconsistent.

Both these studies were exploratory analyses, and the first to examine the impact of T_{app} on CVDs in the respective regions. As discussed in the respective chapters, the results are mostly in line with global findings. Although the outcomes differed, our findings further allude to the local temperature range playing a major role in determining the optimal temperature for various diseases for the local population. They also stand as a testament to the importance of regional adaptive capacity amongst the population and the importance of considering sex-specific interventions and actions.

Although not comparable, we found that both CVD mortalities and morbidities are sensitive to temperature. The lag structure for the association was interesting in both cases. In Puducherry, contrary to the patterns in other similar studies, cold had an immediate and bi-level response. The first peak occurred immediately and was short lived, followed by a sustained cold effect 8 days after exposure. Exposure to heat did not have an immediate effect, rather it was a sustained effect occurring after 5 days of exposure. As discussed in Chapter 4, other studies have found an immediate and short lived heat effect and a lagged, sustained cold effect. In Limpopo, heat was associated with more CVD hospitalizations than cold. The lag structure for cold was inconsistent and we were unable to draw conclusions from it, whereas heat effects appeared immediately and were short lived. Possible explanations, including socio-cultural components, have been discussed in the respective chapters. It would make an interesting case to study whether the hot and cold attributable fractions show similar trends for mortality in Limpopo and morbidity in Puducherry.

Limitations

One of the limitations of our studies is that air pollution is not accounted for, largely due to unavailability of data at the desired resolution. Both chapters discuss these limitations in further detail. The outcome was in-hospital CVD mortalities and CVD hospital admissions in Puducherry and Limpopo respectively.

It is important to note that modelling temperature-CVD or climate change-health outcome associations are challenging to quantify with 100% certainty given the numerous factors influencing how an individual reacts to environmental exposure. Additionally, the reactions of individuals to environmental exposures is the product of both internal and external determinants. As such, CVDs are a complicated disease that develops over a lifetime and it is impossible to claim with certainty which trigger is responsible for hospitalization or mortality. As done in these studies, however, it is possible to estimate the fraction of CVD outcomes that can be attributed to temperature in a selected population. The results presented here should therefore be interpreted with caution and taken as estimated trends, rather than precise quantifications.

9.2.2. Qualitative studies: perceptions and barriers

Chapters 5 and 6 contain the findings from two related qualitative studies conducted in Puducherry on the perceptions and research barriers related to climate change and health amongst key stakeholders.

Analytical framework

Given that this was the first study of its kind to our knowledge, we developed our analytical framework based on the conceptual framework for climate change risk perception by van Eck *et al* [197] and the conceptual framework for health inequalities proposed by Rudolph *et al* [198]. Our framework consists of three themes, namely systems knowledge, socio-cultural dynamics and public engagement and institutional determinants, spread out over two chapters to encompass the broad and rich data we collected. In Chapter 7, we applied the framework to understanding institutional barriers faced in conducting climate change and health research, thus showing another application of our framework.

The process behind developing the analytical framework, including the sub-themes and categories has been explained in Chapter 6 and 7. The framework was discussed and agreed upon by all the authors, based on which the interviewing author carried out verbatim transcription and coding in MaxQDA. The initial code-book was validated by another member of the team before being finalized and applied to all interviews. The final themes and categories presented were also agreed upon by all co-authors.

We used a combination of purposive sampling and snowball sampling to identify the key stakeholders we interviewed in Puducherry. The participant selection was initiated with prior knowledge of the local collaborator working with the Government of Puducherry as the State Surveillance Officer. Further participants were added through referrals from interviewed participants based on their knowledge. We wanted to focus on participant working in or adjacent to fields related to health, especially CVDs, climate change and policy making. Thus, our sample consisted of medical doctors or academics, and environmentalists working on Puducherry's State Action Plan for Climate Change.

Both studies are conducted among the same sample using key informant interviews. Further information on the semi-structured questionnaire used in the interviews and methodology are presented in the relevant chapters. The aim was to explore the perceptions of these stakeholders about climate change and health and any research barriers they face on this topic. The motivation behind these studies was to gauge the knowledge, education and awareness on the topic as well as research priorities and difficulties in conducting environmental health research in light of the paucity of studies on this topic from the region. Additionally, we wanted to identify potential areas or gaps in the current knowledge that could be targeted with future interventions. Both these chapters address climate change broadly, rather than stick to temperature as in the quantitative studies. This is partly to ensure the aim is not too narrow and something participants would be able to discuss in detail as we were not aware of the level of understanding on the issue amongst the stakeholders.

By using semi-structured key informant interviews to collect the data, we were able address individual perceptions, observations and recommendations in a non-constrained manner. The questionnaire we finalized was ever-evolving based on the information provided by the participants, thus not restraining the information provided to a pre-determined list of questions and allowing individuals to freely express their thoughts, even when not part of the questionnaire. The data was analysed for both studies using a data-driven inductive and deductive thematic analysis. This further allowed us to tease out information relevant to our aim, while ensuring flexibility to incorporate additional themes.

Findings

In Puducherry, amongst medical professionals, environmentalists and policy makers, there was a perceived gap in technical education about climate change and health, despite awareness of the same. The perceived health risks from climate change were largely a product of individual knowledge of the local public health burden and vulnerabilities, with some level of scepticism on whether NCDs like CVDs are affected by climate change. There was an expressed need for multi-level awareness and intervention programs which would be inclusive and targeted to different societal levels, with some stakeholder recommendations to fill the gaps. These findings can be used in context to strengthen the regional response to climate change adaptation.

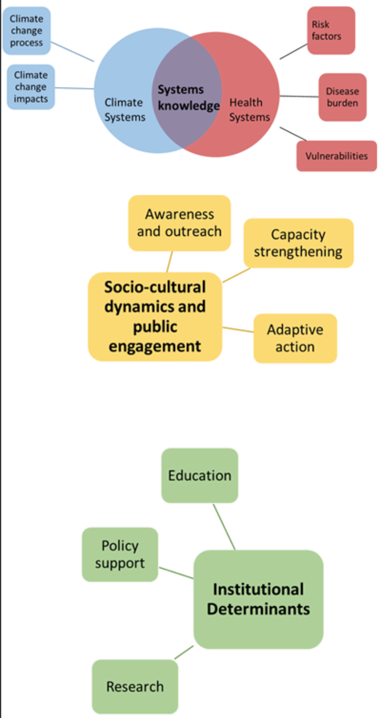
Amongst the same study population as above, barriers in conducting research on climate change and health were explored. Need to improve the data collection system, challenges in accessing data and strengthening technical and methodological research capacity were considered the major barriers. Participants described working against the backdrop of climate impacts on health not having a high political and research priority as well as a limited resources being allocated to the topic. Participants also described a tendency for environmental health research to centre on conventional health outcomes, as opposed to NCDs like CVDs. These findings could contribute to filling the research barriers, leading to an enhanced understanding of climate change and health in India and future interventions informed by this knowledge.

Although the studies were conducted in Puducherry, the findings shed light on the overall situation in the Indian context. The rich data we obtained can also provide potential insight into points of intervention to strengthen awareness, education and knowledge on climate change and health (Chapter 6) and improving research capacity and prioritization of environmental health in the research agenda in other similar LMIC settings, depending on the contextual needs (Chapter 7).

Limitations

The ongoing COVID-19 restrictions were one of the challenges faced in terms of the sample size. Despite having a relatively small sample size, our aim was specific to a select group of individuals which we covered in our studies. The number of respondents was not a determining factor of the quality of data, but rather the depth, richness and research relevance of the data determines the quality and rigour of the findings [332]. The sampling method we used further allowed us to restrict the interviewees to those with relevant backgrounds respective to our aim. Sampling was ongoing until no new information was emerging from interviews, showing data saturation.

The Figure 26 below summarizes the findings of both chapters fit into the complete framework.



Systems knowledge	• Climate change is an acute and growing problem for India • Climate change ultimately affects health through domino effects • Knowledge of the public health burden and vulnerabilities influenced perceived health risks from climate change • Indirect health impacts of climate change experiences • Scepticism about climate change affecting CVDs
Socio-cultural dynamics and public engagement	• Perceived credibility and societal role of information communicator are important for uptake and public awareness • Need for alternate solutions and incentivized, targeted programs on all societal levels • Integrating climate change impacts in schools, universities and continuing education curricula • Seasonal workplace guidelines
Institutional determinants: knowledge and perceptions	• Limited knowledge and awareness on climate change and health related policies
Political and institutional barriers	• Disengaged leadership and low political prioritization of climate change and health • Weak inter-departmental integration and co-ordination for climate change and health
Educational and informational barriers	• Gaps in climate change and health in higher education curricula • Weakness in inter-sectoral information dissemination • Scepticism and low awareness on non-conventional health impacts of climate change
Technical barriers and research	• Insufficient resources and workforce dedicated to research • Underdeveloped transdisciplinary research capacity • Research slowed by unavailablity and limited access to quality data

Figure 26: *A summary of findings on the perceptions and climate change and health research barriers amongst key stakeholders in Puducherry using the Health adaptation in response to climate change based on knowledge, perceived risks and barriers to action: A Research Framework shown in [6] and [7].*

9.2.3. Systematic framework synthesis and policy review

In Chapter 8, we present a systematic framework synthesis and policy review of how climate change and CVDs are addressed in the Indian policy context.

Taking into account regional diversity in the health impacts of climate change, India has also launched the development of State-level action plans on climate change and health. These were also included in the analysis to provide a comprehensive understanding of the prioritization, interventions and actions for addressing CVDs in the context of climate change.

Methodological approaches
This chapter also incorporates climate change broadly and includes other related elements, including air pollution, which are considered important in the context of health in India. Given the spectrum of information, the findings of this chapter were divided into two parts based on the methodological approach used.

The policies were identified and extracted using a systematic method from websites of relevant governmental departments, with further details provided in Chapter 8. Overall, 12 national level and 29 State-level policies were included in the analysis. The analytical process followed a combination methodological approach, employing both thematic and content analysis. The thematic analysis followed a similar methodology as the qualitative studies, with both inductive and deductive coding, done by a single member of the team and agreed upon by all members of the team. The analytical framework was based of the WHO conceptual framework for health, which we modified to make it specific to our aim and CVDs. The State level plans were analysed using a manifest content analysis using the lexical search function of MaxQDA. All the policies were searched for mentions of words related to CVDs (the entire list is provided in the methods section of Chapter 8) and their frequency tabulated to analyse whether CVDs are included in the policies. We similarly used content analysis to analyse select national level policies in two ways: (1.) To analyse the mention of climate change and CVD related words in the policies; and (2.) To analyse the frequency at which different climate sensitive diseases listed in India's national action plan on climate change and health are listed in the policies. We only performed content analysis on six of the national policies, as the remaining four were specific to NCDs or CVDs, which would have resulted in findings biased towards CVDs.

Findings
Based on our findings, there is a need to better contextualize CVDs in the context of climate change. Thus far, most of the efforts in tackling climate sensitive diseases remain centred on vector borne illnesses and heat related illnesses, the latter of which does not fully encompass all climate sensitive CVDs. Strengthening health surveillance systems to capture CVDs could also contribute to improving research output on the topic from India and strengthen contextual adaptation planning. The political commitment to addressing the health impacts of climate change as well as CVD management could be used in tandem to facilitate interventions and actions on climate change and CVDs. As many of the State level plans were found to be incomplete or simply templates, there is an urgent need to focus on ensuring the development or completion of these plans.

Limitations
While the study considered how and to what extent CVDs are incorporated in climate action plans, further empirical research is needed to understand the on-ground situation and compliance with the planned action set out in these policies, potentially through more qualitative studies involving members of the public, policy makers and NGOs working on the topic, amongst other actors.

9.3. Reflections and implications for India and South Africa

Through the studies conducted in this thesis, we can show that climate change can be associated with an increased risk of CVD mortality in Puducherry and although there are effort on the part of the Indian government to address these impacts, CVDs are inadequately addressed as climate-sensitive diseases.

One of the major challenges I faced during this thesis, which also limited the scope of the work, was the COVID-19 pandemic, which was declared a few months into the start of this project. Along with immense challenges in collecting health data from overburdened health systems from both countries, travel restrictions meant I had to regrettably forego conducting qualitative studies in South Africa. As a result, I cannot comment on stakeholder perceptions of climate change and health in Limpopo, which to the best of my knowledge, has not been studied yet.

As mentioned, one of the major drawbacks encountered during the analysis in both countries was obtaining health data. The need to improve regional disease surveillance, at least for CVDs, is an urgent need in both countries, perhaps by adding onto existing health surveillance programs. In South Africa, while these systems are well developed, their servicing and data capturing in remote and rural areas could be strengthened. In India, as seen in Chapter 8, also has an integrated disease surveillance system, but little is known about the regions, levels of healthcare centres, quality and accessibility of the diseases actually tracked. At present, CVDs, as classified by the ICD-10, are not captured as per the IDSP website.

Improved surveillance systems, not only for CVDs but for all climate sensitive diseases, is one of the first steps to ensuring research and evidence based understanding how climate change is and will affect health in different regions and populations. It is also essential to move towards evidence informed action planning and implementation of interventions such as disease-specific early warning systems, education and awareness campaigns. Early warning systems have previously been successful in other contexts for air pollution, heat and infectious diseases [333-335]. We did not find evidence of a year-round system based on temperature and CVDs developed till date, which is another area that could be a potential research focus. Given the discrepancies and incompleteness we found in State level climate change and health action plans, there is a need for periodic monitoring and evaluation of these plans and their implementation, both of which would also benefit from improved disease surveillance.

Most of India's efforts to tackle the health impacts of temperature focus extensively on heat, with little efforts dedicated to cold. As seen in chapter 4, cold non-optimal temperature contribute to a sizable amount of the in hospital CVD mortalities even in regions that are inherently hot. This further shows that even in India, it is not only heat which could drive up the CVD burden, but non-optimal temperatures in general and there is an urgent need for assessing optimal temperature ranges for various diseases at sub-regional levels and plan interventions informed by the findings. Stakeholder engagement is unknown in adaptation matters, although it is mentioned in the adaptation plans, and would benefit from further research.

Finally, we found that not only was the limited awareness about climate change and CVDs amongst the key stakeholders we interviewed, but there were many reported challenges they faced when conducting research on climate change and health in general. Backed by a pillar of strong institutional support, these barriers need to be addressed to improve research capacity and evidence synthesis.

9.4 Insights for global health

By taking a step back from the focus on CVDs, it is worth acknowledging that responding to and managing the health impacts of climate change remains one of the most daunting public health challenges of our time. Although in this thesis I have focused extensively on CVDs, it is a small piece of a very large puzzle of health impacts of climate change, which have been touched upon in Chapters 5 and 6. With the emergence of new evidence, adaptation needs to gradually be transformed into sustainable and adaptive management practices, including the establishment of robust climate resilient healthcare systems [4].

The IPCC in its latest report found an adaptation deficit across the globe, contributing to avoidable adverse health impacts [25]. Given the sheer range of causal pathways through which health is affected, a lateral, multi-sectoral systems based approach is of the essence to protect population health. The unequal distribution of impacts globally also contributes to global health inequality, with the most vulnerable being affected the most. Transformative action to reduce the exposure, risk, vulnerability and strengthen the health systems response requires a lateral public health approach [83]. Lateral public health considers hazard, exposure and vulnerability as components of risk as a while, thereby accounting for contextual needs in the long term. This is opposed to the traditional vertical public health approach, which focuses on a single-health outcome while operating within the confines of governmental operations. At its heart, lateral public health aims to develop the resilience capacity of the community for reducing the risks from climate change by involving multiple stakeholders. This includes transcending traditional public health silos to using a transdisciplinary approach which involves community engagement, including NGOs, academia and civil society, in the decision making process [336]. Both climate action and health are part of the 17 sustainable development goals (SDGs). Implementing each of these goals requires coordination and collaboration across different sectors. By acting on both climate change and health simultaneously, the actualization of several other related SDGs can be integrated into the common goal.

9.5. The way ahead

The field of climate change and health is an upcoming and ever-evolving one, with new insights and findings regularly improving our understanding of the various ways human health will be impacted in the face of a changing climate. Globally, climate change is a risk factor compounding the existing disease burden. Alongside mitigation efforts taken at a global and national level, it is also urgent to boost the work being done on the adaptation front. Even with fast-tracked and tremendous reduction in GHG emissions, the damage already done will continue to affect health, and for that matter life on Earth, for generations to come. The health co-benefits of robust mitigation policies, such as air pollution and CVDs, also needs to be further elaborated to bridge the gap between adaptation and mitigation.

Over the years, there have been several advances in work on climate change and health, including the drafting of climate change and health action plans by several countries. Global initiatives such as the IPCC reports and the Lancet Countdown on Climate Change and Health have provided additional credibility to the issue.

The vulnerability a population group is to climate change is governed by many interrelated drivers and determinants and depends on the region, micro and macro climatic factors, which has been discussed in chapters 4 and 5. It also varies across and within communities, with socio-economic factors, occupation, health systems, household and community characteristics contributing to individual vulnerability. Thus, future studies can also be conducted among sub-populations, such as those living in dense urban conglomerates or different occupational and socio-economic groups, to further understand the contextual impacts and needs of different groups.

The contemporary narrative and research remains focused on heat related mortalities for the most part. While temperatures and heatwaves are projected to increase in the near future due to climate change, there is a need to shift the focus to regional non-optimal temperatures. In fact, globally more mortalities, both from CVDs and all-causes, are attributed to cold rather than heat. Broadly speaking, there are two possibilities of temperature change patterns due to climate change: (1) a rapid and dramatic increase in temperature, the frequency and intensity of heat waves; and (2) a scenario where temperatures would increase gradually [25]. In the former case, there would also be a need to understand how rapid temperature variations affect CVDs. In the latter scenario, the regional temperature ranges would shift over time, with both minimum and maximum temperatures increasing, which would also allow the population to get acclimatized. As per the 6th IPCC report, there is a high confidence that heat-related CVD mortality due to climate change is projected to increase by the end of the 21st century [25]. Thus, there is a need for increased resources and interventions focusing on protecting cardiovascular health from non-optimal temperature. This includes cross-cutting domains such as occupational stress, loss of livelihoods, mental health and air pollution. What is considered as ‘hot’ currently might be the new normal in the future.

Given the complexity and region-specificity, synthesis of knowledge quantifying the impacts of climate change on various diseases is perhaps the most crucial steps that need to be taken to inform contextual adaptive policy intervention measures. Understanding challenges in conducting climate change and health research is also important to fill critical research gaps that exist around the world. Secondly, there is also a need to encourage medical professionals and other relevant stakeholders such as environmentalists to spread awareness and promote environmental health. Medical professionals in particular have the capacity to play a key role in informing the population in ways to protect cardiovascular health from environmental risk factors [228, 337].

When it comes to future research directions, it is my belief that there is a need to build on this thesis in both India and South Africa, as well as potentially conducting similar studies in other regions with a high climate change vulnerability and poorly understood health impacts. Future research can start with regional studies exploring the association between various meteorological parameters and diverse climate sensitive disease outcomes. The findings can then be used to draft or strengthen adaptive actions. Additionally, continuous stakeholder involvement, through informant interviews or focus group discussions, could lend support to improving these actions based on the on-ground needs and gaps. In terms of policies, through future studies similar to the one we conducted in Chapter 8, other climate sensitive diseases can be assessed through a climate policy framework. Other dimensions such as the role of other sectors and crucial determinants of climate sensitivity and resilience need to be examined in greater detail to improve the policy response to climate related CVD and health threats in general.

Chapter 10. Conclusion and recommendations

10.1 Conclusions

The climate change emergency is also a global public health emergency, with vulnerable regions being disproportionately affected. The work done in this thesis examines a wide breadth of the impacts of climate change on CVDs in India and South Africa. This work contributes to the understanding of how non-optimal temperature affects CVD mortality and morbidity. It also sheds a light on the research barriers and selected stakeholders' perspectives on climate change and health along with examining the policy response to climate change and CVDs.

In India, the evidence synthesized shows for the first time the short term association between non-optimal temperature and CVD mortality in Puducherry. Interestingly, despite it being an inherently hot region, cold, relative to the optimal temperature range, has an almost equal fraction of CVD mortalities associated with it as does heat. Additionally, it highlights the role of sex and age in driving individual vulnerability to temperature. Similarly, in South Africa, the findings show both cold and hot temperature, relative to the optimal temperature, are associated with an increased risk of CVD hospitalization. In fact, we found a higher attributable fraction for cold than heat. The findings from both regions point towards the need to address temperature impacts on CVDs at large.

While India has taken strides in recent years to address the health impacts of climate change, CVDs are not adequately represented in the plans. The predominant focus related to CVDs is on heat related illnesses and heat strokes, which fails to account for a sizable portion of the heterogeneous disease group to which CVDs belong. There is a crucial need for further studies on the impacts if climate change on CVDs in both countries and understanding and addressing research barriers would contribute to facilitating such studies. Finally, in light of the limited awareness and knowledge amongst medical professionals, environmentalists and ministerial officials on climate change and CVDs, it is important to conduct a national level situation assessment in order to understand gaps and develop interventions targeted to improving awareness on this topic.

As both India and South Africa continue to grapple with the health impacts of climate change, it is important to improve the respective adaptive capacity, including preparedness to absorb the impacts of climate change while simultaneously protecting population health. With respect to CVDs, adaptation measures need to be transdisciplinary, tackling the issue at large with both short-term and long-term strategies, alongside mitigation efforts. Here, I propose some recommendations for adapting to the CVD impacts of climate change.

10.2 Recommendations

While heat is a topic of growing urgency in the near future, at present, interventions and actions need to focus on all non-optimal temperature, as relatively cold temperature is also associated with CVDs. In the short-term, first and foremost, city or state level associations between temperature and CVDs needs to be modelled to estimate the burden of CVDs attributable to temperature, which can be used as a reference point with which to design city or region specific adaptation strategies. Secondly, this information needs to be disseminated amongst the population to increase awareness on protective measures. Care must be taken to account for sex and age differences and other vulnerability factors, which influence protective measures. These measures can include things such as temperature appropriate clothing, air conditioning and ventilation, sun protection and adequate hydration. Third, research capacity and funding for environmental health research needs to be improved, which will be facilitated by improved health surveillance systems and data collection. Fourth, the available data needs to be used to inform city or region level adaptation policies, which include all climate-sensitive diseases, including CVDs. The existing adaptation plans need to be updated to include CVDs. At present, the State level plans first need to be completed and then periodically reviewed and updated. These can include components of hospital preparedness and protocols to handle climate sensitive diseases and workplace and school policies to ensure adequate protection from non-optimal temperature.

In the long run, there is a need to facilitate green and sustainable architecture and transport systems. Traditional architectural forms and construction materials could be used to improve ventilation and sustainability. The ‘greening’ of cities would also contribute to improving air quality and simultaneously cooling down urban areas. In this manner, by using a transdisciplinary approach that cuts across silos, the populations of both countries could prepare to adapt to the changing climate and prevent adverse health effects.

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Appendix A

Chapter 4 Supplementary material

Table S1: *CVD classification code system used in this study. ICD-10 codes (given in brackets) have been adapted to form the categories used in this study. We divided the CVDs into 3 broad categories, namely ischemic heart diseases, cerebrovascular accidents, and other heart diseases, which included 7 sub-categories.*

Category and ICD-10 codes	**Sub-categories and ICD-10 codes**
IX Diseases of the circulatory system	
Ischemic Heart Diseases (I20-I25)	
Cerebrovascular Accidents (I60-I69)	
Other heart diseases	Rheumatic heart diseases (I00-I09)
	Hypertensive heart diseases (I10-I15)
	Cardiopulmonary diseases (I26-I28)
	Other heart diseases (I30-I52)
	Aortopathies (I70-I79)
	Peripheral vascular diseases (I80-I89)
	Congenital heart diseases (I51.8, I52, Q21)

Table S2: *Distribution of climate variables based on population characteristics.*

	Mean	**Minimum**	**1st Quartile**	**Median**	**3rd Quartile**	**Maximum**
Apparent temperature (°C)						
Male	33.25	23.25	30.66	33.82	35.95	40.60
Female	33.43	23.25	30.92	34.01	36.07	40.60
Less than 48	33.32	24.01	30.83	33.86	36.0	40.60
More than 48	33.32	23.25	30.77	33.90	36.09	40.60
Comorbidities	33.42	24.30	30.98	34.0	36.07	40.60
Cerebrovascular accidents	33.37	23.25	30.85	33.95	36.14	40.60
Other CVD types	33.20	24.41	30.60	33.81	35.94	40.60
Ischemic heart disease	33.34	23.25	30.86	33.90	36.10	40.60
Average Temperature (°C)						
Male	28.40	21.25	26.30	28.45	30.45	35.15
Female	28.55	21.25	26.45	28.70	30.65	36.0
Less than 48	28.47	23.05	26.35	28.55	30.55	35.15
More than 48	28.47	21.25	26.30	28.60	30.60	35.10
Comorbidities	28.46	21.25	26.35	28.55	30.55	36.0

Cerebrovascular accidents	28.49	21.25	26.35	28.65	30.60	35.10
Other CVD types	77.04	22.70	26.25	28.45	30.45	36.0
Ischemic heart disease	28.52	21.25	26.35	28.55	30.65	36
Humidity (%)						
Male	77.06	43.0	72.75	77.25	81.75	100.0
Female	76.68	47.25	73.0	77.0	81.50	100.0
Less than 48	76.80	43.0	72.50	77.0	81.50	100.0
More than 48	76.79	47.25	72.50	77.0	81.50	100.0
Comorbidities	76.89	43.0	72.75	77.0	81.50	100.0
Cerebrovascular accidents	76.69	47.75	72.50	77.0	81.50	99.0
Other CVD types	77.04	43.0	73.0	77.12	81.50	100.0
Ischemic heart disease	76.70	43.0	72.50	77.0	81.50	100.0

Sensitivity analysis

All models are compared to the model used in the final analysis. We changed the placement of the exposure-response knots as shown in Figure S1 and S2. Here, model 1 has 2 equally placed knots, model 2 has 3 knots at the 5^{th}, 50^{th} and 95^{th} percentile of the T_{app} model3 has 3 knots at the 25^{th}, 50^{th} and 75^{th} percentile and model 4 has 2 knots on the 5^{th} and 95^{th} percentile. There is no significant difference between models.

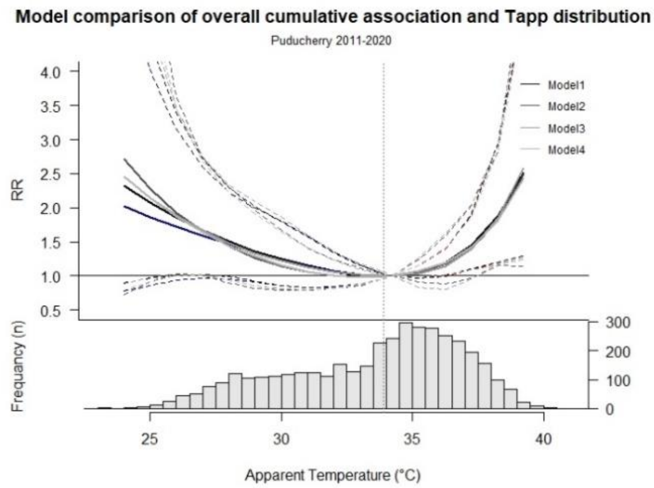

Figure S1: *Comparison of the T_{app}-mortality association in models with varying knot placements. Model 1 has 2 equally placed knots, model2 has 3 knots at the 5^{th}, 50^{th} and 95^{th} percentile of the T_{app} model3 has 3 knots at the 25^{th}, 50^{th} and 75^{th} percentile and model 4 has 2 knots on the 5^{th} and 95^{th} percentile of the T_{app}..*

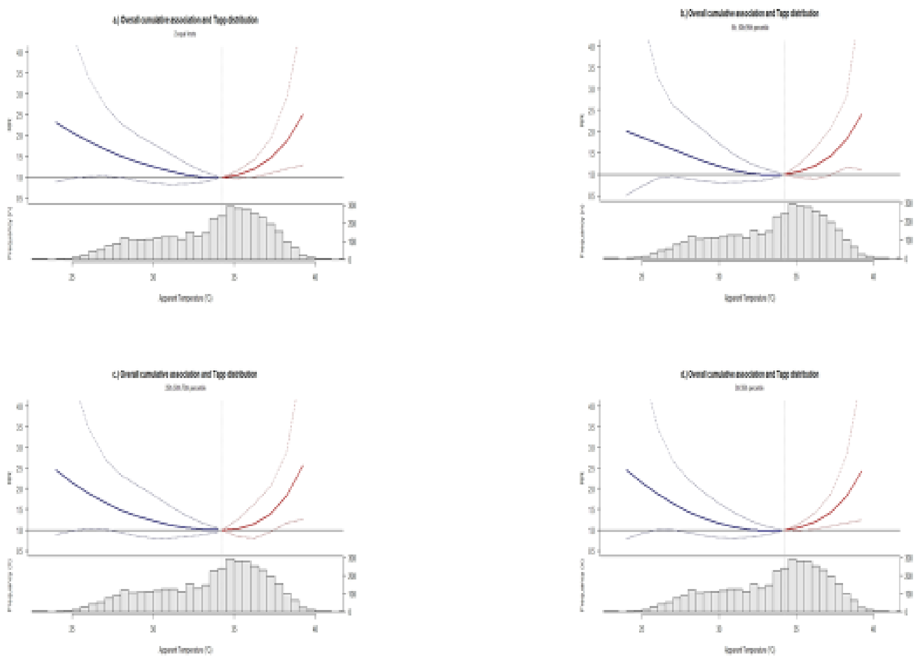

Figure S2: *Individual exposure-response associations for the 4 models depicted in figure S1.*

We repeated the analysis comparing our final model fitted with a negative binomial likelihood to one with a quasi-Poisson likelihood as shown in Figure S3, as is commonly used in many studies. The two models typically produce very similar results, but in the quasi-Poisson the variance is a linear function of the mean, whilst in the negative binomial model it is a quadratic function of the mean, allowing for slightly more flexibility in the specification of the variance. We found the associations to be similar, suggesting that our findings were not sensitive to the choice of likelihood.

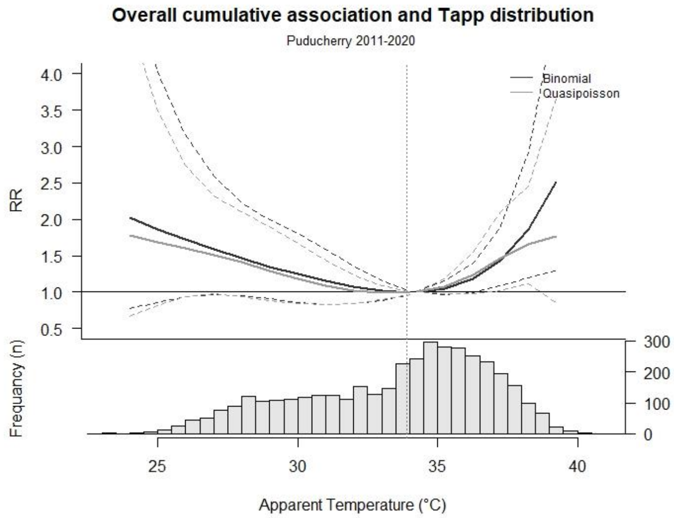

Figure S3: *Comparison of the exposure-response association assuming either a Quasi-poisson or conditional logistic regression with binomial likelihood, such as the one we used*

We repeated the analysis using data from only 2016-2020, which had data across the entire hospital. As seen in Figure S4, there does not appear to be a significant difference between the associations.

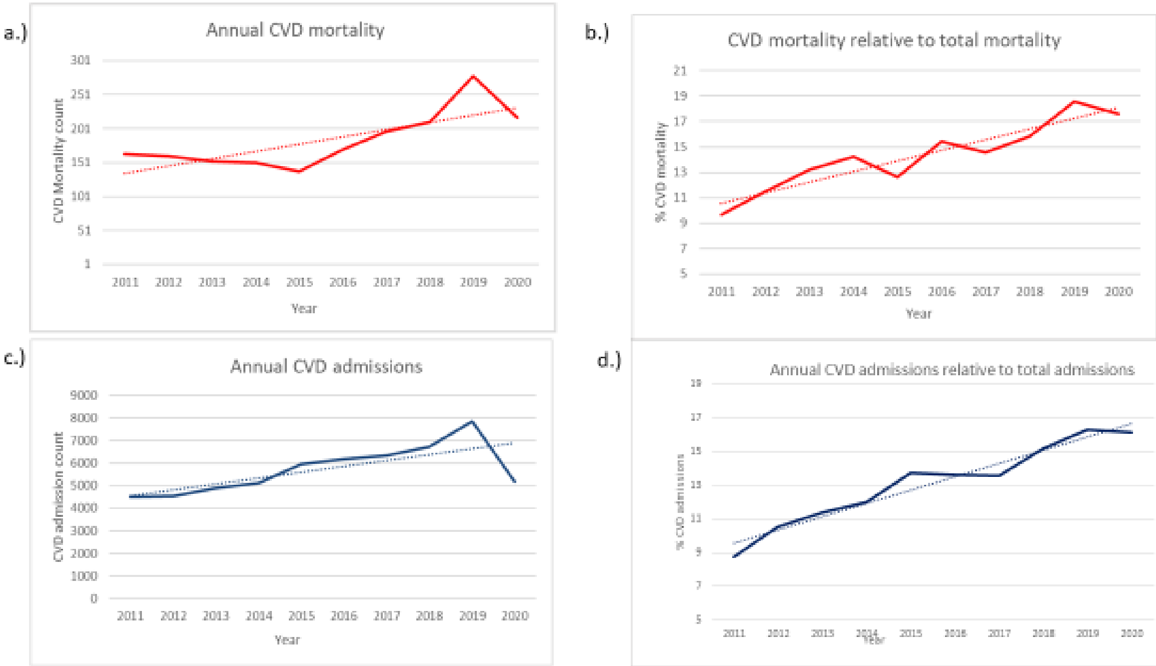

Figure S4: *Comparison of the exposure-response association using the complete 10 year data set with cases only from the cardiology department for 2011-2015 and from both the cardiology department and all other departments for 2016-2020 vs using only 5 year data with cases from all the departments from 2016-2020.*

Figure S5 shows the annual trends in the monthly hospital admission and mortality from CVDs. A.) shows the annul CVD mortality while b.) shows the CVD mortality relative to the total mortality. C.) shows the annual CVD admissions while d.) shows the annual CVD

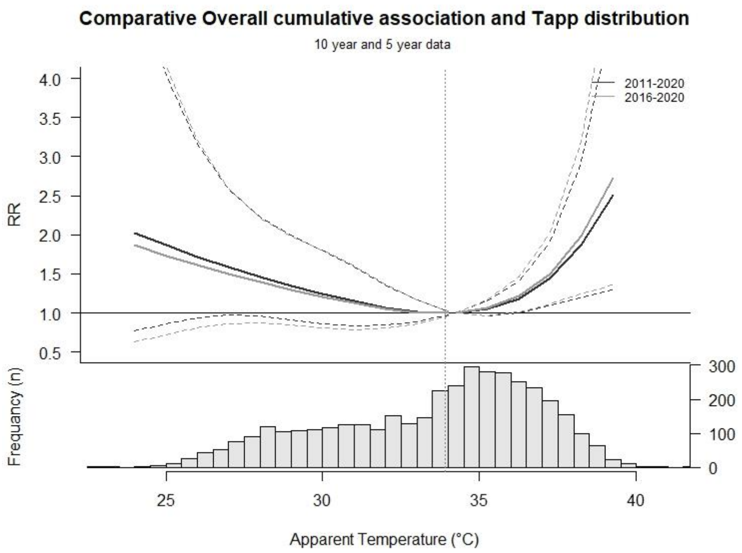

Figure S5: *Annual trends in CVD admissions and mortality*

admissions relative to the total admissions. As can be seen, there is an increase in both the hospital admissions and mortalities from CVDs over the past 10 years.

Figure S6 shows the 3-D plot of the lagged association between T_{app} and CVD mortality in Puducherry. The temperature-CVD mortality association shows a non-linear pattern. The 3-D view of this relationship shows that the risks of in-hospital CVD mortality attributed to temperature has a temporal distribution.

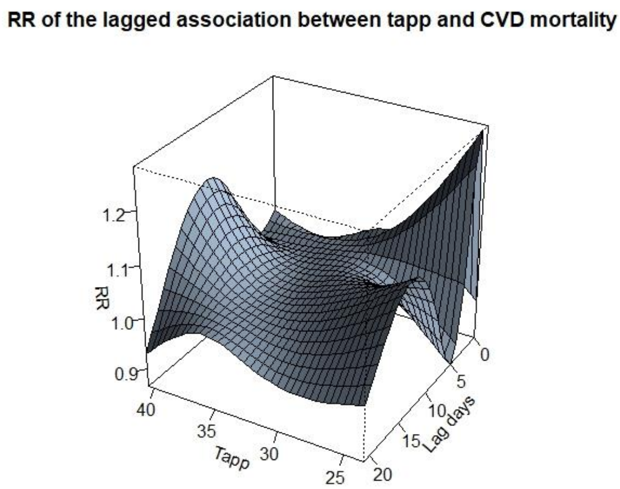

Figure S6: *3D- model depicting the RR for the lagged exposure-response association.*

We see that cold temperature has an almost immediate response or increase in RR while hot temperatures show a delayed association by about 5 days. The cold effect peaks at day 1 before gradually decreasing below 1 around lag day 5. The cold-CVD mortality association risk increases slightly from around day 9 to day 16 where it peaks at day 11. Hot temperatures show a delayed response with the risk of CVD-mortality only seen after 5 lag days which persists for 16 days. This risk is relatively lesser compared to the cold-CVD mortality risk for 5 lag days.

Figure S7 shows the results of the sensitivity analysis comparing all the patients versus patients who were admitted for less than 10 days before dying. The results show that there is relatively no difference in the association between patients who spent less than 10 days and the association for all patients.

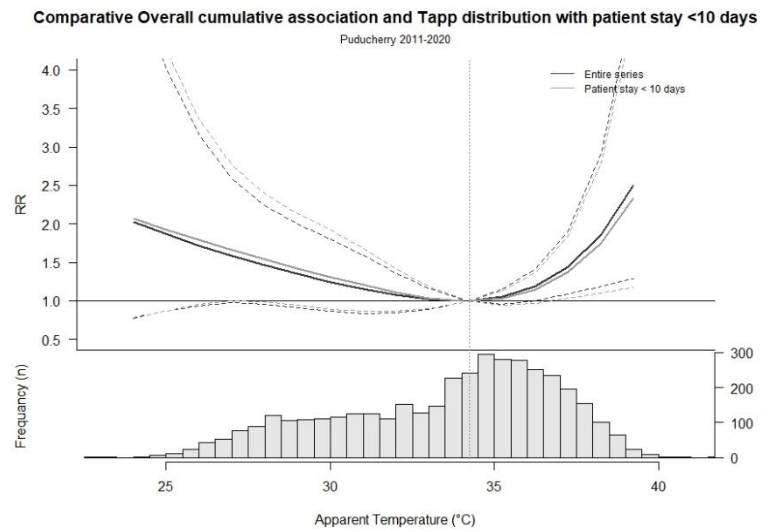

Figure S7: *Comparison of the exposure-response association using the complete 10 year data set vs restricting it to patients who spent less than 10 days in hospital. The black line depicts the overall association while the grey line depicts the patients who spent less than 10 days admitted to hospital before dying.*

Figure S8 shows the RR of CVDs at lag day 1, 5, 15 and 20. Cold has an immediate outcome at lag day 1 which attenuates around day 5 as heat starts to have an effect. The effects of both hot and cold temperatures last for a bout 15 days.

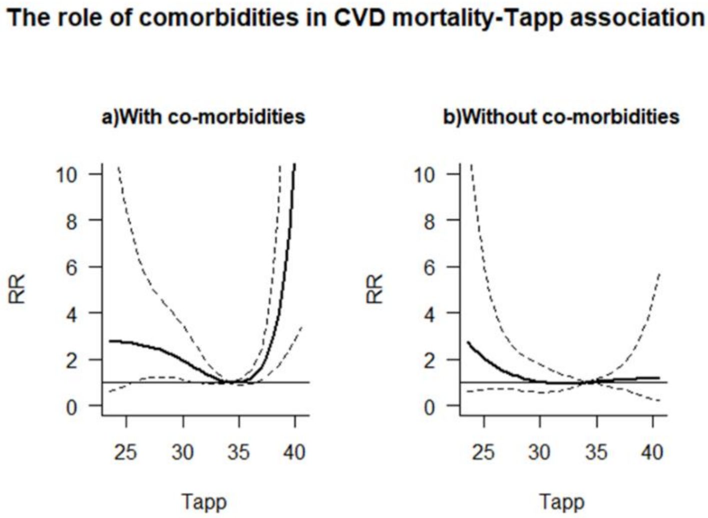

Figure S8: *Exposure-response association at different lag days. a.) 1 day, b.) 5 days, c.) 10 days and d.) 20 days.*

Figure S9 shows the RR for temperature associated CVD mortalities between people with and without co-morbidities such as hypertension, diabetes and alcoholism. People with co-

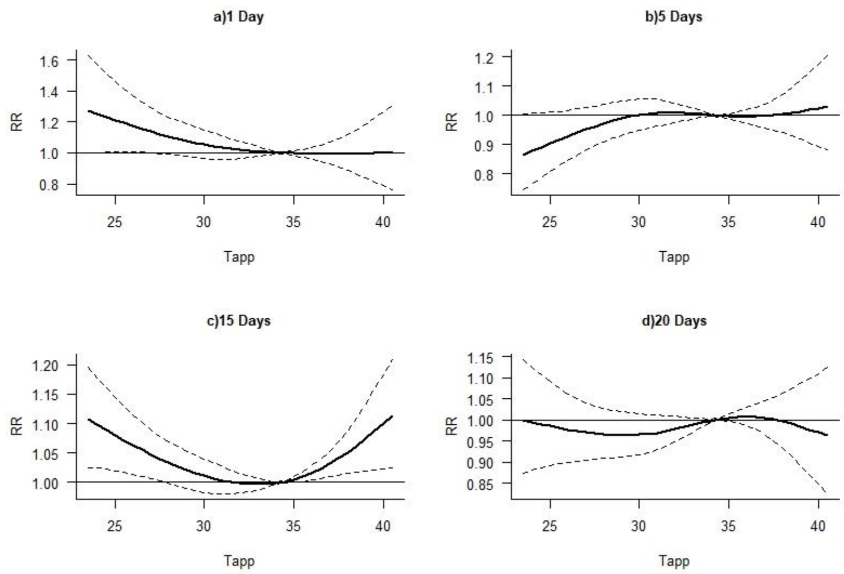

Figure S9: *The role of co-morbidities in the exposure-response association. a.) population with co-morbidities and b.) Population without co-morbidities.*

morbidities appear to be more vulnerable to the effects of non-optimal temperatures than those without.

This association was further stratified by age groups as shown in Figure S10. All groups were vulnerable to non-optimal temperatures except for those over 50 without co-morbidities. We recommend further studies to better understand this phenomenon.

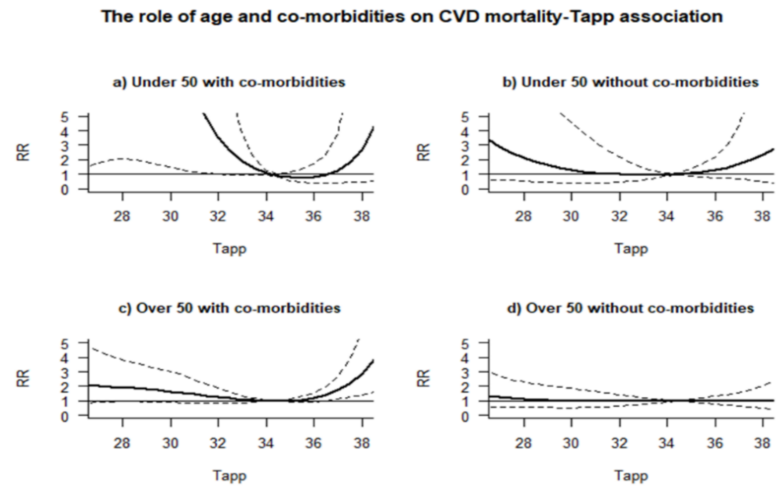

Figure S10: *The role of age and co-morbidities in the exposure-CVD mortality association. a.) Population under 50 with co-morbidities, b.) Population under 5o without co-morbidities, c.) Population over 5 with co-morbidities and d.) Population over 50 without co- morbidities. Graph restricted to the central 95t percentile of the T_{app} distribution due to wide Cis at extreme ends.*

Figures S11 shows a comparison of the daily T_{app} values from individual stations. We used an average value of data from both substations in our analysis, which has been presented in Figure S12.

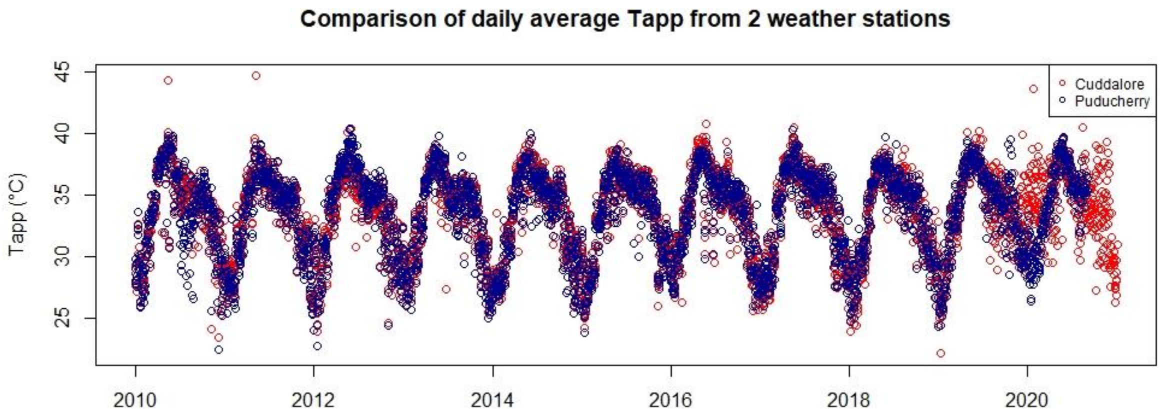

Figure S11: *Comparison of daily T_{app} values from the two weather stations we used in our analysis, namely Cuddalore and Puducherry.*

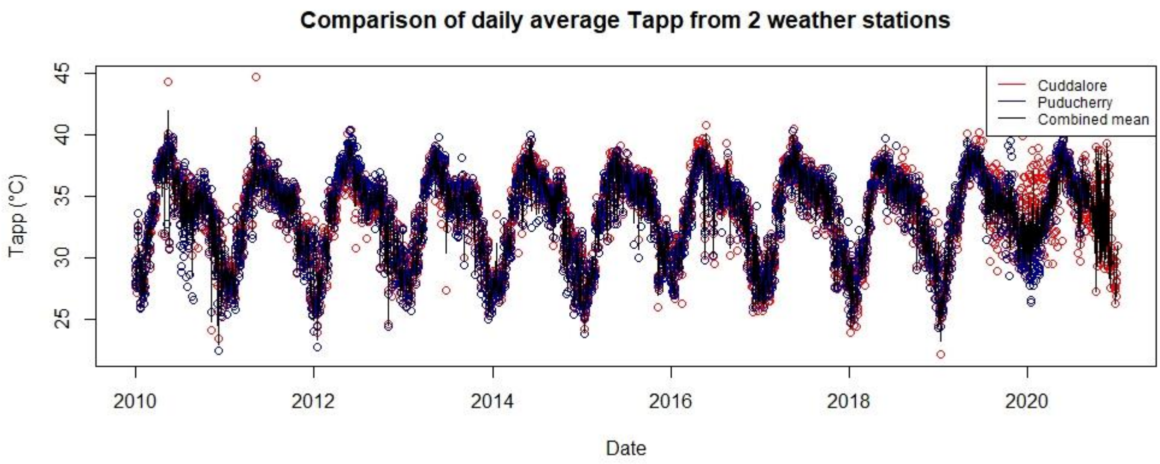

Figure S12: *Comparison of daily T_{app} values from the two weather stations we used in our analysis, namely Cuddalore and Puducherry, along with the average of both which we used in our model (depicted in black).*

Appendix B

Chapter 5 Supplementary Material

***Table S3**: Definitive list of cardiovascular diseases considered in this study from two public hospitals in Limpopo, South Africa.*

- Coronary artery disease
- Angina
- Myocardial infarction
- Stroke
- Heart failure
- Hypertensive heart failure
- Rhematic heart failure
- Cardiomyopathy
- Heart murmurs
- Congenital heart failure
- Valvular heart disease
- Carditis
- aortic aneurism
- peripheral artery disease
- thromboembolic dieses
- congestive cardiac failure (CCF)
- cerebrovascular accident (CVA)
- Atherosclerosis
- High blood pressure
- Hypertension
- High cholesterol/cholesterol
- Deep Vein Thrombosis/Venous thrombosis/ DVT

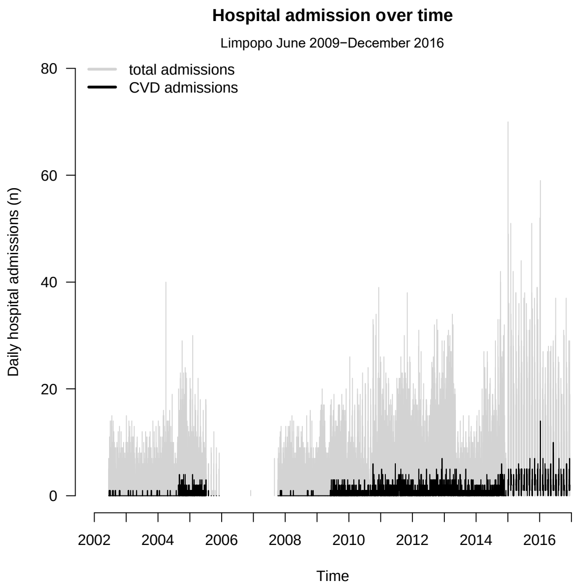

Figure S13: *A descriptive overview of the distribution of daily total (N=57,619) and cardiovascular disease (CVD) (N=4,368) hospital admission counts from 1.January 2002 until 31. December 2016 from two public hospitals in Limpopo, South Africa.*

Table S4*: Knot placement at different apparent temperatures (T_{app}) and the corresponding Akaike Information Criteria (AIC) for the negative binomial regression model and distributed lag non-linear model.*

T_{app}	**AIC**
15°C, 26°C	6684.9
17°C, 26°C	6685.1
18°C, 26°C	6685.4
15°C, 20°C, 25°C	6693.3

Table S5: *The relative risk (RR) of apparent temperature (T_{app}) on cardiovascular disease hospital admissions cumulated over 21 days of lag, relative to 26°C in Limpopo, South Africa (N=3,124). The upper (u95) and lower (l95) bound of the 95% confidence intervals are presented. The frequency (Freq.) of each T_{app} occurring throughout the study period from 1.June 2009 until 31.December 2016 in Limpopo is shown.*

T_{app}	**RR**	**l95**	**u95**	**Freq.**
6°C	0.59	0.25	1.37	2
7°C	0.66	0.32	1.33	4
8°C	0.73	0.41	1.30	9
9°C	0.82	0.52	1.28	13
10°C	0.90	0.65	1.26	19
11°C	0.99	0.78	1.25	46
12°C	1.07	0.91	1.25	68
13°C	1.14	1.00	1.3	97
14°C	1.20	1.04	1.38	118
15°C	1.24	1.05	1.45	177
16°C	1.25	1.05	1.48	151
17°C	1.24	1.05	1.47	169
18°C	1.22	1.05	1.43	154
19°C	1.19	1.04	1.36	176
20°C	1.15	1.03	1.29	156
21°C	1.11	1.01	1.22	163
22°C	1.07	0.99	1.16	163
23°C	1.04	0.97	1.11	177
24°C	1.01	0.95	1.07	199
25°C	1.00	0.96	1.04	188
26°C	1.00	1.00	1.00	155
27°C	1.02	0.96	1.08	153
28°C	1.06	0.92	1.21	109
29°C	1.11	0.88	1.39	66
30°C	1.17	0.83	1.64	42
31°C	1.24	0.79	1.96	14
32°C	1.33	0.75	2.36	4

	6°C			7°C			8°C			9°C			10°C			11°C			12°C			13°C		
Lag days	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**
0	1.01	0.67	1.53	1.05	0.73	1.51	1.09	0.80	1.49	1.13	0.86	1.48	1.16	0.91	1.48	1.19	0.96	1.48	1.22	1.00	1.48	1.23	1.02	1.49
1	1.18	0.96	1.46	1.17	0.97	1.40	1.15	0.98	1.35	1.14	0.99	1.31	1.12	0.99	1.27	1.11	0.99	1.24	1.10	0.99	1.21	1.08	0.98	1.19
2	1.11	0.88	1.40	1.10	0.90	1.35	1.08	0.91	1.29	1.07	0.91	1.25	1.05	0.92	1.21	1.04	0.92	1.18	1.03	0.92	1.16	1.02	0.92	1.14
3	0.96	0.84	1.09	0.97	0.86	1.08	0.98	0.88	1.08	0.98	0.90	1.07	0.99	0.92	1.07	1.00	0.93	1.07	1.00	0.94	1.07	1.01	0.95	1.07
4	0.88	0.77	1.00	0.90	0.80	1.00	0.92	0.83	1.01	0.93	0.86	1.02	0.95	0.88	1.02	0.97	0.91	1.03	0.98	0.93	1.05	1.00	0.94	1.06
5	0.85	0.74	0.98	0.87	0.77	0.99	0.89	0.80	1.00	0.92	0.84	1.01	0.94	0.87	1.02	0.96	0.89	1.03	0.98	0.92	1.04	0.99	0.93	1.06
6	0.86	0.76	0.97	0.88	0.79	0.98	0.90	0.82	0.99	0.92	0.85	1.00	0.94	0.87	1.01	0.96	0.90	1.02	0.98	0.92	1.03	0.99	0.94	1.05
7	0.89	0.80	0.98	0.90	0.83	0.98	0.92	0.85	0.99	0.93	0.88	1.00	0.95	0.90	1.00	0.96	0.92	1.01	0.98	0.93	1.02	0.99	0.95	1.03
8	0.92	0.85	0.99	0.93	0.87	1.00	0.94	0.88	1.00	0.95	0.90	1.00	0.96	0.92	1.00	0.97	0.93	1.01	0.98	0.95	1.02	0.99	0.95	1.02
9	0.95	0.88	1.02	0.95	0.89	1.02	0.96	0.90	1.02	0.96	0.92	1.01	0.97	0.93	1.01	0.98	0.94	1.02	0.98	0.95	1.02	0.99	0.95	1.02
10	0.97	0.89	1.05	0.97	0.90	1.04	0.97	0.92	1.04	0.98	0.93	1.03	0.98	0.93	1.03	0.98	0.94	1.02	0.98	0.95	1.02	0.99	0.95	1.03
11	0.99	0.90	1.07	0.99	0.91	1.06	0.99	0.92	1.05	0.99	0.93	1.04	0.99	0.94	1.04	0.99	0.94	1.03	0.99	0.95	1.03	0.99	0.95	1.03
12	1.00	0.92	1.09	1.00	0.92	1.08	0.99	0.93	1.06	0.99	0.94	1.05	0.99	0.94	1.04	0.99	0.94	1.04	0.99	0.95	1.03	0.99	0.95	1.03
13	1.01	0.93	1.10	1.00	0.93	1.08	1.00	0.94	1.07	1.00	0.94	1.05	0.99	0.95	1.04	0.99	0.95	1.04	0.99	0.95	1.03	0.99	0.95	1.03
14	1.01	0.94	1.09	1.01	0.94	1.08	1.00	0.95	1.06	1.00	0.95	1.05	1.00	0.95	1.04	0.99	0.95	1.03	0.99	0.95	1.03	0.99	0.95	1.02
15	1.01	0.94	1.09	1.01	0.95	1.07	1.00	0.95	1.06	1.00	0.96	1.05	1.00	0.96	1.04	0.99	0.96	1.03	0.99	0.96	1.02	0.99	0.96	1.02
16	1.01	0.95	1.08	1.01	0.95	1.06	1.00	0.96	1.05	1.00	0.96	1.04	1.00	0.96	1.03	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.96	1.01
17	1.00	0.94	1.07	1.00	0.95	1.06	1.00	0.95	1.05	1.00	0.96	1.04	0.99	0.96	1.03	0.99	0.96	1.02	0.99	0.97	1.02	0.99	0.97	1.01
18	1.00	0.92	1.08	1.00	0.93	1.06	0.99	0.94	1.05	0.99	0.95	1.04	0.99	0.95	1.03	0.99	0.96	1.03	0.99	0.96	1.02	0.99	0.96	1.02
19	0.99	0.90	1.09	0.99	0.91	1.08	0.99	0.92	1.06	0.99	0.93	1.05	0.99	0.94	1.05	0.99	0.94	1.04	0.99	0.95	1.04	0.99	0.95	1.03
20	0.98	0.87	1.11	0.98	0.88	1.09	0.98	0.90	1.08	0.99	0.91	1.07	0.99	0.92	1.06	0.99	0.93	1.05	0.99	0.94	1.05	0.99	0.94	1.05
21	0.97	0.83	1.13	0.97	0.85	1.11	0.98	0.87	1.10	0.98	0.89	1.09	0.99	0.90	1.08	0.99	0.91	1.07	0.99	0.92	1.07	0.99	0.93	1.07

Table S6: *The relative risk (RR) of cardiovascular disease hospital admissions in Limpopo, South Africa, by lag days at specific apparent temperatures (N=3,124). The tables show the upper (u95) and lower (l95) bounds of the 95% confidence interval. The RRs are relative to 26°C.*

		14°C			15°C			16°C			17°C			18°C			19°C			20°C			21°C	
Lag days	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**
0	1.24	1.04	1.48	1.24	1.05	1.47	1.23	1.04	1.44	1.20	1.04	1.40	1.18	1.03	1.34	1.14	1.02	1.29	1.11	1.01	1.23	1.08	0.99	1.17
1	1.07	0.98	1.17	1.06	0.97	1.15	1.04	0.96	1.13	1.03	0.96	1.12	1.02	0.95	1.10	1.01	0.95	1.08	1.01	0.95	1.06	1.00	0.96	1.04
2	1.01	0.91	1.12	1.00	0.91	1.11	1.00	0.91	1.09	0.99	0.91	1.08	0.99	0.92	1.07	0.99	0.92	1.06	0.99	0.93	1.05	0.99	0.94	1.04
3	1.01	0.95	1.07	1.01	0.96	1.07	1.01	0.96	1.07	1.01	0.96	1.06	1.01	0.97	1.06	1.01	0.97	1.05	1.01	0.98	1.04	1.01	0.98	1.03
4	1.01	0.96	1.07	1.02	0.97	1.07	1.02	0.97	1.08	1.03	0.98	1.08	1.03	0.98	1.07	1.03	0.99	1.07	1.02	0.99	1.06	1.02	0.99	1.05
5	1.01	0.95	1.07	1.02	0.96	1.08	1.03	0.97	1.08	1.03	0.98	1.08	1.03	0.99	1.08	1.03	0.99	1.07	1.03	0.99	1.07	1.02	0.99	1.05
6	1.00	0.95	1.06	1.01	0.96	1.07	1.02	0.97	1.07	1.03	0.98	1.07	1.03	0.99	1.07	1.03	0.99	1.07	1.03	0.99	1.06	1.02	1.00	1.05
7	1.00	0.96	1.04	1.01	0.97	1.05	1.01	0.98	1.05	1.02	0.98	1.05	1.02	0.99	1.05	1.02	0.99	1.05	1.02	1.00	1.04	1.02	1.00	1.04
8	1.00	0.96	1.03	1.00	0.97	1.03	1.01	0.98	1.04	1.01	0.98	1.04	1.01	0.99	1.04	1.01	0.99	1.04	1.01	0.99	1.03	1.01	1.00	1.03
9	0.99	0.96	1.03	1.00	0.96	1.03	1.00	0.97	1.03	1.00	0.97	1.03	1.00	0.98	1.03	1.01	0.98	1.03	1.01	0.99	1.03	1.01	0.99	1.02
10	0.99	0.95	1.03	0.99	0.96	1.03	0.99	0.96	1.03	1.00	0.97	1.03	1.00	0.97	1.03	1.00	0.98	1.03	1.00	0.98	1.02	1.00	0.99	1.02
11	0.99	0.95	1.03	0.99	0.95	1.03	0.99	0.95	1.03	0.99	0.96	1.03	0.99	0.96	1.03	1.00	0.97	1.02	1.00	0.98	1.02	1.00	0.98	1.02
12	0.99	0.95	1.03	0.99	0.95	1.03	0.99	0.95	1.02	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.97	1.02	1.00	0.97	1.02	1.00	0.98	1.02
13	0.99	0.95	1.02	0.99	0.95	1.02	0.99	0.95	1.02	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.97	1.02	0.99	0.97	1.02	1.00	0.98	1.01
14	0.99	0.95	1.02	0.99	0.95	1.02	0.99	0.95	1.02	0.99	0.96	1.02	0.99	0.96	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.98	1.01
15	0.99	0.96	1.02	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.98	1.01
16	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.98	1.01	0.99	0.98	1.00
17	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.96	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.98	1.01	0.99	0.98	1.00
18	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.97	1.01	0.99	0.98	1.01
19	0.99	0.95	1.03	0.99	0.95	1.03	0.99	0.95	1.03	0.99	0.96	1.03	0.99	0.96	1.02	0.99	0.96	1.02	0.99	0.97	1.02	0.99	0.97	1.01
20	0.99	0.94	1.05	0.99	0.94	1.05	0.99	0.95	1.05	0.99	0.95	1.04	0.99	0.95	1.04	0.99	0.96	1.03	0.99	0.96	1.02	0.99	0.97	1.02
21	1.00	0.93	1.07	1.00	0.93	1.07	1.00	0.94	1.06	1.00	0.94	1.06	1.00	0.94	1.05	0.99	0.95	1.04	0.99	0.96	1.03	0.99	0.96	1.02

		23°*C*			24°*C*			25°*C*			26°*C*			27°*C*			28°*C*			29°*C*			30°*C*	
Lag days	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**	**RR**	**l95**	**u95**
0	1.03	0.97	1.08	1.01	0.97	1.05	1.11	1.01	1.23	1.00	1.00	1.00	1.01	0.98	1.04	1.03	0.97	1.10	1.06	0.96	1.18	1.10	0.95	1.28
1	0.99	0.96	1.02	0.99	0.97	1.01	1.01	0.95	1.06	1.00	1.00	1.00	1.01	0.99	1.02	1.02	0.98	1.06	1.03	0.97	1.10	1.05	0.96	1.14
2	0.99	0.96	1.02	0.99	0.97	1.02	0.99	0.93	1.05	1.00	1.00	1.00	1.00	0.99	1.02	1.01	0.97	1.05	1.01	0.95	1.08	1.02	0.93	1.12
3	1.00	0.98	1.02	1.00	0.99	1.01	1.01	0.98	1.04	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.98	1.03	1.01	0.97	1.04	1.01	0.96	1.06
4	1.01	0.99	1.03	1.01	0.99	1.02	1.02	0.99	1.06	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.98	1.02	1.00	0.97	1.04	1.00	0.95	1.06
5	1.01	0.99	1.03	1.01	0.99	1.02	1.03	0.99	1.07	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.97	1.02	1.00	0.96	1.04	1.00	0.94	1.05
6	1.01	1.00	1.03	1.01	1.00	1.02	1.03	0.99	1.06	1.00	1.00	1.00	1.00	0.99	1.01	0.99	0.97	1.02	0.99	0.96	1.03	0.99	0.94	1.04
7	1.01	1.00	1.02	1.01	1.00	1.02	1.02	1.00	1.04	1.00	1.00	1.00	1.00	0.99	1.00	0.99	0.98	1.01	0.99	0.97	1.02	0.99	0.95	1.03
8	1.01	1.00	1.02	1.01	1.00	1.01	1.01	0.99	1.03	1.00	1.00	1.00	1.00	0.99	1.00	0.99	0.98	1.01	0.99	0.97	1.01	0.99	0.96	1.02
9	1.01	1.00	1.02	1.00	1.00	1.01	1.01	0.99	1.03	1.00	1.00	1.00	1.00	0.99	1.00	0.99	0.98	1.01	0.99	0.97	1.01	0.99	0.96	1.02
10	1.00	0.99	1.01	1.00	1.00	1.01	1.00	0.98	1.02	1.00	1.00	1.00	1.00	0.99	1.00	0.99	0.98	1.01	0.99	0.97	1.01	0.99	0.95	1.02
11	1.00	0.99	1.01	1.00	0.99	1.01	1.00	0.98	1.02	1.00	1.00	1.00	1.00	0.99	1.00	0.99	0.98	1.01	0.99	0.97	1.01	0.99	0.95	1.02
12	1.00	0.99	1.01	1.00	0.99	1.01	1.00	0.97	1.02	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.98	1.01	0.99	0.97	1.02	0.99	0.95	1.02
13	1.00	0.99	1.01	1.00	0.99	1.01	0.99	0.97	1.02	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.98	1.01	0.99	0.97	1.02	0.99	0.96	1.03
14	1.00	0.99	1.01	1.00	0.99	1.01	0.99	0.97	1.01	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.99	1.01	1.00	0.97	1.02	0.99	0.96	1.03
15	1.00	0.99	1.01	1.00	0.99	1.00	0.99	0.97	1.01	1.00	1.00	1.00	1.00	0.99	1.01	1.00	0.99	1.01	1.00	0.98	1.02	1.00	0.97	1.03
16	1.00	0.99	1.00	1.00	0.99	1.00	0.99	0.98	1.01	1.00	1.00	1.00	1.00	1.00	1.01	1.00	0.99	1.01	1.00	0.98	1.02	1.00	0.98	1.03
17	0.99	0.99	1.00	1.00	0.99	1.00	0.99	0.98	1.01	1.00	1.00	1.00	1.00	1.00	1.01	1.00	0.99	1.01	1.01	0.99	1.02	1.01	0.98	1.03
18	0.99	0.98	1.00	1.00	0.99	1.00	0.99	0.97	1.01	1.00	1.00	1.00	1.00	1.00	1.01	1.01	0.99	1.02	1.01	0.99	1.03	1.01	0.98	1.04
19	0.99	0.98	1.01	1.00	0.99	1.00	0.99	0.97	1.02	1.00	1.00	1.00	1.00	1.00	1.01	1.01	0.99	1.02	1.01	0.99	1.04	1.02	0.98	1.06
20	0.99	0.98	1.01	0.99	0.98	1.01	0.99	0.96	1.02	1.00	1.00	1.00	1.00	1.00	1.01	1.01	0.99	1.03	1.02	0.98	1.05	1.02	0.98	1.07
21	0.99	0.97	1.01	0.99	0.98	1.01	0.99	0.96	1.03	1.00	1.00	1.00	1.01	0.99	1.02	1.01	0.99	1.04	1.02	0.98	1.06	1.03	0.97	1.09

Lag days	RR	31°*C* l95	u95	RR	32°*C* l95	u95
0	1.15	0.94	1.40	1.19	0.93	1.54
1	1.06	0.95	1.19	1.08	0.93	1.25
2	1.03	0.91	1.16	1.03	0.88	1.20
3	1.01	0.95	1.09	1.02	0.93	1.11
4	1.00	0.94	1.08	1.01	0.93	1.10
5	1.00	0.93	1.07	1.00	0.91	1.10
6	0.99	0.93	1.06	0.99	0.91	1.08
7	0.99	0.94	1.04	0.98	0.92	1.05
8	0.98	0.94	1.02	0.98	0.93	1.03
9	0.98	0.94	1.02	0.98	0.93	1.03
10	0.98	0.94	1.02	0.98	0.93	1.03
11	0.98	0.94	1.03	0.98	0.92	1.04
12	0.98	0.94	1.03	0.98	0.92	1.04
13	0.99	0.94	1.03	0.98	0.93	1.04
14	0.99	0.95	1.03	0.99	0.94	1.04
15	1.00	0.96	1.04	0.99	0.95	1.04
16	1.00	0.97	1.04	1.00	0.96	1.05
17	1.01	0.97	1.04	1.01	0.97	1.06
18	1.02	0.98	1.06	1.02	0.97	1.07
19	1.02	0.97	1.08	1.03	0.96	1.10
20	1.03	0.97	1.10	1.04	0.96	1.12
21	1.04	0.96	1.12	1.05	0.95	1.16

Table S7: *Model coefficients, standard errors (SE) and p-values for the negative binomial regression model (N=3,124). v1, v2 and v3 correspond to the gradient of the exposure- response association in the first, second and third interval of a spline, respectively. "l1" corresponds to the gradient of the lagged association in the first interval of a spline, "l2" to that in the second interval, and so on. The coefficients for the adjustment of days of the week, long term trends and total admissions are also represented.*

Parameter	**Coefficient**	**SE**	**p-value**
Intercept	-3.15	0.473	<0.001
Mean Temp v1.l1	-0.158	0.183	0.389
Mean Temp v1.l2	0.156	0.105	0.138
Mean Temp v1.l3	0.11	0.115	0.341
Mean Temp v1.l4	-0.275	0.147	0.061
Mean Temp v1.l5	0.154	0.106	0.145
Mean Temp v2.l1	-0.613	0.488	0.209
Mean Temp v2.l2	0.622	0.3	0.038
Mean Temp v2.l3	-0.343	0.31	0.269
Mean Temp v2.l4	0.204	0.416	0.624
Mean Temp v2.l5	-0.049	0.295	0.868
Mean Temp v3.l1	0.007	0.171	0.968
Mean Temp v3.l2	0.023	0.1	0.815
Mean Temp v3.l3	-0.013	0.105	0.904
Mean Temp v3.l4	-0.037	0.136	0.785
Mean Temp v3.l5	0.082	0.096	0.391
Monday	0.069	0.068	0.311
Saturday	0.057	0.071	0.416
Sunday	0.071	0.073	0.33
Thursday	0.019	0.069	0.783
Tuesday	0.101	0.072	0.161
Wednesday	0.139	0.071	0.05
LongTerm v1	0.405	0.17	0.017
LongTerm v2	0.034	0.22	0.878
LongTerm v3	0.806	0.189	<0.001
LongTerm v4	-0.247	0.211	0.241
LongTerm v5	0.552	0.194	0.004
LongTerm v6	0.895	0.143	<0.001
LongTerm v7	0.734	0.391	0.061
LongTerm v8	0.867	0.141	<0.001
Total admissions	0.855	0.03	<0.001

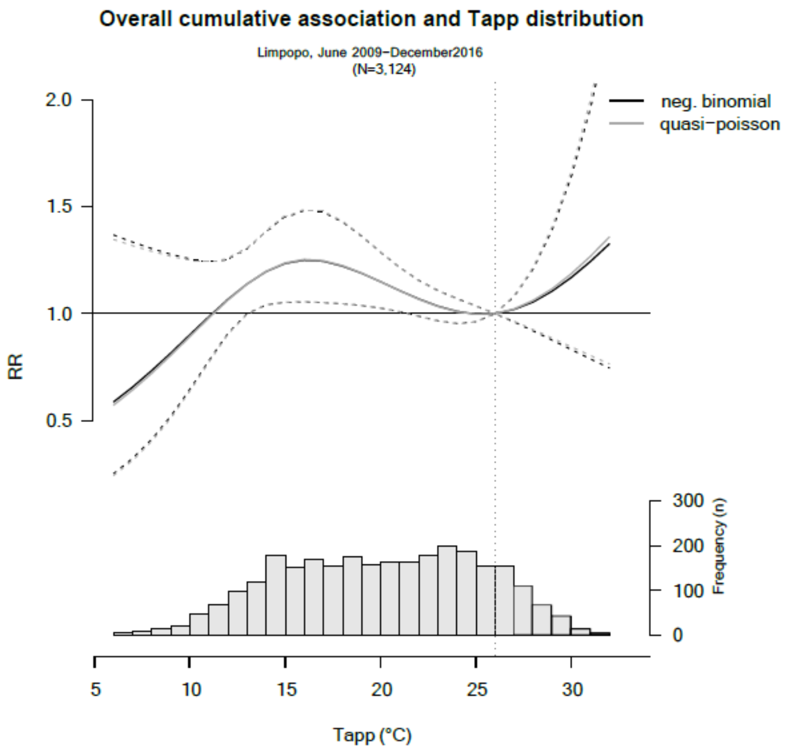

Figure S14: *The relative risk (RR) of cardiovascular disease hospital admissions by apparent temperature (T_{app}) cumulated over 21 days of lag, relative to 26°C (N=3,124) in Limpopo, South Africa. The black and grey thick lines represent the RR using a negative binomial regression model and a quasi-poisson regression model, respectively. The dotted lines represent the 95% confidence intervals and the grey vertical dotted line marks the optimum T_{app} at 26°C. The histogram at the bottom shows the frequency of each T_{app} occurring in Limpopo between 1.June 2009 and 31.December 2016.*

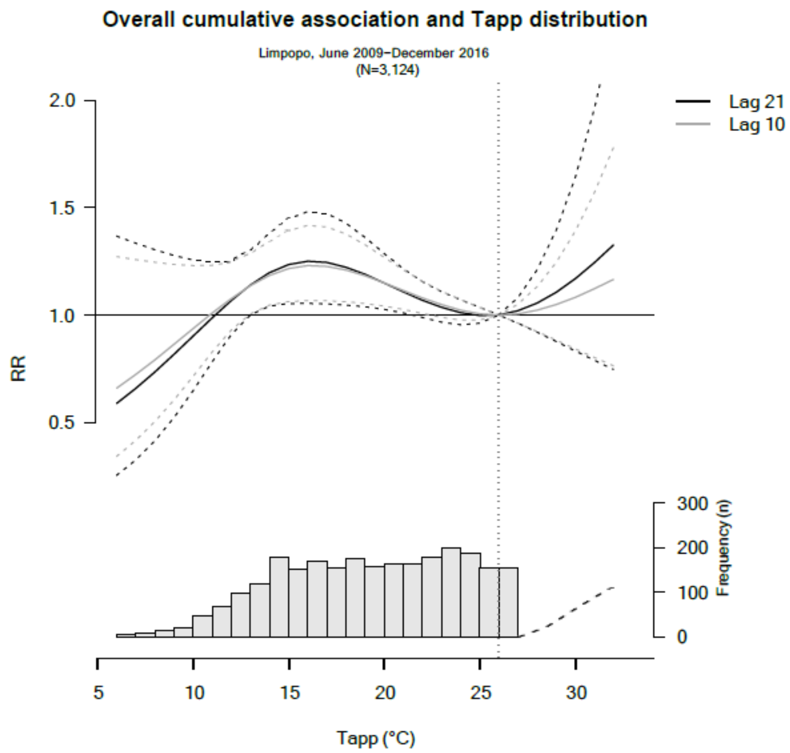

Figure S15: *The relative risk (RR) of cardiovascular disease (CVD) hospital admissions by apparent temperature (T_{app}) cumulated over different lag periods, relative to 26°C in Limpopo, South Africa (N=3,124). The black and grey thick lines show the effect of apparent temperature (T_{app}) on CVD hospital admissions cumulated over 21 and 10 days of lag, respectively. The dotted lines represent the 95% confidence intervals and the grey vertical dotted line marks the optimum T_{app} at 26°C. The histogram at the bottom shows the frequency of each T_{app} occurring in Limpopo between 1.June 2009 and 31.December 2016.*

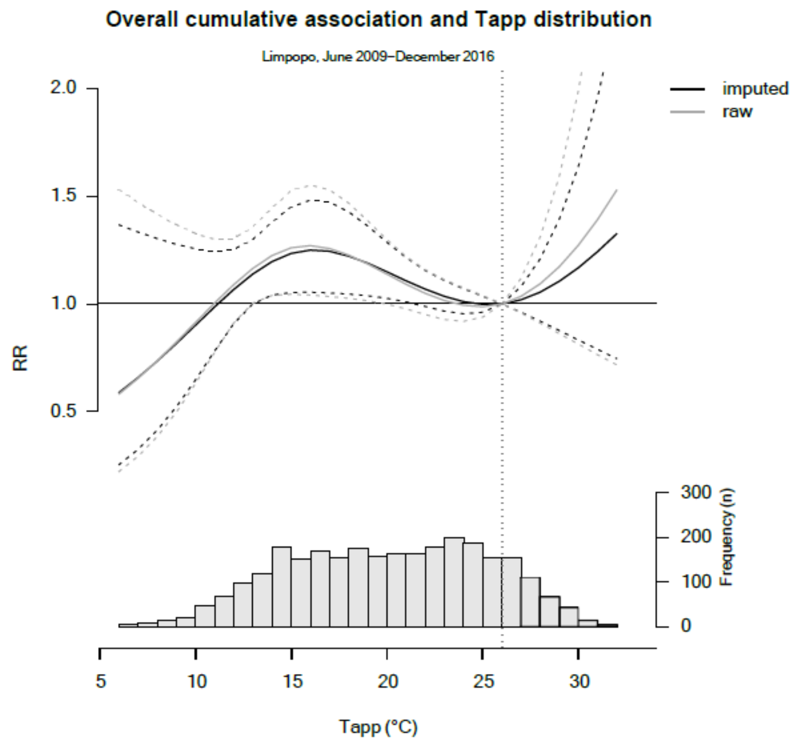

Figure S16: *The relative risk (RR) of cardiovascular disease hospital admissions by apparent temperature (T_{app}) cumulated over 21 days of lag, relative to 26°C in Limpopo, South Africa. The black and grey thick lines represent the RR using the imputed dataset (N=3,124) and raw dataset (N=2,371), respectively. The dotted lines represent the 95% confidence intervals and the grey vertical dotted line marks the optimum T_{app} at 26°C. The histogram at the bottom shows the frequency of each T_{app} occurring in Limpopo between 1.June 2009 and 31.December 2016.*

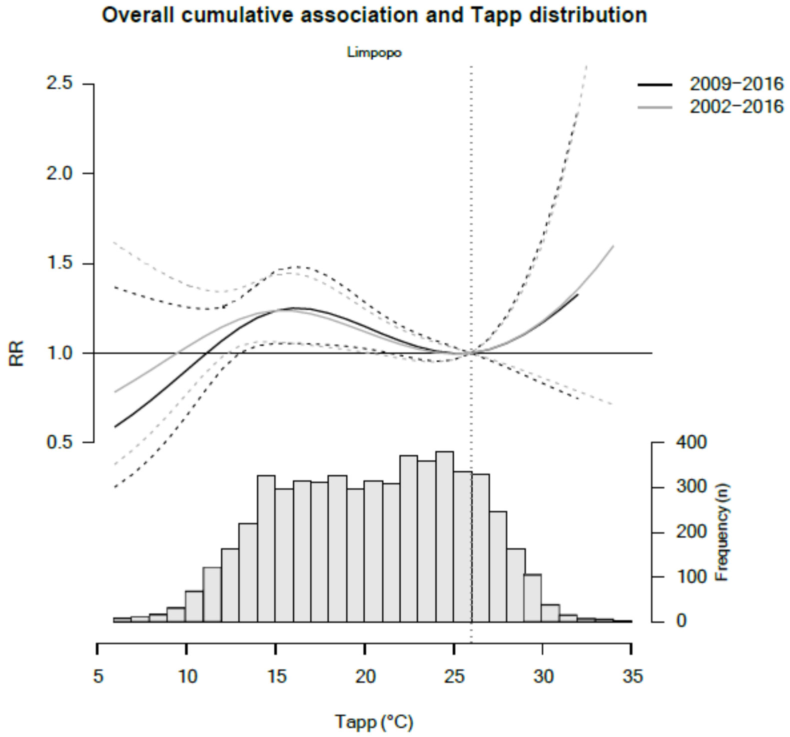

***Figure S17**: The relative risk (RR) of cardiovascular disease hospital admissions by apparent temperature (T_{app}) cumulated over 21 days of lag, relative to 26°C in Limpopo, South Africa. The black and grey thick lines represent the RR using data from 1.June 2009 until 31.December 2016 (N=3,124) and non-imputed data from 1.January 2002 until 31.December 2016 (N=2,642), respectively. The dotted lines represent the 95% confidence intervals and the grey vertical dotted line marks the optimum T_{app} at 26°C. The histogram at the bottom shows the frequency of each T_{app} occurring in Limpopo between 1. January 2002 and 31. December 2016.*

Appendix C

Chapter 6 Supplementary Material

Table S8: *Interview questions guide for medical professionals and members of the Department of Science, Technology and Environment (DSTE) working on the Puducherry State Adaptation plan*

COMMON QUESTIONS

Target group	Themes	Aims	Questions
COMMON	Participant information	To get the basic demographic and professional information about the participant	1. Age 2. Nationality 3. Place of residence 4. Educational background and speciality 5. Occupation 6. Years in occupation 7. Professional experience related to climate change and/or health
	Background knowledge-climate change	To establish level of knowledge about climate change with 'warm up' questions	1. What comes to mind when you think of climate change? 2. What do you think are physical manifestations of climate change? 3. Have you experienced or been aware of any climate change events in the past few years? 4. What, according you, are the most common consequences of climate change?- Which aspects of life do they affect most severely?
	Climate change and health, climate	To establish knowledge/ awareness about climate change and	1. Have you ever thought about the health impacts of climate change?

	change and CVDs	health and climate change and CVDs	2. What aspects of human health do you think climate change will have the biggest impact on? 3. Are you aware about the impacts of climate change on NCDs such as cardiovascular diseases? 3.1. If yes to above question, what do you know about it? How do you know about it (eg through research or through professional experience?)
	Policies and plans	To establish knowledge and awareness levels about policies and plans on the issue of climate change and health	1. Are you aware or have you been part of any policies/plans/programs on the issue of climate change and health? 2. If yes, what were/are they?- What diseases or health topic did it focus on? What was the work done (aim)? Do you think it was successful and beneficial? 3. Do you know any plans/programs specifically targeting climate change and heart diseases? (can be from any sector). 4. Do you know about the national/state climate change adaptation plan? 5. If yes, do you know of the role health plays in it?
	Challenges and outlook	To understand challenged faced, potential solutions and planned changes	1. Are you aware of any upcoming or recent changes to the health adaptation plans or any other relevant policy that target climate change and health? 2. Do you know any policies which can be used to

			increase awareness and research on the impact of climate change on CVDs in India? 3. According to you, what are the biggest drawbacks and challenges faced- why do you think health or NCD impacts of climate change are not a priority? 4. What can be done to change that? 5. Can you think of some measures to mitigate the impacts of climate change? - Your contribution to mitigating the impact, whether it's individual or you think it should be more at a governmental level? - Examples can be green healthcare facilities etc
Medical Professionals	Climate change and health-medical experience	To understand perceptions on the extent to which climate/temperature affects patient health	1. Do you think climate, especially temperature affects health based on hospital admissions and mortality? 2. Can you explain what you have observed (eg, more patients on particularly hot days). 3. Which diseases have you observed to be the most sensitive to climate/temperature? 4. Based on your day to day observations, do you see an association between temperature and CVDs? 5. Do you think we will see an increase in the CVD deaths

			attributable to temperature in the future?
	Population vulnerability	To understand views on how different people are affected based on demography	1. Which people have you observed to be the most vulnerable to temperature? (eg, age, gender, occupation, SE status etc) 2. Do you see a big gender difference in CVD patients with and without the influence on external temperatures? 3. Have you observed an association between age/gender and temperatures? For example, are a certain group of people more susceptible to heat or cold? 4. Do the public and private sectors work together during disasters? - How is the communication, facility and equipment sharing?
	Education and training	To understand level of training and awareness among doctors on climate sensitive diseases	1. Have you ever been explicitly trained, either during medical school or professionally, on climate sensitive diseases? 2. If yes, where did the course take place (India or abroad, college or professional) and what did it cover (broadly) 3. If yes, did the course include CVDs? 4. Did it include gender differences in terms of symptoms? 5. Do you think such a course is needed or would be beneficial?

	Measures to be taken	To discuss possible measures to be taken to increase awareness and preparedness on climate sensitive diseases	1. Assuming that we will be seeing an increase in CVD mortalities attributable to temperature in the future, what measures do you think can be taken to prepare and adapt to it? - In hospitals, in medical schools, - Give an example..early warning systems, emergency cardio bays in hospitals, awareness drives etc 2. What policy measures do you feel would benefit with the issue of climate sensitive diseases? For CVDs?
Health department (policy makers, ministerial representatives)	Current policies	To understand current health policies and whether climate change in included in them- include CVD policies and training	1. Do any of the current health policies include climate change? 2. Are there any specific policies on climate sensitive diseases? - Guidelines for disasters - Guidelines for heat 3. If yes, do any policies include NCDs or CVDs specifically?
	Challenges and outlook	To understand current challenges and future plans	1. The national adaptation plan recently added health as one of its climate change missions- why do you think this was not always a priority? 2. FOR PUDUCHERRY- Why is there no health mission in the state adaptation plan? Are there plans to include it?

			If yes, what diseases will be focused on? 3. Are any activities being planned around climate sensitive diseases especially CVDs? - Awareness programs - Education and training in medical schools? 4. Are there any plans to develop and expand heat action plans nationally? (eg. Ahmedabad heat action plan) 5. Which diseases will be a priority area for climate sensitivity in terms of policy and research? 6. Is there any research or study being conducted on the health impacts of climate change? Are there any plans to do so? 7. CVD effects and most other effects of climate change affect vulnerable populations most-how do you plan to address some of these challenges? - Rural vs urban exposures and requirements differ. Are there plans that specifically target different populations? - What about different communities? Do you feel different communities have different needs to protect themselves against the climate? Can you elaborate?

			- What about different SE groups?
Department of Science, Technology and Environment	Current policies	To understand the development process of the adaptation plan and how health is included in current policies	1. The adaptation plan has recently added a health mission, but it does not have a comprehensive list and guidelines for climate sensitive disease management? 2. The adaptation plan is an intersectional plan with involvement from many departments. Does the steering committee have regular meetings to review and stay perpared, if so how often? - Review meetings? - Do you make changes to the plan based on new evidence or incidences? 3. Is there a reason that NCDs such as CVDs, despite having a huge burden of disease are not explicitly included and researched in terms of climate attributable burden? 4. What plans/programs/campaigns are presently ongoing that deal with climate-health adaptation? Are there any specific to CVDs? 5. Can you tell me about any plans or policies that have been previously implemented on the topic of climate sensitive diseases? - Were they successful and effective? - What is the present status of these?

			- What were the biggest challenges faced? 6. CVD effects and most other effects of climate change affect vulnerable populations most-how do you plan to address some of these challenges? - Rural vs urban exposures and requirements differ. Are there plans that specifically target different populations? - What about different communities? Do you feel different communities have different needs to protect themselves against the climate? Can you elaborate? - What about different SE groups?
	Challenges and outlook	To understand challenges faced and future plans	1. What is the biggest challenge in formulating and implementing climate sensitive disease policies or policies related to climate impacts on health? 2. Are there any plans to include NCDs and CVDs as a separate component of climate sensitive diseases? 3. Are there research projects planned on this topic to inform priority setting and policy formulation? 4. What measures do you think need to be taken to help formulate better , more comprehensive climate change policies that are

			informed by health research?
			The adaptation plan is an intersectional plan with involvement from many departments. Does the steering committee have regular meetings to review and stay perpared, if so how often? 1. Review meetings? 2. Do you make changes to the plan based on new evidence or incidences? 3.
EDUCATION- either department or medical college educators	Current practices	To understand current medical curriculum and whether climate change is included in it	4. Does the current medical school curriculum include climate change with respect to diseases that are sensitive to it? 5. Do you feel this needs to be taught? 6. Do you think temperature affects diseases? 7. What diseases do you think are most sensitive to climate change that need to be included in the curriculum? 8. If yes to above questions, does it include gender differences?
	Challenges and outlook	To understand challenges in teaching students about climate change and plans for future along with suggestions	1. Are there any plans to include climate sensitive diseases in the curriculum? 2. What other measures do you think can be taken with respect to the training of medical workers to reduce the burden of climate sensitive diseases? - Ex, emergency bays, more ambulances or

			staff during days of particular temperature etc

2. Themes and categories

Table S9: *Structural codes and framework matrix*

Theme	Sub-theme	Category
Climate change and health: systems knowledge and perceptions	Climate change process	1. Climate change as an acute and growing problem for India 2. Climate change ultimately affects health through domino effects 3. Indirect health impacts of climate change experienced 4. Scepticism about climate change affecting CVDs 5. Knowledge of the public health burden and vulnerabilities influenced perceived risks from climate change
	Climate change impacts	
	Risk factors	
	Disease burden	
	Vulnerabilities	
Socio-cultural dynamics and public engagement	Awareness and outreach	1. Credibility and societal role of information source important for uptake and public awareness 2. Need for alternate solutions and incentivized, targeted programs on all societal levels 3. Integrated climate change impacts in schools, universities and continuing education curriculums 4. Seasonal workplace guidelines
	Capacity strengthening	
	Adaptive action	
Institutional determinants	Policy support	
	Education	
	Research and challenges	

3. Additional supporting quotes

a. Systems knowledge: Climate change is an acute, growing problem for India

"…I think nowadays, we cannot predict when the rains are coming and when it is going to go. I think more of cyclones are coming….we will have a drought and the other year, we will have a flood. That's what is happening nowadays" #2, Medical doctor/researcher.

b. Systems knowledge: Indirect impacts of climate change experienced

"Yeah it affects agriculture. It makes people unemployed. The more agriculture commodities that get damaged, so we cannot do anything about the agricultural damage." #1, Practicing physician.

"Water is one of the important sectors in which I feel that climate change will have a larger impact. Because already due to the overpopulation, there's a stress in the groundwater resources. And because of the climate change, the increasing heat, the soil moisture will get affected and there will be a lot of stress on the aquifers also. As the surface water also gets-evaporates due to increase in temperature, I see the possibilities of the future where there will be a lot of competition for the water." #7, Environmentalist.

c. Systems knowledge: Skepticism about climate change affecting CVDs

"I work in cardiology department; we didn't feel like there is increased deaths or increased number of myocardial infarction during the season in the period." #12, Practicing physician.

d. Socio-cultural dynamics and public engagement: Credibility and societal role of information source is important for uptake and public awareness

"Once we have accumulated the knowledge about this disease and the climate, we can make a manual or we can issue it to the patients with the support of the newspaper, radio and television so you can make…We can advise about the preventive measures." #13, Practicing physician.

e. Socio-cultural dynamics and public engagement: integrating climate change in schools, universities and continuing education curriculum

"And especially as a teacher, I would like this to be a part of the curriculum also. Because we don't have a separate chapter on climate change or you know. I think, more of, expanding the curriculum from school to the collegiate also. Because ultimately, COVID has (taught us) that, you know, many things are not always under our control. So climate change is another one." #2, Medical doctor/researcher.

"Medical UG courses itself it should be added in. Input of what is climatic change what we are going to face and how it's a disaster and how to do the system management…First we need to teach to doctor students, then they'll be able to teach to others actually." #6, Practicing physician.

Appendix D

Chapter 7 Supplementary Material

1. Interview questions guide for medical professionals and members of the Department of Science, Technology and Environment (DSTE) working on the Puducherry State Adaptation plan

COMMON QUESTIONS

Table S10: *Semi structured interview framework utilized in interviews.*

Target group	Themes	Aims	Questions
COMMON	Participant information	To get the basic demographic and professional information about the participant	8. Age 9. Nationality 10. Place of residence 11. Educational background and speciality 12. Occupation 13. Years in occupation 14. Professional experience related to climate change and/or health
	Background knowledge- climate change	To establish level of knowledge about climate change with 'warm up' questions	5. What comes to mind when you think of climate change? 6. What do you think are physical manifestations of climate change? 7. Have you experienced or been aware of any climate change events in the past few years? 8. What, according you, are the most common consequences of climate change?- Which aspects of life do they affect most severely?

	Climate change and health, climate change and CVDs	To establish knowledge/ awareness about climate change and health and climate change and CVDs	4. Have you ever thought about the health impacts of climate change? 5. What aspects of human health do you think climate change will have the biggest impact on? 6. Are you aware about the impacts of climate change on NCDs such as cardiovascular diseases? 6.1. If yes to above question, what do you know about it? How do you know about it (eg through research or through professional experience?)
	Policies and plans	To establish knowledge and awareness levels about policies and plans on the issue of climate change and health	6. Are you aware or have you been part of any policies/plans/programs on the issue of climate change and health? 7. If yes, what were/are they?- What diseases or health topic did it focus on? What was the work done (aim)? Do you think it was successful and beneficial? 8. Do you know any plans/programs specifically targeting climate change and heart diseases? (can be from any sector). 9. Do you know about the national/state climate change adaptation plan? 10. If yes, do you know of the role health plays in it?
	Challenges and outlook	To understand challenged faced, potential solutions and planned changes	6. Are you aware of any upcoming or recent changes to the health adaptation plans or any other relevant

			policy that target climate change and health? 7. Do you know any policies which can be used to increase awareness and research on the impact of climate change on CVDs in India? 8. According to you, what are the biggest drawbacks and challenges faced- why do you think health or NCD impacts of climate change are not a priority? 9. What can be done to change that? 10. Can you think of some measures to mitigate the impacts of climate change? - Your contribution to mitigating the impact, whether it's individual or you think it should be more at a governmental level? - Examples can be green healthcare facilities etc
Medical Professionals	Climate change and health-medical experience	To understand perceptions on the extent to which climate/temperature affects patient health	6. Do you think climate, especially temperature affects health based on hospital admissions and mortality? 7. Can you explain what you have observed (eg, more patients on particularly hot days). 8. Which diseases have you observed to be the most sensitive to climate/temperature? 9. Based on your day to day observations, do you see an

			association between temperature and CVDs? 10. Do you think we will see an increase in the CVD deaths attributable to temperature in the future?
	Population vulnerability	To understand views on how different people are affected based on demography	5. Which people have you observed to be the most vulnerable to temperature? (eg, age, gender, occupation, SE status etc) 6. Do you see a big gender difference in CVD patients with and without the influence on external temperatures? 7. Have you observed an association between age/gender and temperatures? For example, are a certain group of people more susceptible to heat or cold? 8. Do the public and private sectors work together during disasters? - How is the communication, facility and equipment sharing?
	Education and training	To understand level of training and awareness among doctors on climate sensitive diseases	6. Have you ever been explicitly trained, either during medical school or professionally, on climate sensitive diseases? 7. If yes, where did the course take place (India or abroad, college or professional) and what did it cover (broadly) 8. If yes, did the course include CVDs?

			9. Did it include gender differences in terms of symptoms? 10. Do you think such a course is needed or would be beneficial?
	Measures to be taken	To discuss possible measures to be taken to increase awareness and preparedness on climate sensitive diseases	3. Assuming that we will be seeing an increase in CVD mortalities attributable to temperature in the future, what measures do you think can be taken to prepare and adapt to it? - In hospitals, in medical schools, - Give an example..early warning systems, emergency cardio bays in hospitals, awareness drives etc 4. What policy measures do you feel would benefit with the issue of climate sensitive diseases? For CVDs?
Health department (policy makers, ministerial representatives)	Current policies	To understand current health policies and whether climate change in included in them- include CVD policies and training	4. Do any of the current health policies include climate change? 5. Are there any specific policies on climate sensitive diseases? - Guidelines for disasters - Guidelines for heat 6. If yes, do any policies include NCDs or CVDs specifically?
	Challenges and outlook	To understand current challenges and future plans	8. The national adaptation plan recently added health as one of its climate change missions- why do you think

			this was not always a priority? 9. FOR PUDUCHERRY- Why is there no health mission in the state adaptation plan? Are there plans to include it? If yes, what diseases will be focused on? 10. Are any activities being planned around climate sensitive diseases especially CVDs? - Awareness programs - Education and training in medical schools? 11. Are there any plans to develop and expand heat action plans nationally? (eg. Ahmedabad heat action plan) 12. Which diseases will be a priority area for climate sensitivity in terms of policy and research? 13. Is there any research or study being conducted on the health impacts of climate change? Are there any plans to do so? 14. CVD effects and most other effects of climate change affect vulnerable populations most-how do you plan to address some of these challenges? - Rural vs urban exposures and requirements differ. Are there plans that specifically target different populations? - What about different communities? Do you feel different

			communities have different needs to protect themselves against the climate? Can you elaborate? - What about different SE groups?
Department of Science, Technology and Environment	Current policies	To understand the development process of the adaptation plan and how health is included in current policies	7. The adaptation plan has recently added a health mission, but it does not have a comprehensive list and guidelines for climate sensitive disease management? 8. The adaptation plan is an intersectional plan with involvement from many departments. Does the steering committee have regular meetings to review and stay perpared, if so how often? - Review meetings? - Do you make changes to the plan based on new evidence or incidences? 9. Is there a reason that NCDs such as CVDs, despite having a huge burden of disease are not explicitly included and researched in terms of climate attributable burden? 10. What plans/programs/campaigns are presently ongoing that deal with climate-health adaptation? Are there any specific to CVDs? 11. Can you tell me about any plans or policies that have been previously implemented on the topic of climate sensitive diseases?

			- Were they successful and effective? - What is the present status of these? - What were the biggest challenges faced? 12. CVD effects and most other effects of climate change affect vulnerable populations most-how do you plan to address some of these challenges? - Rural vs urban exposures and requirements differ. Are there plans that specifically target different populations? - What about different communities? Do you feel different communities have different needs to protect themselves against the climate? Can you elaborate? - What about different SE groups?
	Challenges and outlook	To understand challenges faced and future plans	5. What is the biggest challenge in formulating and implementing climate sensitive disease policies or policies related to climate impacts on health? 6. Are there any plans to include NCDs and CVDs as a separate component of climate sensitive diseases? 7. Are there research projects planned on this topic to inform priority setting and policy formulation?

			8. What measures do you think need to be taken to help formulate better , more comprehensive climate change policies that are informed by health research?
			The adaptation plan is an intersectional plan with involvement from many departments. Does the steering committee have regular meetings to review and stay perpared, if so how often? 9. Review meetings? 10. Do you make changes to the plan based on new evidence or incidences? 11.
EDUCATION- either department or medical college educators	Current practices	To understand current medical curriculum and whether climate change is included in it	12. Does the current medical school curriculum include climate change with respect to diseases that are sensitive to it? 13. Do you feel this needs to be taught? 14. Do you think temperature affects diseases? 15. What diseases do you think are most sensitive to climate change that need to be included in the curriculum? 16. If yes to above questions, does it include gender differences?
	Challenges and outlook	To understand challenges in teaching students about climate change and plans for future along with suggestions	4. Are there any plans to include climate sensitive diseases in the curriculum? 5. What other measures do you think can be taken with respect to the training of medical workers to reduce

			the burden of climate sensitive diseases? - Ex, emergency bays, more ambulances or staff during days of particular temperature etc

2. Participants profile

***Table S11:** Profile of the participants interviewed in this study*

Sector/background	***n***	**Females**	**Males**	**Age range (Years)**	**Range of experience (Years)**
Medicine (in-practice)	8	0	8	32-51	3-20
Medicine (research/academic)	3	1	2	40-44	11-20
Environment/governmental	5	2	3	28-53	4-30
Total	16	3	13	28-53	3-30

***Table S12:** Structural codes and framework matrix.*

Theme	Sub-theme	Categories
Climate change and health: systems knowledge and perceptions	Climate change as an acute and growing problem for India	
	Domino effect on impacts of climate change ultimately converges at health	
Role of institutions	Political and institutional barriers	Limited knowledge and awareness on climate change and health related policies
		Disengaged leadership and low political prioritization of climate change and health
		Weak inter-departmental integration and co-ordination for climate change and health

	Educational and informational barriers	Gaps in climate change and health in higher education curricula
		Need to strengthen inter-sectoral information dissemination
		Scepticism and low awareness on non-conventional health impacts of climate change
	Technical barriers to research	Insufficient resources and workforce dedicated to research
		Underdeveloped transdisciplinary research capacity
		Research slowed by availability and access to quality data
Socio-cultural dynamics, outreach and engagement	Need for alternate solutions, targeted campaigns and programs at all levels	
	Role of experts and famous personalities in awareness building	
	Climate informed health policies and seasonal workplace guidelines	
	Integrating climate change in the curriculum and continuing educational courses	

6. Additional supporting quotes

i. Institutional Knowledge and perceptions: Limited knowledge and awareness on climate change and health related policies

"Priority areas means, uh, for example, climate change in the health department, there is no clear cut guidelines is there. There is no clear cut guidelines, there is no clear cut programs are not there regarding climate and health." #16, Practicing physician

ii. Institutional barriers: Disengaged leadership and climate change not seen as immediate health concern

"When we practice medicine, because we are more concerned with treating the patient rather than you know, going and finding out the cause and prevent the incident in happening. So there the problem is a disconnect between, uh, what is happening (and) the preventive aspects, we were not able to quantify, especially in our setup here in India." #2, Medical doctor/academic

iii. Institutional barriers: Integration of climate change-health as a separate, inter-departmental body

"Because one thing is, it is not about criticizing some other officer, it is like they have to do their work, not other department's work. So then the head should accept that they have to spare their times [for] this climate change work.. It depends on who the nodal officer is, who the higher officer is, and who the head of the bureaucracy is. So when people are okay with working on this, things would be fine. But people don't care things will be the other way. So, in short, I would say that it has to come from the top down approach." #9, Environmentalist

iv. Technical barriers: Availability and access to quality data slowing down research progress

"The state government has the, uh, database. We may not have a line list. So without line list we cannot call it as database, but they will have each primary health center how many patients with NCDs, diabetes, hypertension, stroke, they have the data. So that is there. But, uh, I think last two to three years only they started screening households for diabetes, hypertension and cervical cancer, but not specifically targeting high risk groups. For the private side, we don't have the database on how many are-It's not like a tuberculosis program. We have the line list, total line list of whether they are part of the public health program or the private. So there we will have a database of patients but not for the non-communicable diseases." #3, Medical doctor/academic

v. Technical barriers: Need for more resources and workforce dedicated to research

"One is like, if you know, India should actually allocate more funds from the GDP towards the health sector. Actually, if you speak, there is not much of research work going on. Probably in the last like three to four years, it might have picked up… Most of the Indian government funding is going to the Central Institutes. For example, if you go to any government, hospital, state run government hospital, they don't have any separate data entry and don't have any separate research. You should bringing the students into the studies, which are happening only in the institutions not in the state run hospitals. Because they actually- many funds are- see now also funds are coming to state. They're giving directly to the institutes. But no one knows where the fund goes. Ultimately, it doesn't reach the students. It disappears at the level of consultants."#14, Practicing cardiologist

"Definitely they will select the more burden because the more causing immediately they will put a resource on that. So that climate change part, maybe they are giving a least preference. That's why it's not that much implemented." #16, Practicing physician

vi. Technical barriers: Scepticism and low awareness on non-explicit health impacts of climate change

"*When it comes to non communicable disease, one is this relationship it's also is not synced into us…Once people know that this is going to happen, then actually there's a percolation of knowledge that 'climate change is affecting this, and you have to look for it.' But as of now, if I go and tell a clinician that climate change is affecting NCDs, or cardiovascular disease, they will be laughing at me. They tell it's the lifestyle diseases, which is affecting them. So I'll be a fool actually for talking to them…Even if I work on it and show, if I don't have expertise, they're going to snub me off tell that "no, it's only a remote, it could be this, it could be a confounding, it could be a bias."* #4, Medical doctor/academic

vii. Technical barriers: Need for transdisciplinary research capacity

"One important thing that I would like to register is we ourselves need to participate in certain workshops which are done by certain other people, for example, DST [Department of Science and Technology] from New Delhi. For example, in the last two years, the only technical work that we've done for our city, is like this vulnerability assessment. But…we in our cell, or even officials here, we are not pre-sensitized with all these things. So only when we take up learnings from outside, we can execute that for our city, for our state." #9, Environmentalist

viii. Specific challenges in studying the cardiovascular impacts of climate change

"In hospitals, even this point of you know, we are expecting more of even this trend of increased changing of our climate and (that) has to be made aware to people. (When we were discussing on the topic of climate change) when it went to the clinicians, they're like, "how is it going to help me? It's not going to help me". They are very careful with the infectious disease..."#4, Medical doctor/academic

"But non communicable disease, like cardiovascular disease, no one tells complaints noone also correlates all those things. They just think of diabetes, hypertension, cholesterol, and all these things maybe because of the elevated sugar, and the BP it might have got the ,uh, cardiac complaint. Now one doesn't correlates all the things since he has gone in the rainy-rain or since he has got the cold. Noone correlates. And I think we should also think about all those things." #13, Practicing physician

Appendix E

Chapter 8 Supplementary Material

Cross-sectoral actions

Management of CVD determinants

We identified several cross-sectoral themes related to managing the determinants and risk factors of CVDs and related NCDs. The need for multi-stakeholder collaborations on activities to reduce NCD and CVD risks through tobacco, alcohol, diets and physical inactivity were laid out in several analysed policies, along with health promotion and population based NCD screening (NAPCPD, NNAPNCD, NMAPNCD, NAPMFNCD).

There were several policies, which laid out specific guidelines to protect vulnerable populations, which involved NCD or CVD management. These included guidelines for protecting schoolchildren from HRIs during extreme weather (NAPHRI, NAPCCHH). Another area for protection included occupational vulnerability, through the establishment and strict implementation of occupational health standards, including regular health checks for air pollution related diseases (NAPCCHH); using the National Policy on Safety, Health and Environment at Workplace (2009) to frame comprehensive health promotion strategies, including tobacco awareness, availability of healthy food and promoting alternate livelihood options to beedi (cottage tobacco industry) rollers under the Beedi Workers Welfare Fund Act (1976) (NMAPNCD, NAPMFNCD). There were also mentions of multi-sectoral collaborations to include air pollution and health impacts for health professionals and protecting women and children from indoor air pollution (NAPDAP).

We found several policies supporting the strengthening of policies and legislations for healthy diets, reducing food with high trans-fat, salt and sugar content, junk food and artificial food colouring, especially for children (NAPCCHH, NMAPNCD, NAPMFNCD) as well as a call to increase access to healthy food (NMAPNCD, NAPMFNCD). A proactive approach to nutrition was also recommended as 48% of children under 5 are malnourished and 55% of women and 24% of men are anaemic, which is further threatened by climate change (NAPCCHH, NAPCC). Revising national nutrition policy (1993) and national nutrition action plan (1995) to address the new paradigm and include latest standards on salt, saturated fat, sugar levels which are a risk for chronic diseases was also mentioned (NMAPNCD, NAPMFNCD).

There were policies discussing the need for enhances policies to reduce air pollution through activities such as regular emission checks for vehicles; supporting companies with policies that reduce vehicular travel; bans on biomass and waste burning; reducing indoor air pollution through incentives such as promoting clean cooking fuel, especially in tribal and socio-economically backward areas (NAPCCHH, NAPDAP, NAPMFNCD).

CVD co-benefits of education, awareness and communication on climate impacts

The NAPPCCHH included a proposal to revise curricula to include adaptation and mitigation components and the NMAPNCD proposed including healthy lifestyles in the National Curriculum Framework. There were also mentions of conducting operational research and evaluation studies (NAPCCHH). There were several proposed sections related to healthy schools, which could potentially include a climate component in the future. These included implementing monitoring actions for prohibiting the sale of unhealthy foods in educational institutes and promotion of healthy foods; promoting physical activity; tobacco free schools; low salt and saturated fat diet in mid-day meal programs; displaying health promotion messages in educational institutes (NMAPNCD); improving air quality in educational institutes (NAPCCHH); sensitizing teachers and students to use the Air Quality Index, especially when planning outdoor activities (NAPCCHH); and analysing the economic and financial implications of climate change and air pollution on health (NAPCCHH).

Several policies contained references to communication and awareness generation for both climate change and health. The use of media was prominently featured in this regard, including media campaigns on impacts of climate change, publicizing climate change and air quality alerts (NAPCPD, NAPCCHH); informed mass media campaigns, folk or popular culture to raise awareness on all aspects of NCDs, especially risk factor prevention (NMAPNCD, NAPDAP); enforcing relevant provisions of the Cable Television Networks Act (1995) to regulate tobacco advertisements (NAPCCHH); using the media and NGOs to disseminate success stories and raise awareness on methods to promote preventive measures and first aid to reduce the health impacts of extreme weather and air pollution (NAPCCHH, NMAPNCD); developing policies for media houses to allocate free air time for health promotion messages, especially for NCDs, in local languages through Corporate Social Responsibility (CSR) (NAPCCHH, NMAPNCD); and regulation of advertising, marketing and promotion of unhealthy food to children (NMAPNCD, NAPMFNCD). There were also references to developing information, education and communication (IEC) and advocacy material in local languages, training modules and communication plan for disseminating health alerts (NAPCCHH, NAPCC).

Climate resilient and sustainable infrastructure and technology

Two policies included the mention of "green" health systems through the use of renewable energy, water conservation and efficient resource consumption. There were also mentions of disaster management guidelines for hospital safety released focus on making health facilities resilient to climate change related disasters, including heat, cold, waves, floods and droughts; regular infrastructural maintenance of critical facilities; capacity building among design engineers, project planners and financial institutions to incorporate elements of disaster management (NAPCCRD, NAPCC).

We found proposals to improve green area conservation to improve health, rainwater harvesting (HVACC); upgrading building bylaws proposed by the Indian Public Health System to adapt to the changing climate scenario and region specific vulnerabilities (NHACCRD, NAPCC); improving architectural design to allow for more energy efficiency, including temperature control (NAPCCHH, NAPCC) and notifications on Environmental Impact

Assessments to reform environmental assessment prior to construction and promote environmental sustainability (NAPCC).

We also identified actions pertaining to urban infrastructure such as providing safe and improved public transport, including temperature controlled buses and trains, at affordable prices (NAPCCHH, NAPCC); expansion of metro rail systems in major cities, imposing congestion tax to discourage the use of private cars in cities with sufficient public transport capacity (NAPCC); improving walkability and access to educational institutes with non-motorized transport (NAPCCHH); and promoting physical activity in urban areas along with preserving environments supporting physical activities in community settings such as walking and cycling infrastructure (HVACC, NAPMFNCD).

Table S13: *Status of SAPCCHH in all the Indian states and the inclusion of CVDs in these plans.*

No	State	SAPCCHH availability thorugh NCDC	CVDs listed	VA/data for CVDs
1	Andaman and Nicobar Islands	NO	N/A	N/A
2	Andhra Pradesh (draft)	YES	Yes	No
3	Arunachal Pradesh	YES	No	No
4	Assam (draft)	YES	Yes	No
5	Bihar	YES	Yes	No, but do for HRI
6	Chandigarh	YES	No	No
7	Chhattisgarh	YES	No	No
8	Dadra and Nagar Haveli and Daman & Diu (draft)	YES	Yes	No
9	Delhi	NO	N/A	N/A
10	Goa (incomplete/draft)	YES	No	No
11	Gujarat	YES	No	No
12	Haryana (template)	YES	Yes	No
13	Himachal Pradesh (template)	YES	Yes	No
14	Jammu and Kashmir (Jammu division) (template)	YES	Yes, but section missing	No
15	Jammu and Kashmir (Kashmir division) (template)	YES	Yes	No
16	Jharkhand	YES	Yes	Partial

17	Karnataka (draft)	YES	Yes	No
18	Kerala (draft)	YES	Yes	For HRI
19	Ladakh	NO	N/A	N/A
20	Lakshadweep	NO	N/A	N/A
21	Madhya Pradesh (draft)	YES	Yes	No
22	Maharashtra	NO	N/A	N/A
23	Manipur (template)	YES	Yes	No
24	Meghalaya (template)	YES	Yes	No
25	Mizoram	YES	Yes	No
26	Nagaland	NO	N/A	N/A
27	Odisha	YES	Yes	No
28	Puducherry	YES	Yes	Partial
29	Punjab	YES	Yes	Yes
30	Rajasthan	NO	N/A	N/A
31	Sikkim (draft/template)	YES	Yes	No
32	Tamil Nadu (draft)	YES	Yes	No
33	Telangana	NO	N/A	N/A
34	Tripura (draft- 9 pages)	YES	No	No
35	Uttarakhand (draft)	YES	Yes	No
36	Uttar Pradesh	YES	Yes	No
37	West Bengal (provisional)	YES	Yes	No

Table S14: *Other national level policies included in the review*

No	Policy name	Abbreviation	Year	Type	Sector	Source/Deprartment
1	National Health Policy	Health policy	2017	National policy	Health	Ministry of Health and Family Welfare
2	National Environment Policy	Environmental policy	2006	National policy	Environment	Ministry of Environment, Forest and Climate Change

Curriculum vitae

Shreya Shrikhande

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EDUCATION

- **PhD candidate in Epidemiology** **[2019-June 2023]**

Swiss Tropical and Public Health Institute, University of Basel, Switzerland

- **MSc Cardiovascular Science** **[2016-2018]**

University of Göttingen, Germany

- **BSc (Honours) Biomedical Science** **[2013-2016]**

Royal Holloway, University of London, England

- **Higher Secondary Certificate (Arts and Humanities)** **[2011-2013]**

Fergusson College, Pune, India

AWARDS AND CERTIFICATES

• EU Horizons 2020 Marie Curie Global P3HS fellowship (in connection with PhD position) •OMEGA-NET scholarship for course on Occupational Epidemiology • Swiss Plexus fellowship for summer school in public health policy, economics and management • Royal Holloway Passport Gold award for exceptional volunteering • Swiss School of Public Health ScienceFlashTalk winner 2022

Certificates and courses • Filmmaking for scientists • Scientific writing process • Occupational epidemiology (non-standard employment, work environment and health) • Sustainable development, politics, natural resources and health systems from a conflict perspective • Social inequalities and social problems in health • Non-communicable disease control and systems strengthening approaches • Land and the 2030 agenda

PROFESSIONAL EXPERIENCE

- **Intern**/***World Health Organization***, *Switzerland* **[April 2023- present]**

Intern in the Policies and Interventions for Environment and Health Unit within the Department of Environment, Climate Change and Health (ECH) at the WHO. Carried out an overview of systematic reviews to develop a repository of systematic reviews on interventions in all ECH topics.

- **PhD Candidate/*Swiss Tropical and Public Health Institute***, *Switzerland* **[2019-present]**

Researching the impacts of climate change on cardiovascular diseases in India and South Africa. Awarded the EU Horizons 2020 Marie Curie Global P3HS fellowship for planning a multi-disciplinary project involving statistical modelling, qualitative stakeholder studies and policy analysis. Undertook several specialised training and interest-based transferable skills courses. Project results communicated through scientific publications, presentations at conferences and multi-media science communication. Experience in successfully applying for research grants and building international collaborative networks.

- **Research Assistant, *University of GÖttingen,*** *Germany* **[March 2017-September 2018]**

Associated with the Department of Developmental Biochemistry. Worked on a project that used the fruit fly, *Drosophila* melanogaster, as a model to study cell migration and signalling in cancer research. Assisted in planning and running experiments and analysing data.

- **Residential Support Assistant/*Royal Holloway, University of London,*** *UK* **[September 2015-June 2016]**

Part of a small team of nine students responsible for student welfare in the campus halls of residence, acting as a liaison between the students and college. Training for this role included conflict management and mediation. Handled several serious incidences when on call throughout the night.

- **Student Ambassador/*Royal Holloway, University of London***, *UK* **[November 2013-June 2016]**

Recruited and trained to represent the college at various events, including Open Days and education fairs. Role included conducting campus tours and interacting with potential students and parents.

RESEARCH, VOLUNTEER AND LEADERSHIP EXPERIENCE

- **Student Supervisor/*Swiss Tropical and Public Health Institute,*** *Switzerland* **[December 2020-August 2022]**

Supervised two Master’s students during their thesis, from initial proposal writing and project planning, analysis and data presentation to final thesis defence. Role included mentoring, tutoring and editing written work.

- **MSc Thesis/*University of Pompeu Fabra,*** *Spain* **[January 2018- June 2018]**
  - **Thesis:** Functionalization of gold nanoshells for the early detection of cardiac ischemia.

- **Lab rotation/*King Edward Memorial Hospital,*** *India* **[August 2017-October 2017]**

Conducted a project describing and characterising long-segmental aortic thrombosis in the Indian population for the first time through a retrospective cohort study.

- **Lab rotation/ *University of GÖttingen,*** *Germany* **[April 2017-June 2017]**

Carried out a project using stem cell engineered cardiac muscle units to test the effects of various pharmaceutical products in the Zimmerman Lab of the Department of Pharmacology.

- **BSc Thesis/*Royal Holloway, University of London***, *UK* **[June 2015-December 2015]**
  - **Thesis:** *Dictyostellium discoideum* as a biomedical model to the test the effect of quercetin and tannic acid on heart disease.

- **Community Action International Team Leader**/***Royal Holloway, University of London,*** *UK* **[September 2014-June 2016]**

Led/co-led (planning, organization and management) several projects including teaching English to young refugees and asylum seekers. Played a key role in launching and establishing 'Contact the Elderly', a project aimed to reduce loneliness among the elderly living alone. Built relations with partners and provided sensitivity training for volunteers working with vulnerable people.

- **Volunteer at Grassroots/***United Kingdom* **[October 2013-February 2014]**

Worked with people with neurological and psychological challenges, helping to better integrate them into society through a series of activities including creative and tactile projects, like gardening.

- **Intern/*Deep Griha Society***, *India* **[July 2014-September 2014]**

Worked at NGO that works with socio-economically disadvantaged people in Pune. Part of the project on HIV and responsible for researching and answering anonymous queries about HIV, helping to organize a matrimonial event for HIV positive people.

- **Volunteer and Intern/*Protecterra Ecological Foundation,*** *India* **[December 2010-2014]**

Led book and nature clubs, helped organise awareness campaigns and fundraising events and assisted at various nature camps for children.

PUBLICATIONS

- ^Shrikhande, S., Wolf, J., Vert, C. *et al.* World Health Organization repository of systematic reviews on interventions in environment, climate change and health: a new resource for decision makers, intervention implementers, and researchers. *Environ Health* **23**, 88 (2024). https://doi.org/10.1186/s12940-024-01105-y
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- *Shrikhande, S.S., Pedder, H., Röösli, M. *et al.* Non-optimal apparent temperature and cardiovascular mortality: the association in Puducherry, India between 2011 and 2020. *BMC Public Health* **23**, 291, **2023.** https://doi.org/10.1186/s12889-023-15128-6
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- Muñoz-Ortiz T *et al*. Molecular Imaging of Infarcted Heart by Biofunctionalized Gold Nanoshells. *Adv Healthc Mater*, **2021 F**eb 17:e2002186. doi: 10.1002/adhm.202002186 (MSc Thesis)

(*Peer-reviewed publications for PhD thesis; ^Peer-reviewed publication as part of internship done within the framework of the Marie Skłodowska-Curie grant agreement No 801076, through the SSPH + Global PhD Fellowship Programme in Public Health Sciences)