EXTREME WEATHER EVENTS AND HUMAN HEALTH IN SOUTH AFRICA: IMPLICATIONS FOR CLIMATE SERVICES

by

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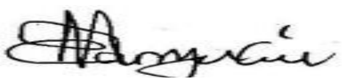
DECLARATION

I **Albert Edgar Manyuchi** declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

__28th _______day of __October_________________2022_______at_Johannesburg



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Albert Edgar Manyuchi

ABSTRACT

Extreme weather events (EWEs), defined as 'weather events that are rare at a particular place and time of the year', have increasingly been affecting many countries worldwide (IPCC 2014). The increased occurrence and intensity of EWEs, among other factors, has increased public interest and demand for climate information. More detail is needed on EWEs and how they can be more effectively coupled to climate services in Africa. This study brings a compendium of empirical evidence, conceptual clarity and transdisciplinary approaches to policymakers, researchers and practitioners dealing with these crucial issues. The main aim of this study is to explore the human health effects of EWEs, particularly heat and the delivery of climate services for health in Africa. Through a systematic review, the study examines the potential impacts of heat on human health in Africa. Using a case study approach heat-health effects are evaluated including the status of climate services in the Agincourt subdistrict of South Africa. A novel systems theory-based conceptual framework and an inclusive analytical framework are employed to explore climate services delivery within the context of climate change adaptation.

The study produces two main findings. First, EWEs particularly heat, potentially affects human health in Africa by changing mortality and morbidity patterns. In the Agincourt sub-district in particular, heat may be associated with adverse health effects on vulnerable populations, including inter alia the elderly, children and outdoor workers. Despite this, Africa-specific heat-health interventions and policy suggestions are scarce. Second, climate services are generally in embryonic stages of development and climate services for health in Agincourt subdistrict are non-existent. Within the South African context, the main barriers to delivery of climate services for health are paucity of interagency coordination and gaps in meteorological data. One of the key conclusions of the study is that African countries can promote development of climate services to adapt to EWEs such as heat. Heat, and heatwaves, for example, are already affecting populations, and are projected to increase in frequency and intensity with concomitant adverse effects on health outcomes on vulnerable population groups.

The three key recommendations from this study are as follows. First, African policymakers and practitioners must avoid a reductionist approach to analysis of EWEs, especially heat impacts and start viewing these as harmful to human health. Therefore, governments must prioritise interventions, create institutions and formulate policy measures to deal with the health effects of heat within their national adaptations plans. Second, African countries must prioritise policy mixes that promote climate services in general and climate services for health in particular. And finally, further policy-science research that generates empirical evidence for African policymakers and practitioners engaged in international negotiations and programmes for climate change adaptation and climate services should be encouraged.

Keywords: Africa, Climate Change, Climate Services for Health, Heat Events, Human Health.

STRUCTURE AND OUTPUTS OF THE THESIS

This thesis comprises articles already submitted for publication. Therefore, it is structured as follows: Chapters 1 and 8, which are the introduction and conclusion chapters followed by the papers for publication forming the main body of the thesis. Noteworthy, A.E. Manyuchi did the research and wrote the first manuscripts for chapters for chapters 2,3,5,6 and 7. All co-authors for chapters 2,3,5,6 and 7 are my research supervisors who reviewed and guided the manuscript writing and submission processes. The first author for chapter 4 is my supervisor who wrote the first manuscript and submitted it for publication, while the co-authors contributed to some sections and reviewed the final manuscript. All publications in this Thesis do not predate the PhD candidature. The structure and authorship of the chapters is as follows:

Chapter Number	Chapter Title	Authors and Author Contribution		Journal submitted to and impact factor		Status
		Author	% Cont	Journal Name	Impact Factor	
1	Introduction	A.E. Manyuchi	100%	None	None	Not for Publication
2	Extreme heat events, high ambient temperatures and human morbidity and mortality in Africa: A systematic review	A.E Manyuchi	30%	South African Journal of Sciences	2021 = 2.197	Accepted for publication
		C. Vogel	20%			
		M. Chersich	15%			
		C.Y. Wright	15%			
		R. Matsika	10%			
		B. Erasmus	10%			
2.3 (Chapter in appendix)	Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic Review and meta-analysis	M.F. Chersich	20%	British Medical Journal	19.697	Published
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2.4 (Chapter in appendix)	Climate change and control of diarrhoeal diseases in South Africa: Priorities for action	Boeckmann, M., Roux, T., Robinson, M., Areal, A., Durusu, D., Wernecke,B., Manyuchi,A., Pham,MD., et al., Climate Change and Heat-Health Group	10%	South African Journal of Medicine	1.500	Published
3	The self-reported human health effects associated with heat exposure in Agincourt sub-district of South Africa	A.E. Manyuchi	40%	Humanities and Social Sciences Communication	None	Published
		C. Vogel	25%			
		C.Y. Wright	25%			
		B. Erasmus	10%			
4	Climate Services in Africa: Re-imagining an inclusive, robust and sustainable service	C. Vogel	40%	Climate Services	5.656	Published
		A. Styenor	30%			
		A.E. Manyuchi	30%			
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Chapter Number	Chapter Title	Authors and Author Contribution		Journal submitted to and impact factor		Status
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5	Systems approach to climate services for health	C. Vogel	25%			
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		C.Vogel	25%			
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		B. Erasmus	10%			
7	The status and content of climate services for health in Agincourt subdistrict in South Africa	A.E Manyuchi	40%	Climate Services	5.656	Under Review
		C. Vogel	25%			
		C.Y. Wright	25%			
		B. Erasmus	10%			
8	Conclusions	A.E. Manyuchi	100%	None	None	Not for publication

DEDICATION

In memory of my sister

Evangelista Taurai Manyuchi

23 January 1981 – 7 May 2021

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ABBREVIATIONS

ACMAD	African Centre of Meteorological Application for Development
ARC	Agriculture Research Council
BRACED	Building Resilience and Adaptation to Climate Extremes and Disasters
CCAS	Climate Change Adaptation Services
CSAG	Climate System Analysis Group
CSC	Climate Services Centre
CSIS	Climate Services Information System
DALY	Disability-Adjusted Life Year
DWD	Deutscher Wetterdienst
ECDC	European Centre for Disease Prevention and Control
EHP	Environmental Health Program
EMoH	Ethiopian Ministry of Health
EWEs	Extreme Weather Events
FCFA	Future Climate for Africa
FOCUS-Africa	Full-Value chain Optimized Climate User-centric Services for Southern Africa
FRACTAL	Future Resilience of African Cities and Lands
GCI	Global Change Institute
GCOS	Global Climate Observing System
GFCS	Global Framework for Climate Services
HDSS	Health and Socio-Demographic Surveillance System
HHAP	Heat Health Action Plan
HHWS	Heat- Health Warning System

ICPAC	Intergovernmental Authority on Development Climate Prediction and Application Center
IPCC	Intergovernmental Panel on Climate Change
IUCMA	Inkomati-Usuthu Catchment Management Agency
KNMI	Royal Netherlands Meteorological Institute
MoH	Ministry of Health
NHI	National Health Insurance
NIHHIS	National Integrated Heat Health Information System
NFCS	National Framework for Climate Services
NMHS	National Meteorological and Hydrological Services
NMSoE	National Meteorological Services of Ethiopia
NOAA	National Oceanic and Atmospheric Administration
RCC	Regional Climate Centre
RCLOs	Regional Climate Outlooks
SADC	Southern African Development Community
SADC CSC	Southern African Development Community Climate Service Centre
SAMRC	South African Medical Research Council
SANParks	South African National Parks
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SAWS	South African Weather Service
UNFCCC	United Nations Convention Framework on Climate Change
UK	United Kingdom
USA	United States of America
US-CDC	United States of America Centres for Disease Control
US-EPA	US Environmental Protection Agency

WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use
WCRP	World Climate Research Programme
WISER	Weather and Climate Information Services for Africa
WHO	World Health Organization
WMO	World Meteorological Organisation

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INTRODUCTION

1.1 Chapter Overview

In this chapter, a summary of the research background, research problem, research questions, research approach and methodology, as well as the structure of the thesis are presented. The overarching aim of this research was to provide new Africa-specific empirical evidence on extreme weather events (EWEs), especially impacts of extreme heat events on human health. The aim was to assess the evolution and efficacy of evolving climate services, particularly climate services for heat-health, and to inform community adaptation and resiliency, adaptation policies and practice.

1.2 Background

It is now axiomatic that climate change and variability are likely exacerbate the frequency and intensity of global environmental risk factors, including inter alia EWEs (Martinez Garcia and Sheehan, 2016). EWEs have been defined as 'the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable'(Lal et al., 2012, p.5). EWEs include high ambient temperatures (heat), heatwaves, cold waves, floods, droughts, hurricanes, tropical cyclones, heavy rain, windstorms and snowfalls (Hashim and Hashim, 2016).

There is mounting evidence that in most parts of the world, the frequency, intensity and duration of EWEs associated with climate change and variability are on the increase (IPCC, 2021). EWEs are likely to affect human health both directly and indirectly through inter alia causing morbidities and mortalities as well as promoting the proliferation of water and vector-borne diseases. The health risks or impacts of an EWE are a function of the severity, duration, surprise, category, and nature and degree within the category (Hashim and Hashim, 2016).

Among other recurring EWEs, the adverse health effects of hot weather and heatwaves have been investigated in existing literature (McMichael et al., 2008; Huang et al., 2011; Russo et al., 2014; Smith, Elliot, Hajat, Bone, Smith, et al., 2016; Ana M. Vicedo-Cabrera et al., 2018; Manyuchi et al., 2018). Most studies associate temperature extremes, especially heat and heatwaves, with heat-related morbidity and mortality (Bell et al., 2008; Oudin Åström et al., 2011; Xu et al., 2013; Benmarhnia et al., 2016; Guo et al., 2017; Yin and Wang, 2017;

Wichmann, 2017; Ahmadalipour and Moradkhani, 2018; Green et al., 2019; Vanos et al., 2020). Indeed, extreme heat has adverse effects on human health and wellbeing as well as productivity.

Demographic or individual factors make some individuals more vulnerable to heat exposure, including age (infants and the elderly), gender, and pre-existing or underlying health conditions (acute, chronic health conditions) (Bittner et al., 2014; Lunze and Hamer, 2012; Schifano et al., 2009; Kovats and Hajat, 2008). These individual factors are mediated by socioeconomic factors, for example, poverty, low economic status, low educational level, being homeless, social isolation, lack of air conditioning, as well as environmental conditions, including air pollution, poor housing, occupational exposures and living in urban areas, to influence heat-health outcomes (World Health Organization, 2011). Existing research and projections, albeit complex and informative in understanding the health impacts of heat highlighting some of the intricacies of human physiological responses to heat that are crucial for determining vulnerability to heat, have remained less clear (Vanos et al., 2020). Therefore, it is important to be cautious when attributing morbidity or mortality to heat or any other EWEs (Sippel et al., 2015; Stott et al., 2016).

There are several emerging interventions to the health impacts of EWEs, including heat encompassing surveillance systems, early warning systems and heat-health plans (Kovats and Hajat, 2008; Lowe et al., 2011; Smith, Elliot, Hajat, Bone, Smith, et al., 2016). The use of climate information is central to responding to heat. Climate services are defined as the,

> ‘transformation of climate-related data - together with other relevant information - into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices development and evaluation of solutions and any other services in relation to climate that may be use for the society at large’ (Street, 2016, p.3).

Climate services are generally essential to individual and community adaptation as well as resilience to heat. Climate services have not been emphasised and valued as part of climate change adaptation initiatives. Possible reasons include a lack of skills to articulate relevant services, gaps in climate information and ability to translate climate information into useful interventions and programs (Thompson, 2011). It is imperative that adaptation and resiliency to heat effects on human health are included as a specific category of climate services, namely climate services for health. These are ‘the entire iterative process of joint collaboration between relevant multidisciplinary partners to identify, generate and build capacity to access, develop, deliver and use relevant and reliable climate knowledge to enhance health decisions’ (Shumake and Fernandez-Montoya, 2016, p.15). They involve the use of climate and environmental information in healthcare decision-making based on the realisation that climate is a key variable in managing the overall burden of disease and excess mortality, increasing life expectancy (Tadese et al., 2008).

Overall, despite acknowledging that increased and projected increased ambient temperatures or heat will adversely affect human health, the glaring knowledge gap is in connecting this information to actual implementable climate services and climate services for health – an omission that has important implications for setting the direction and focus for heat-health research. Therefore, the heat-health research described in this thesis focused on providing conceptually relevant, empirical evidence for heat-health policy and practice, with a special focus on Africa.

1.3 Problem-in-Context

Internationally, the impacts of EWEs on health are widely acknowledged, as evidenced in international policy documents, development plans, interventions guidelines and response actions. The African continent has experienced different types of weather-related extreme events such as heatwaves, floods and droughts, and these have been estimated to be around 1 560 over the past three decades (Russo et al., 2016). Despite this, the subject of EWEs is generally under-researched in Africa. A research emphasis on developed countries and temperate regions has led to the exclusion of most of the countries on the African continent (Lazenby et al., 2014). Yet, there is growing evidence that most African countries will be affected by climate change and variability, and this will aggravate the incidence of EWEs (Costello et al., 2009). Among the EWEs affecting African countries, events such as drought and floods have been studied more than others (Braman et al., 2013). Other studies have focused on vector-borne diseases, particularly malaria (Selemani and Mrema, 2018; Macherera et al., 2016; Caminade et al., 2014; Ermert et al., 2012; Omumbo et al., 2011; Graves et al., 2008; Ceccato et al., 2007; Tonnang et al., 2010; Thomas et al., 2004; Craig et al., 2004).

There is growing evidence showing that heat and heatwaves are increasingly affecting global population health (Vicedo-Cabrera et al., 2018). But there is no universal definition of "extreme heat", and this complicates the analysis of heat-health issues (The Lancet, 2018). From a physiological point of view, heat can be defined as elevated ambient temperatures that impair human cognitive and task performance and reduce comfort and tolerance. This definition simplifies many complex aspects of heat effects on the human body. Many factors influence individual human body responses to heat, including age, whether a person is obese, chronically ill and taking chronic medication, working indoors, underground or outdoors, working in an airconditioned or non-airconditioned environment, pregnant, doing sporting activities, taking an examination, the types of clothes worn, and acclimatisation, among others (Chersich et al., 2020; Kenny et al., 2010).

The United States Environmental Protection Agency (US-EPA) defines extreme heat as 'weather that is much hotter than average for a particular time and place—and sometimes more humid, too' (US-EPA 2016, p.3). This definition is much broader than that provided by the United States Centres for Disease Control (US-CDC), which defines extreme heat as summertime temperatures that are hotter or more humid than average for a defined location. While the US-CDC definition is narrow, it establishes an important aspect of the effect of seasonality and heat. In most places, heat effects on population health are more pronounced in summer. The definition implicitly alludes to location-specific differences in population exposure to heat, especially the differences in heat effects on persons living in urban and rural areas. Persons living in urban areas tend to experience more heat due to the heat island effect (Witze, 2021).

The different definitions of heat show that there are multiple dimensions to heat. Factors such as location, weather conditions encompassing humidity, temperature and cloud cover and the time of the year affect the occurrence, effects and definition of extreme heat. Notwithstanding the various dimensions of heat, an important investigation of one of the understudied dimensions of heat – the effects of heat on human health – was carried out in this study. The key dimension interrogated was how heat affects the health of the African population, particularly populations living in the Agincourt sub-district of South Africa.

Unlike the non-universal definitions of heat, the definition of heatwaves has evolved over time. In this thesis, heatwaves are considered the same as heat events or heat spells. In the past, meteorologists defined a heatwave as 'an increase of 5°C above the average maximum temperature from 1961-90 that lasts for 5 days or longer' (The Lancet, 2018, p.359). This definition has been refined over time. Most recently, a heatwave has been defined as 'a period of at least two days where both the daily minimum and maximum temperatures are above the 95th percentile of their respective climatologies' (Watts et al., 2019, p.6). This definition is widely accepted. It is comparable to the definition provided by the World Meteorological Organisation (WMO) (WMO 2019). It covers aspects encompassed in other definitions (Di Napoli et al., 2019). In addition, it captures 'the health effects of both direct heat extremes (i.e. caused by high maximum temperatures) and the problems associated with lack of recovery (i.e. caused by high minimum temperatures) over persisting hot periods' (Watts et al., 2019, p.6).

Heatwaves are also unique from many other EWEs because their close association with anthropogenic climate change is undisputed. To elaborate this, the WMO avers that 'almost every significant study of significant heatwaves since 2015 has found that probability has significantly increased by anthropogenic climate change. For example, Imada et al., (2019) found that heatwaves that affected Japan in July 2018 would have been impossible without human influence' (WMO 2019, p.15). Thus, clear attributions of heatwaves to human influence are significant and substantiated by recent research.

Apart from the definitional challenges, the policy responses to heat and heatwaves have generally been mixed. On the one hand, some developed countries whose populations have been affected by heat and heatwaves have crafted policies to prevent loss of lives and heat-related illnesses (Watts et al., 2015). The key policy responses to heat and heatwaves include identification of the most vulnerable and exposed communities, early warning systems, and effective contingency planning (Pascal et al., 2021). These countries have also created heat action plans (Matthies et al., 2008). The plans encompass training healthcare workers, altering urban planning and infrastructure to include green corridors and spaces, and improving the design of and constructing climate-sensitive social amenities such as transport, energy, health and school infrastructure (Issa et al., 2021).

The policy responses may differ, with some policies focusing on heat as an emergency necessitating prioritising life-saving actions, while others emphasise a vulnerability perspective premised on dealing with the persistent and chronic effects of heat on human health. In addition, the creation and execution of heat plans may follow top-down or bottom-up or integrated approaches (Ebi, 2019; Guardaro et al., 2020). Intrinsically, most heat and heatwave plans in developed countries cater for persons living in urban areas. These policy responses to heat form part of the national adaptation plans of the countries prone to heat and heatwaves.

On the other hand, most developing countries, especially in Africa, have not yet crafted policies for responding to heat and heatwaves (Nowak et al., 2021). The main barrier to creating policy responses for heat is the scarcity of empirical evidence that can inform policy makers on the effects of heat and heatwaves on population health in many of these countries (Thompson 2011). In addition, the integration of health and climate policies, as well as a human rights approach to population health, is lacking in most developing countries (Viveros-Uehara 2019). Existing literature shows that African policymakers' understanding of the effects of heat on population health is limited, which may be related to a lack of skills to interpret scientific information on heat trends and projections (Nana et al., 2019). For brevity, lack of human capacity and skills to develop policies for complex challenges, limited financial resources to deploy towards research, absence of public pressure and lack of political interest and have variously affected policymaking for heat events in Africa (Parkes, Buzan, and Huber, 2022). Of great concern to this study is that African countries lack explicit heat-health policies and have not integrated heat-health aspects in their existing national adaptation plans.

Apart from definitional and policy shortcomings in existing literature, it is important to point out that even though studies on heat have been carried out globally, their articulation of African exposure and vulnerability to heat is quite limited. The global studies have limited depth and breadth in their exploration and analysis of Africa-specific heat exposures and vulnerabilities. This research gap exists despite climate projections showing that African countries are already being affected and will continue to experience increased temperatures (Engelbrecht et al., 2015), as well as increased frequency and intensity of heatwaves (Mbokodo et al., 2020). Even recent Africa-focused studies have several limitations; for example, a recent literature review shows that key concepts such as "heat stress" in the context of Africa are not clearly defined and clear programme and policy recommendations for African policymakers are also lacking (Ncongwane et al., 2021).

These gaps in existing heat-health literature are of great concern because the health effects of heat are likely to affect population health at continental, sub-regional levels. At the sub-regional level, for example, increased maximum and minimum temperatures have been observed for many countries in Southern Africa over the past decade, and temperatures are projected to increase in various parts of South Africa in particular (Chersich and Wright, 2019). At national level, a study by Scovronick et al., (2018) observed that mean temperatures are warming faster in South Africa, especially in the past fifty years, while Byass et al., (2017) reported a trend towards increased temperatures in the Agincourt area of Mpumalanga in South Africa (Byass et al., 2017).

Africa-specific studies on heat and health are nonetheless limited. Notably, some studies have arrived at mixed findings on the association of heat and morbidity and mortality (Azongo et al., 2012). The mixed findings in the existing literature do not necessarily lead to any clear, verifiable proof that can be used in evidence-based policymaking and charting clear-cut directions for heat-health responses in Africa. Furthermore, not much is known in terms of climate services, particularly climate services for health and heat-health services on the continent. Given the mounting evidence showing that heat will variously affect African population health, it is concerning that literature on this subject is limited. The lack of studies on the effects of heat on human health deprives African policymakers and practitioners, as well as African communities, of opportunities to plan and act in an informed manner. African policymakers currently do not have access to a wide variety of empirical evidence on how to respond to heat-health impacts.

Both policymakers and practitioners on the continent are thus faced with a lack of clear conceptual frameworks that can act as guideposts on how to respond to heat effects of human health. This has caused several practitioners and policymakers to adopt reductionist approaches premised on discipline-based analysis of issues. In this case, scholars with Public Health leanings recommend Public Health approaches, while those with Environmental Sciences backgrounds make recommendations informed by their discipline. This approach has various limitations. Transdisciplinary approaches, it is suggested, are imperative in dealing with complex issues such as heat and health. Given this, this thesis advances transdisciplinary approaches to address the complex issues of heat effects on human health in Africa, particularly focusing on the Agincourt sub-district of South Africa.

1.4 Rationale for the Study

There are several reasons that justify and inform this study. First, the study assesses the extent to which Africa is experiencing and will be affected by extreme temperature changes, especially heat and heatwaves. Generally, existing studies have not been Africa-specific. Therefore, this study will provide new Africa focused evidence that will fill the existing knowledge gap in this area.

The second objective of the study is to investigate the connection between increased effects of heat on human health with the evolution of climate services and climate services for health. This study creates new knowledge in this critical area. Closely linked to this is an objective to probe the state of climate services in Africa, South Africa and the Agincourt sub-district. As such, the content or quality of climate services in Africa, the institutions and policies for delivering climate services are interrogated. Through a qualitative multiple embedded case study, the nature and coherence of climate services in South Africa and the Agincourt sub-district are examined.

The third objective is to examine the discourse of heat and health in Africa by reviewing existing literature and policies on this subject. Indeed, there is paucity in the extent to which African countries have created heat policies as well as examining the content of the policies and how they are being implemented. Underlying this objective is to investigate how inequalities in health services delivery disproportionately dispose populations to vulnerability to heat and heat events on the continent. Thus, the policy measures and responses to heat and heat events are investigated.

The fourth objective is to bring new knowledge and conceptual clarity on climate services in Africa and climate services for health in Agincourt subdistrict. Non-linear conceptual frameworks that explore delivery of climate services in general and climate services for health grounded on the African context in existing literature are underdeveloped and inadequate. The importance of non-linear conceptual frameworks is to elaborate iterations and feedback loops that exist between producers and users of climate services on the content. Given this, this study explores the feasibility of applying novel non-linear conceptual frameworks to explain the production and delivery of climate services, especially climate services for health on the continent. Opportunities for co-creation and endogenous growth of authentic climate services are further probed.

The fifth objective is to investigate the extent to which transdisciplinary approaches can be used to explore heat-health on the continent. It is acknowledged that disciplinary silos have continued to thrive and dominate knowledge generation on the continent. However, there is a genuine disquiet that continued exploration of complex and super wicked problems such as climate change and health in general, and heat-health in particular through strict disciplinary lenses will be inadequate. Hence, this study assesses whether transdisciplinary approaches can be used in the African context to explore the health effects of extreme heat.

1.5 Research Aim and Research Questions

The aim of this research was to explore the human health effects of EWEs, particularly heat and the related consequences on the delivery of appropriate climate services, including climate services for health in Africa.

The overarching questions the study attempted to answer are: In what ways do EWEs, especially heat, affect human health in Africa, and what implications does this have on the delivery of climate services, particularly climate services for health?

The subsidiary questions were:

1. What are the human health effects of EWEs, particularly heat in Africa and the Agincourt sub-district of South Africa?
2. What are the socioeconomic and demographic characteristics of persons susceptible to health complications from the heat in Agincourt sub-district of South Africa?
3. What is an Africa-relevant conceptual framework that can be used to explore climate services for health in Africa?
4. What is the status/conditions of climate services in Africa and climate services for health in the Agincourt sub-district of South Africa?
5. Which Africa-specific responses can be applied by African countries to respond to the human health effects of heat?

1.6 The Research Design and Methodology

1.6.1 Research Approach

In this research, qualitative research approaches were largely employed. Qualitative research can be defined as 'the systematic inquiry into social phenomena in natural settings' (Teherani et al., 2015, p.669). This research approach is generally used where researchers seek to '(a) share individual stories, (b) write in a literary flexible style, (c) understand the context or setting of issues, (d) explain mechanisms or linkages in casual theories, (e) develop theories, and (f) when traditional quantitative statistical analyses do not fit the problem at hand'(Colorafi et al., 2020, p.1).

The qualitative multiple embedded case studies presented in chapters 3 and 7 variously attempt to fulfil the six points highlighted in this immediate quote. Elaborate quotations that clearly articulate the voices of the community members residing in the Agincourt sub-district, as well as key informants, are presented in these chapters. As research participants explored the complex subjects of heat-health effects, climate services and climate services for health, invaluable empirical evidence grounded in the natural settings of the Agincourt sub-district was exposed. Presenting the results qualitatively allowed for the voices of the vulnerable communities to be heard and the complex research subjects to be explored in depth with communities vulnerable to climate change effects, something difficult to achieve had quantitative methodology been used.

It is important to note that 'qualitative research takes into account the natural contexts in which individuals or groups function to provide an in-depth understanding of real-world problems' (Korstjens and Moser, 2017, p.275). This research deals with a super wicked real-world African problem where data are insufficient to proffer tangible solutions (Lazarus, 2009; Peters, 2017). Precisely, the qualitative research approach was aptly used to explore a real-world problem on the effects of heat on human health in Africa and the evolution and delivery of climate services and climate services for health.

The philosophical orientation of the research is transdisciplinarity. This is closely aligned to the Mode 2 theory of knowledge production characterised by knowledge creation in the context of application, heterogeneity, heterarchical and transient engagements and socially accountable as well as reflexive ethos.(Gibbons, 1994) For this study, transdisciplinarity is considered an integrative, non-linear, unconventional and non-discipline-specific approach for dealing with complex real-world problems encompassing interactive learning and knowledge co-creation involving professionals and non-professionals.

This conceptualisation of transdisciplinarity is further explained in chapters 6 and 7. While in chapter 6, transdisciplinarity is characterised as an essential element of inclusive climate services for health, in chapter 7, it is a framework applied to assess the evolution and efficacy of the evolving climate services for health in the Agincourt sub-district. Overall, the transdisciplinary approaches, as applied in this thesis, 'link abstract and case-specific knowledge in order to grasp the complexity of real-world problems and to take into account the diversity within and between scientific and life world perceptions of problems' (Hegger et al., 2012, p.53). Transdisciplinarity is, therefore, a philosophical orientation that informs the conceptual study framework that guides the analysis of issues in this research as well as a methodological approach including triangulation of different data sources.

1.6.2 Research Methodology

The research methodology denotes the procedure the researcher used to explore the reality associated with the phenomena being researched. In this study, a case study methodology was used. According to Ebneyamini and Sadeghi Moghadam (2018), an all-encompassing definition of a case study methodology was provided by Yin, 2003. The broad definition states that,

> 'A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the object of study and context are not clearly evident. It copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to coverage in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis' (Tenny et al., 2021, p.18).

Several features of the case study methodology from the definition are worth elaborating on. First, it encompasses the study of a unit of analysis over time. Second, it involves obtaining in-depth data over the unit of analysis. Third, the data gathered are from a few entities, organisations or people. And finally, data are triangulated to provide a holistic picture of the phenomenon investigated.

In this study, a special type of case study methodology, namely the multiple embedded case study methodology, was used. A few cases were deliberately entrenched in the main case study. In this case, the climate services for health case study in the Agincourt sub-district is entrenched in the main case study on climate services in South Africa and the Agincourt area in chapter 7. Similarly, the systematic review on heat-health in Africa presented in chapter 2 is related to the subsequent case study on heat-health effects in the Agincourt sub-district presented in chapter 3. The cases are built through a triangulation of data sources, including systematically reviewed secondary literature on heat-health effects, heat interventions and responses in Africa (presented in chapter 2), international heat indicators (presented in chapter 3), as well as primary data gathered from face-to-face in-depth interviews and structured observations (presented in chapters 3 and 7).

There are several advantages to using the multiple embedded case study methodology and are worth pointing out. First, data on the research subject are scarce. Hence systematic data collection and interpretations helped in filling the data gaps. Second, multiple embedded case studies offer depth and detail of empirical evidence through description. Lastly, the methodology enabled certain propositions to be made and teased with respondents, as well as against existing literature, and this is imperative in building evidence to inform interventions and policies.

Purposive sampling was used in this research. As such, the most appropriate sample was selected according to the researcher's practical knowledge of the research area, appropriateness in answering the research questions, as well as insights from available literature. The choice of South Africa and the Agincourt sub-district was influenced by the availability of data, logistics considerations, the existing public relations between the SAMRC/ Wits Rural Public Health or Health Transitions Research Unit-Agincourt and the communities, among other factors.

Purposive sampling also encompassed inclusion and exclusion criteria for key informants. For example, it was determined *a priori* that the research must include key informants from weather services, the airport, education and health institutions, research institutions, the national park, as well as community leaders. Once these key informants were interviewed, a chain referral method, commonly known as snowballing, was ensured.

Data collection involved primary and secondary sources, interviews and structured observations. Primary data sources were untranslated/untransformed or unmanipulated by persons handling the data and were accessed directly from the officials or persons that had it through writing direct requests, calling or asking them during interviews and discussions. Primary data gathered included meteorological data, reports, health and demographic surveillance data, memos, written speeches, minutes of meetings, newspaper articles, bulletins, among others. Naturally, secondary sources were also gathered. These included inter alia published peer-reviewed journal articles, published reports, books and pamphlets.

Data were also collected through interviews and structured observations. In total, 93 study participants who provided informed consent were interviewed, divided into key informants and respondents, and the findings are reported in chapters 3 and 7. An interview guide was used to collect data from these study participants. Several outdoor venues where people could be observed working were also observed in a structured manner, as presented in chapters 3 and 7. A structured observation form was used to systematically populate information collected during the observations and the findings presented in chapters 3 and 7. As explained in each chapter, data were electronically processed.

1.6.3 Limitations of the Study

There are several limitations to this study. The study did not involve non-random sampling. Therefore, the findings have limited generalisations. However, where possible reasonable generalisations are made within clear parameters and explanations proffered. Response bias may have inadvertently affected the study. Triangulation of data sources and ingrained verification and quality checks, however, minimised the effects of the bias. Also, the large number of study participants mitigated the bias. Study findings in case study chapters are based on self-reported responses. Social desirability bias may have affected the participants' responses. All attempts were made to avoid leading questions and short and clear questions were always used to minimise bias.

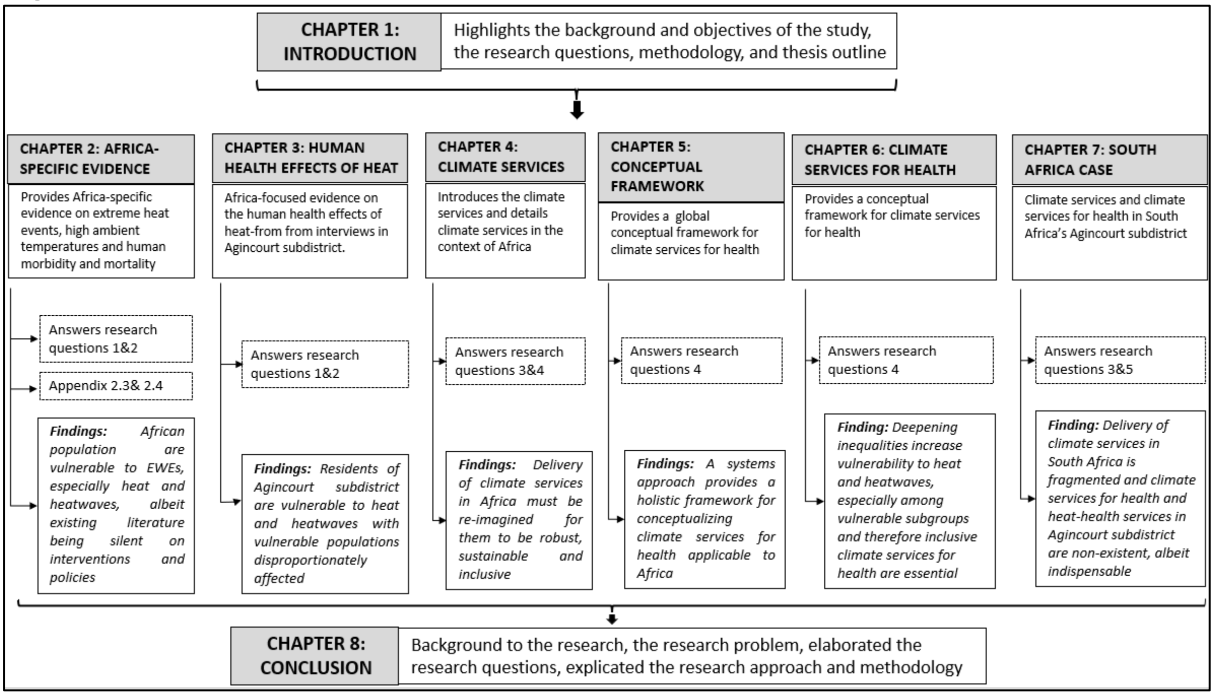
1.7 Study Significance and Contribution to Knowledge

This research is of great significance and contributes to new and existing knowledge in various ways. First, the study creates a novel conceptual framework for analysing climate services for health in Africa, namely the inclusive systems for climate services. In addition, it expands discussions on conceptualisations, including transdisciplinary research and transdisciplinary action research. Second, the research provides comprehensive empirical evidence on the evolution and delivery of climate services, especially climate services for health, important for adaptation policymaking and interventions. Third, the study can provide empirical evidence for international negotiations. Fourth, the study brings to light the importance of planning and executing heat-health interventions, which may help lessen the disease burden on the African continent. In fact, this study shows the complexity associated with creating heat-health interventions and policies and implicitly informs African populations to anticipate responses to a heating continent. Fifth, there are several gaps in knowledge that the research fills. The key gaps are around climate services for health in Africa as well as qualitatively incorporating international heat-health indicators in African settings. Through a systematic review, which outlines policy options and suggested interventions from existing literature, a compendium of updated information is availed to various stakeholders. And finally, the qualitative research, which used respondents' direct quotes, helps articulate the voices to the marginalised communities.

1.8 Structure of Thesis

A summary of each chapter is provided in Figure 1-1. Notably, the content of this thesis is organised into eight chapters.

Figure 0-1: Structure of the Thesis



Instead of presenting a literature review chapter, discussing the methodology and the results all at once as stand-alone chapters, the literature survey, methodology and results are presented and discussed in their respective chapters in this thesis. Furthermore, each chapter except chapters 1 and 8 opens with a chapter overview section and end with a chapter postscript section. These two sections link the chapters facilitating a coherent flow of the argument. With this background, the thesis is structured as follows.

Chapter 1: introduces the theme by highlighting the background and objectives of the study, the research questions, the research methodology and the thesis outline.

Chapter 2: provides Africa-specific evidence on extreme heat events, high ambient temperatures, and human morbidity and mortality. The evidence presented in the chapter is mainly from a systematic review of literature. The chapter partially answers research questions 1 and 2. Associated with chapter 2 are two systematic review articles presented in Appendix 2.3 and Appendix 2.4. These co-authored supplementary systematic review articles include studies from Africa and demonstrate the effects of heat on morbidity and provide supporting updated information on this subject. There are three interrelated key findings presented in this chapter. First, the health effects of EWEs are complex to simply explain in the context of Africa. Second, heat and heatwaves are affecting the African population's health, especially the most vulnerable populations that include infants, the elderly, persons with chronic medical conditions, persons living with disabilities, among others. Third, although exposure to heat and heatwaves is causing vulnerability to African populations, existing literature does not provide tangible and clear suggestions for heat interventions and policies.

Chapter 3: provides Africa-focused evidence on the human health effects of heat. In this chapter, internationally existing heat indicators presented in the 2020 report of the *Lancet* Countdown on health and climate change are innovatively reported against the results of qualitative data gathered from interviews carried out in the Agincourt sub-district. The chapter partially answers research questions 1 and 2. The chapter grounds international heat indicators in the African context. It also provides vital information on the vulnerability to heat of African populations, especially populations from the Agincourt sub-district. The key study results presented in this chapter are as follows. First, populations living in the Agincourt sub-district are vulnerable to exposure to heat and heatwaves. Second, the populations in the area most vulnerable to heat and heatwaves include the elderly, infants, persons living with disabilities, outdoor workers, as well as persons with underlying medical conditions. Third, projected increased changes in temperatures will result in more frequent EWEs with concomitant negative effects on human health.

Chapter 4: broadly focuses on climate services in the context of Africa. As such, it is a chapter that introduces the climate services theme. The chapter partially answers research questions 3 and 4. The chapter initiates a discussion that is elaborated on in chapter 7. The key argument advanced in this chapter is that climate services in and for Africa must be delivered considering the peculiarities of Africa for such services to be relevant and efficient. Therefore, the climate services must be reimagined to be robust, inclusive and sustainable.

Chapter 5: provides a conceptual framework that narrows the discussion of climate services presented in chapter 4 to focus on climate services for health. The chapter specifically elaborates on the systems approach to climate services for health. The systems approach is a conceptual framework that helps guide the analysis of climate services for health. The chapter partially answers research question 4. The main point highlighted in the chapter is that the application of the systems approach to climate services for health enables researchers, policymakers and practitioners to eschew parochial discourses on climate services for health and promotes a holistic framing and understanding of the services.

Chapter 6: deepens further the attempts to conceptualise climate services for health and is closely related to chapter 5. The chapter partially answers research questions 4. It deals with inclusion as an essential component for robust and sustainable climate services for health. As explained in this chapter, ensuring that climate services for health are inclusive guarantees the co-creation of a response that caters for populations most vulnerable to EWEs, including heat. Therefore, as argued in the chapter, mainstreaming inclusiveness is not only an issue of equity but also influences the quality of the climate services for health. The chapter importantly highlights that inclusive climate services for health are imperative for African countries where poverty aggravates vulnerability and inequalities in service access and use are prevalent. The elements comprising the inclusive climate services for health are applied to assess the state of climate services for health in the Agincourt sub-district, and the results are presented in the next chapter.

Chapter 7: answers research questions 3 and 5. It examines the interrelated themes of climate services in South Africa and climate services for health in South Africa's Agincourt sub-district. The conceptual frameworks espoused in chapters 5 and 6 are applied in analysing issues in this chapter. Through the application of the systems approach to climate services for health and the inclusive framework for climate services for health, the chapter assesses the evolution and efficacy of climate services and climate services for health in the Agincourt sub-district. The key finding is that climate services for health are non-existent in these rural communities. In addition, the coordination of agencies necessary to advance climate services in South Africa needs strengthening. The chapter elaborates on the broader transdisciplinary approach necessary for climate services for health that can enhance community adaptation and resiliency to the effects of heat on human health.

Chapter 8: concludes the thesis by revisiting and recapping the research questions, summarising the main findings, elaborating the main conclusions and recommendations, as well as providing directions for future research.

1.9 Conclusion

This introductory chapter provided the background to the research, explained the research problem, elaborated the research questions, explicated the research approach and methodology, as well as the structure of the thesis. The overall aim of this research is to provide new contributions to knowledge in the field of climate change and health, with a focus on the impacts of extreme weather events, specifically extreme heat, on health. In this research, the barriers, challenges and opportunities for effective heat-health risk reduction are examined.

This research also explores opportunities for climate services, especially climate services for health in Africa and discusses the policy, practice and policy implications of climate services for health. The following chapter provides Africa-specific evidence on extreme heat events, high ambient temperatures, and human morbidity and mortality.

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2 EXTREME HEAT EVENTS, HIGH AMBIENT TEMPERATURES, AND HUMAN MORBIDITY AND MORTALITY IN AFRICA: A SYSTEMATIC REVIEW OF THE LITERATURE

2.1 Chapter Overview

In Chapter 1, an introduction to this research was presented. In this Africa-focused chapter, the human health effects of heat and heatwaves are presented. The main purpose of this chapter is to locate the study in the current literature as well as demonstrate the gaps in existing literature, particularly interventions and policy-related gaps. The chapter further elaborates some suggested heat-health interventions and policy options from the literature.

The main argument presented in this chapter is that African countries are already experiencing significant heat in the form of heatwaves and hot days, and more heat is anticipated in future, yet there are no tangible policies and interventions evident in existing literature that policymakers and practitioners can rely on to build a heat-health response. Co-authored systematic review studies in appendices 2.3 and 2.4 also strengthen this argument by demonstrating some of the heat effects on morbidity as the studies included covered some African countries.

The chapter is presented with some minor revisions to the original article submitted to the *South African Journal of Sciences* for publication that is currently under review. The minor revisions were motivated by the need to include information from newly published reports, such as the latest reports from the IPCC published in 2021 and recently published peer-reviewed articles. In addition, the systematic review articles in appendices 2.3 and 2.4 are not part of the original article submitted for publication as they are standalone articles published in different journals.

2.2 Chapter Abstract

Background: Temperature extremes vary across Africa and are likely exacerbated by global climate change in recent years. A continent-wide examination of the association and impacts of extreme heat on the health of African populations and synthesis of Africa-informed evidence is lacking.

Methods: A systematic review of Africa-specific evidence on extreme heat-health effects and associations published in English between 1 January 1992 and 30 April 2019 was undertaken. The links between high ambient temperature, heatwaves and the effects on morbidity and mortality were examined. The population sub-groups most vulnerable to heat exposure on the continent were also investigated. A secondary systematic analysis of evidence was also done that focused on suggested heat-health policies and interventions, and the findings were synthesised with the primary studies.

Results: Twenty primary studies that met the inclusion criteria and 17 studies in additional secondary analyses were included. Eleven mortality outcome primary studies showed that high ambient temperatures and heatwaves have complex, linear and non-linear (J or U) relationships with high mortality in Africa. All (n=9) morbidity outcome primary studies suggested that an increase in temperature results in an increase in disease incidence. Children and the elderly were the most vulnerable population groups to extreme heat exposure. Location-specific interventions and policy suggestions were then considered, including developing early warning systems, creating heat-health plans, changing housing conditions and implementing education awareness campaigns.

Conclusion: This study shows that the heat-health relationship in Africa is complex and extreme temperatures are associated with high mortality and morbidity, especially amongst vulnerable populations. As temperatures are projected to increase, there is an urgent need to create heat-health plans and interventions. Implementing strategies to stop extreme heat-related deaths and diseases will save lives. Future studies must estimate and quantify the costs of acting and not acting on extreme heat-related mortality and morbidity.

Keywords: Africa; heat-health plans/policy; heat-health interventions; heatwaves; high ambient temperature.

2.3 Chapter Introduction

Heatwaves and high ambient temperatures affect human health (Huang et al., 2011, Zeng et al., 2016). Biological, environmental, medical, social and geographical factors influence how extreme heat exposure affects human morbidity and mortality (Xu et al., 2013). The sub-groups most vulnerable to extreme temperatures include infants, the elderly, persons living with disabilities, the chronically sick, persons on chronic medications, pregnant women and outdoor workers (Oudin Åström et al., 2011; Loughnan et al., 2013; Benmarhnia et al., 2016; Yin and Wang 2017). Extreme heat-related diseases and deaths disproportionately affect the poor (Hoegh-Guldberg et al., 2018).

Most studies on the relationship between extreme heat exposure and morbidity/mortality have been carried out in high-income countries (Azongo et al., 2012, Wichmann, 2017, Green et al., 2019). Therefore, less is known about the effects of heatwaves on deaths and diseases among different sub-groups in low-and middle-income countries (Medina-Ramón et al., 2006; Michelozzi et al., 2009; Azongo et al., 2012; Scovronick and Armstrong 2012; MacVicar et al., 2017).

There are a few Africa-focused studies on the impacts of extreme heat events or heatwaves and high ambient temperature on human health (Wichmann, 2017). The few existing studies largely focus on other continents and include selected African countries usually as an add-on. For example, Campbell et al., (2018) undertook a review of global evidence, which had no studies on Africa but generalised the conclusion from other continents to Africa. Green et al., (2019) found few studies on Africa relative to other continents and observed that there are more studies on cities such as Brisbane and Phoenix than for cities on the African continent (Green et al., 2019). A recently published literature review article explores heat stress and human health in Africa, and concluded that there are many gaps in existing literature on this subject (Ncongwane et al., 2021).

To date, an Africa-wide examination of the association and effects of extreme heat events and high ambient temperatures on human morbidity and mortality is lacking. Yet, observed climate trends show increased near surface temperatures of about 0.5 °C or more over most parts of Africa in the past 50 to 100 years, with minimum temperatures warming rapidly relative to maximum temperatures (IPCC, 2021). In addition, future climate projections show that temperatures in Africa will rise much faster than the global average (Hoegh-Guldberg et al., 2018). Yet, African countries are not taking any serious action to respond to the evidence. Maybe African countries have other priorities that preclude them from acting on the evidence.

Africa-focused studies that provide continent-specific insights on the association and effects of extreme temperatures on human health are essential to resilience planning as well as programmes and policies for heat-health adaptation and mitigation (Fraser et al., 2017). The main objective of this article is to provide an up-to-date Africa-wide systematic review of evidence on the association and effects of extreme heat events/heatwaves and high ambient temperature on human morbidity and mortality, to analyse population groups most vulnerable to extreme heat exposure, and to explore the suggested heat-health interventions and policies to protect people on the African continent.

2.4 Methods

2.4.1 Scope of Review

A systematic review of published peer-reviewed literature on the association and effects of extreme heat events and high ambient temperatures on human morbidity and mortality in Africa using an adapted, realist review method was undertaken. This means that the widely used Cochrane systematic review guidelines were not followed to the letter (Cipriani et al., 2011; Chandler and Hopewell, 2013). The adapted realist review was used because it enables researchers to tackle real-world problems guided by some background questions. A realist review or synthesis broadly falls under systematic reviews and it takes a systematic approach to reviewing and synthesising available evidence (Wong et al., 2013). A realist review furthermore attempts to provide answers to complex issues by seeking explanations of issues rather than focusing only on empirical truth (Lacan and Baccou 1996; Greenhalgh et al., 2011). Hence, the review can provide practice and policy relevant evidence by determining what works in what circumstances and with which particular persons and why/how it works. The realist review includes critical qualitative analyses, which provides for depth rather than breadth (Thompson et al., 2010).

While the general principles of systematic reviews include 'the need for clear question(s), the need for transparency of methods and the use of wide-ranging, comprehensive searches to reduce the effects of publication bias.' (Petticrew, 2015, p.2), a realist systematic review encompasses tighter inclusion/exclusion criteria and a smaller number of articles relative to other approaches (Rycroft-Malone et al., 2012). A realist review is applicable for 'complex interventions where evidence of effect may be lacking' (Petticrew et al., 2013, p.1241).

Rather than applying all the core features of the realist review method in their entirety, here an adapted realist synthesis was used. The core features of a realist review, including developing a set of guiding questions and strict inclusion and exclusion criteria as well as undertaking a wide-range and comprehensive search to minimise bias were retained. However, instead of responding to the question of what works, the adapted realist review used mainly responds to questions of effect, that is, what is the effect of heat and heat events on human health in Africa?

The adaptation of the realist review method is in line with Petticrew (2015) who argues that systematic reviews should evolve from answering simple questions to respond to complex phenomena. A secondary analysis with less strict inclusion/exclusion criteria was undertaken to examine policy and practice suggestions. The adapted realist review method was the most suitable method for exploring the complex subject of extreme heat-human health relationships in data scare African settings.

As stated before, four background questions guided the review process in line with the ethos of a realist review: What is the association between heatwaves/high ambient temperatures and human morbidity/mortality in Africa? What are the effects of extreme heat events/high ambient temperatures on specific population groups in Africa? What are the suggested interventions to reduce morbidity/mortality from heatwaves and high ambient temperatures in Africa? Finally, what are the policy propositions suggested to deal with extreme heat/high ambient temperature related morbidity/mortality? The research proposal for this study was approved by the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand (Protocol Number H18/11/18).

2.4.2 Search Strategy

Africa-focused, peer-reviewed studies published between 1 January 1992 and 30 April 2019 were reviewed. The period of research was deliberately chosen to align with available SAMRC/Wits Rural Public Health and Health Transitions Research Unit-Agincourt datasets (Kahn et al., 2012). In addition, the EWEs, especially heat events that took place during this period influenced the selection of this period. Reviewed studies focused on the effects of heatwaves and high ambient temperatures on morbidity and mortality in Africa. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed (Moher et al., 2009). A topic search using the "advanced search" option was performed within the ISI Web of Knowledge, Scopus and PubMed electronic databases and applying the following phrases: Extreme heat events and human mortality in Africa; Extreme heat events and human morbidity in Africa; Heatwaves/heatwaves and human mortality in Africa; Heatwaves/heatwaves and human morbidity in Africa; High ambient temperatures and human mortality in Africa; and High ambient temperatures and human morbidity in Africa.

2.4.3 Eligibility Criteria

All article titles and abstracts arising from the literature search were manually screened based on the inclusion and exclusion criteria presented in Table 2-1. Where the article titles and abstracts proved inadequate to determine relevance or inclusion/exclusion, the full-text paper was retrieved and assessed. Publications on vector-caused human morbidity and mortality were excluded because they lack a direct relationship with heat and health.

Table 2-1: Inclusion and exclusion criteria for systematic literature review

Inclusion Criteria	Exclusion Criteria
• Articles published in English only	• Articles published in other languages than English, for example, French, Portuguese and Arabic
• Articles published from 01 January 1992 to 30 April 2019	• Articles published prior to 1992 and after 1 May 2019
• Peer-reviewed published articles with full article access	• Meetings, comments, abstracts, and inaccessible full articles
• Articles whose focus is an African country, African countries or an African location	• Global studies (no Africa Focus)
• Extreme heat events (heatwaves) and high ambient temperatures as the main area of interest	• Articles whose main area of interest was not heatwaves or high ambient temperatures
• Articles analysing non-vector morbidity and mortality in human populations	• Vector-caused human morbidity and mortality

The reference lists of the retrieved full-text articles were also reviewed. From these lists, relevant references aligned to the inclusion criteria not initially identified were retrieved and added. Both qualitative and quantitative studies were included in this review.

2.4.4 Data extraction

Data were extracted using a standardised data collection form. The variables for data extraction included inter alia: the country or location of study; year of study; study design; study setting; study aims; study population; study outcome measures; geographical and temperature units (lags, temperature units); results and conclusion of the study. Emphasis was placed on estimates of association (i.e., relative risk, attributable risk or percentage increase in morbidity and mortality) and effects on the study population, especially sub-groups (by sex, age, cause of death, among others) obtained from tables, text descriptions and any other supplementary materials. Extracted data were moderated, any differences resolved, and any additional publications not found initially included.

2.4.5 Synthesis of Results and Risk of Bias

Extracted data were collated and reviewed using thematic analysis. A synthesis of key results of some individual studies was provided to stress important points.

2.4.6 Additional Secondary Analyses

An additional secondary analysis encompassing global studies and Africa-specific studies with unreported or missing key variables was also undertaken. For these studies, the reported variables and suggested interventions and policies are outlined.

2.5 Results

2.5.1 Study Characteristics

A flow diagram (Figure 2.1) shows the study selection based on the inclusion and exclusion strategy.

The study characteristics for the 20 primary studies are summarised in appendix 2.1. Based on the United Nations geoscheme for Africa classification of Africa sub-regions, many primary studies focused on the Southern Africa region, followed by the West Africa region and the Central (Middle) Africa region has least studies. Most studies were published between 2016 and 2019 (inclusive). The year in which data were collected in all the primary studies ranged from 1974 to 2015.

Most studies (n=15) applied a time series methodology. The primary studies covered rural and urban areas of Africa and were either location-specific, multi-location or nationwide. Among the primary studies, 11 adjusted for both seasonality and lag effect, three adjusted for seasonality but not lag effect, four adjusted for lag effect and not seasonality, and two did not report whether they adjusted for seasonality and/or lag effect. Several studies estimated the relative risk of association of daily mean temperature with daily mortality using lag strata.

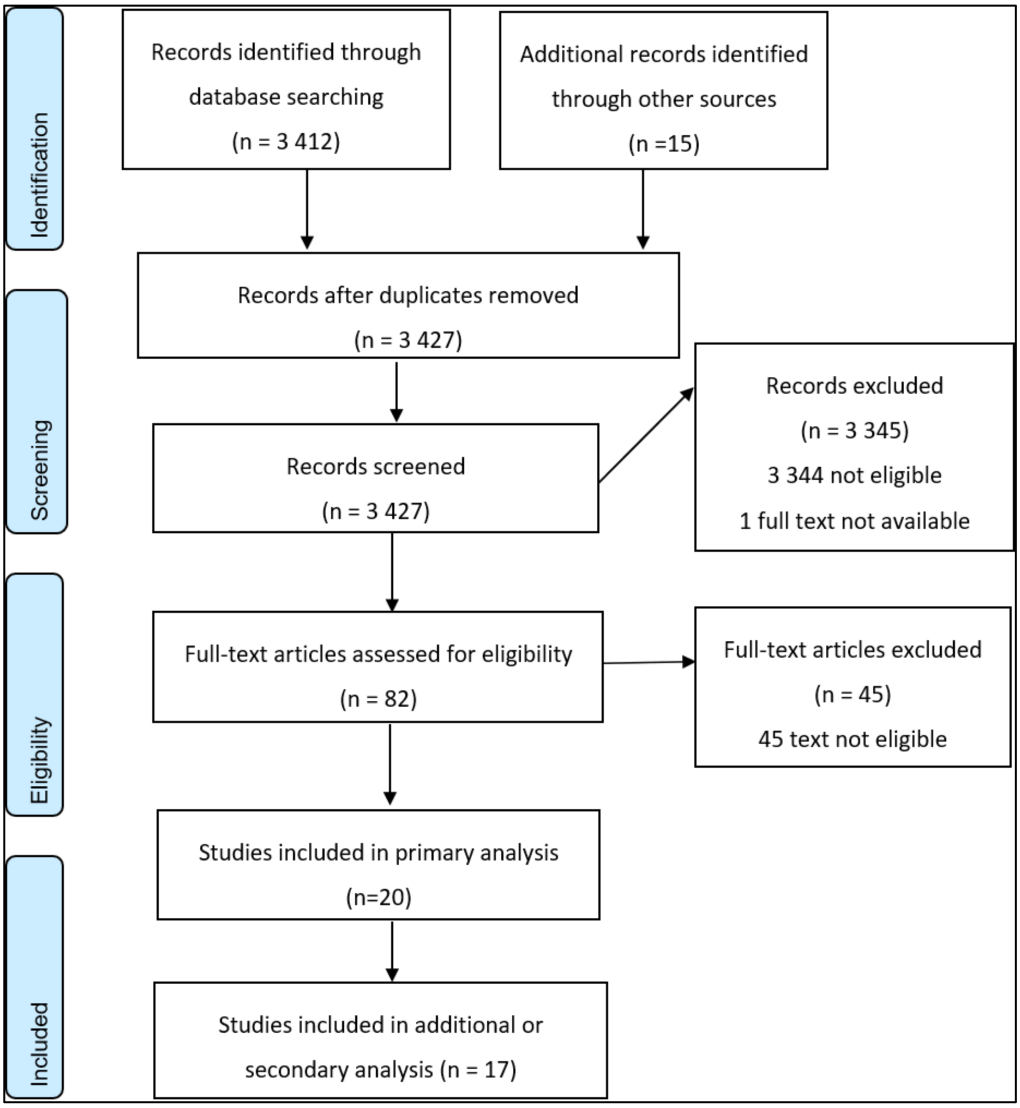

Figure 2-1: Study selection strategy flow diagram

2.5.2 Temperature Data, Including Data Sources

Diverse temperature measurements were used in the studies, including daily minimum and maximum temperature, daily mean temperature, monthly mean temperature and apparent air temperature (also called Tapp). Most studies (n=17) focused on high ambient temperature, and few studies (n=3) encompassed extreme heat events (heatwaves). Most temperature data were gathered from in-country National Meteorological and Hydrological Services (NMHS), including those affiliated with the World Meteorological Organisation (WMO). The NMHS providing temperature data were either located in the study area or some kilometres away from the study area. Some studies supplemented or combined in-country temperature data with that from external sources such as the National Oceanic and Atmospheric Administration (NOAA) of the United States of America (USA), South Africa's Agriculture Research Council, Climate Research Unit of University of East Anglia, the United Kingdom (UK) and the Royal Netherlands Meteorological Institute's (KNMI) Climate Explorer website.

2.5.3 Health Outcome Measures

Of the 20 primary studies, ten focused on mortality, nine on morbidity and one combined these two outcome measures. Mortality outcome studies focused on all-cause mortality as well as disease-specific mortality such as cardiovascular mortality. Most studies with mortality as an outcome measure ascertained the cause of death through the verbal autopsy questionnaire method. Morbidity outcome studies examined cholera and ebolavirus outbreaks (n=3), diarrhoea (n=4), acute respiratory infections (n=1) and cardiovascular diseases (n=1), among others.

2.5.4 Population Groups Examined

Most studies examined heat effects on specific age groups. The age categories were typically 0 to 4 years; 5 to 19 years; 20 to 49 years; 50 to 59 years; and 60 years and above. One study did not follow this age categorisation and its categories were from 40 to 64 years and then 65 years and above (Kynast-Wolf et al., 2010). Four studies focused on children/adolescents aged ≤ 18 years only (Tchidjou et al., 2010; Thompson et al., 2012; Musengimana et al., 2016; Thiam et al., 2017).

2.5.5 Synthesis of Key Findings

a) Extreme heat exposure and morbidity and mortality in Africa: Most studies found a complex association between extreme heat exposure and mortality in Africa (Appendix 2.1). Two studies found a linear association between high ambient temperatures and mortality (Diboulo et al., 2012; Mrema et al., 2012). Three studies explicitly found a non-linear relationship (McMichael et al., 2008; Azongo et al., 2012; Egondi et al., 2012). Three studies found a U-shaped relationship between heat exposure and mortality (Azongo et al., 2012; Diboulo et al., 2012; Scovronick et al., 2018). One study reported a J-shaped temperature-mortality association for all-ages mortality and U-shape for under-five mortality (Egondi et al., 2012).

Reviewed studies on the temperature-morbidity relationship provided unambiguous findings. All reviewed studies (n=9) found an association between extreme heat exposure and morbidity; that is, an increase in temperature resulted in increased incidences of certain diseases. For example, a study reported that a unit increase in temperature resulted in an increased incidence of diarrhoea, respiratory infection, asthma, meningitis and malaria (Thompson et al., 2012). Morbidity outcome studies (n=9) specifically pointed out that increased minimum temperature affects the prevalence of diseases in Africa.

b) Effects on African population: Most studies (n=11) whose study outcome measure was mortality analysed the effects of extreme heat events and high ambient temperature on given population groups by age and gender in Africa (Appendix 2.1). The studies found that infants (0-4 years), children (5-12 years) and young adolescents (13-19 years), as well as the elderly (50 years and above), were most vulnerable to deaths associated with exposure to extreme heat. In addition, higher mortality was found amongst males than females. Few morbidity outcome studies analysed the effects of extreme heat events or high ambient temperature on African population groups. For example, a study found increased incidents of diarrhoea, respiratory infections and malaria, particularly among male children compared to female children (Thompson et al., 2012). Two studies observed increased high ambient temperature related to diarrhoeal incidence among children under five years (Musengimana et al., 2016, Thiam et al., 2017). One study noted increased acute respiratory infections among children aged 18 years and younger (Tchidjou et al., 2010).

c) Additional analyses aspects: An additional secondary analysis, including studies that would not be permissible for inclusion under the established inclusion criteria (Appendix 2.2), was done. These additional studies did not report some key outcome or data variables. The studies included those not presenting data on review outcomes or temperature exposure, systematic reviews and surveys. The additional analysis was to extract suggested Africa-specific interventions as well as policy propositions. The inclusion of the additional literature broadened the literature base from which we drew our findings on suggested interventions and proposed policies. Appendix 2.2 shows the 17 reviewed articles included in the secondary analysis.

d) Suggested interventions: Although we combined primary and secondary analysis results to elaborate the heat-human health interventions focused on African localities, 21 out of the 37 studies explicitly offered tangible Africa-appropriate suggestions, as shown in Table 2-2.

Table 2-2: Suggested interventions from the reviewed literature

Author and year	Approach and key themes	Summary of suggested intervention
Amegah et al., 2016	Prevention approach through health education awareness	It is necessary to invest in meteorological services and strengthen health information systems to guarantee timely, up-to-date and reliable data. It is also important to characterise the groups vulnerable to heat and develop plans to strengthen resilience in these groups. Profiling of socioeconomic differentials in the temperature-health relationships must inform preventative actions.
Dukić et al., 2012	Treatment or curative approach – household-level interventions	Interventions aimed at reducing temperature, dust, smoke and carbon dioxide exposure or increasing relative humidity and ventilation via some household intervention mechanism may reduce the public health burden of meningitis outbreaks, especially during large outbreaks.
Trærup et al., 2011	Prevention approach – health education awareness and surveillance	There is a need for health education to raise awareness of cholera in Tanzania. Furthermore, disease surveillance, early diagnosis and treatment are essential. It is necessary to implement programmes that improve access to clean water and sanitation.
Oloukoi et al., 2014	Prevention and curative approach – surveillance and education awareness	It is important to take urgent action to provide corrective and preventative adaptation measures to combat climate-health risks in the Oke-Ogun region of Nigeria. Primary prevention interventions include providing access to safe drinking water, while secondary prevention entails strengthening disease surveillance programmes and early response to disease

Author and year	Approach and key themes	Summary of suggested intervention
		outbreaks. Supply of medical personnel and systematising improved hygienic behaviour at the household level is important as preventative and corrective interventions.
McMichael et al., 2008	Prevention approach – urban planning and heat-health warning systems	It is essential to minimise unplanned rapid urban development because this has adverse effects on sanitation, air pollution and housing, which affects population vulnerability to extremes of heat exposure. It may be important to develop heat-health warning systems.
Grace et al., 2012	Prevention approach – improved nutrition, water and sanitation	Considering that there is an association between malnutrition and water source, malnutrition and flour type, and malnutrition and education in Kenya, it is important to invest in improved water delivery infrastructure to reduce malnutrition. Since climate change can increase child stunting rates, investments must be made to ensure all households have access to culturally relevant and nutritional food.
Bandyopadhyay et al., 2012	Prevention approach – early warning systems and spatial disease maps	To reduce diarrhoea, it is important to reduce water shortages, promote handwashing, improve access to toilets and better health services, especially among poor households in Africa. Early warning systems that facilitate a preventative approach are important. It is important to develop spatial disease maps that show the prevalence of diarrhoea by region and to identify areas where the risk of diarrhoea from water scarcity and elevated temperature is high.
Green et al., 2019	Prevention – low-cost heat sensors, cash transfers and	It is imperative to improve meteorological and health data, especially heat-health data systems, by deploying low-cost sensors in low-income countries. Conditional cash transfers can be an intervention to reduce population vulnerability to heat exposure. Heatwave

Author and year	Approach and key themes	Summary of suggested intervention
	early warning systems	early warning systems must be developed. Research on actions that reduce mortality during heatwaves is essential.
MacVicar et al., 2017	Prevention approach – nutritional interventions	In rural Uganda, it may be important to provide women in the third trimester of their pregnancy with additional nutritional resources, especially during the dry season. It is also important to monitor changes in seasonal temperature and provide targeted nutritional interventions for pregnant women during the hot season.
Azongo et al., 2012	Prevention approach – improve ventilation	Improve ventilation and sleeping arrangements during hot weather conditions.
Thompson et al., 2012	Prevention approach – health and education awareness campaigns and tree planting	Climate-health responses for children should happen at the family, community, local municipality, NGOs and international agencies levels. Awareness campaigns on the care of children's health must be emphasised. Children's healthcare delivery must be improved. As poor health outcomes among children are related to poverty, job creation is important. Good environmental practices must be practised in communities, including regular environmental sanitation. Environmental education programmes must be implemented, including those focusing on preventing wild veld fires. Tree planting campaigns must also be carried out in communities. Stakeholders, especially women and children, must be involved in child health programmes and the awareness of climate change impacts raised in communities.

Author and year	Approach and key themes	Summary of suggested intervention
Alexander et al., 2013	Prevention approach – local interventions	Locally applied interventions that are sustainable must include sociocultural considerations of public health planning.
Heunis et al. 1995	Prevention approach – early warning systems	It is important to issue early warning weather forecasts to susceptible sectors of the population.
Tchidjou et al., 2010	Curative approach – vaccination campaigns	The high frequency of hospitalisation from acute respiratory infections suggests that influenza vaccination campaigns should be implemented considering the seasonality in Cameroon.
Reyburn et al., 2011	Prevention approach – early warning system	It is important to create an early warning system for cholera in Zanzibar because this will give public health authorities time to mobilise staff and equipment to respond to an outbreak. An early warning system can facilitate mass oral cholera vaccination.
Luque Fernández et al., 2009	Prevention approach – early warning systems	A cholera early warning system is imperative for sub-Saharan Africa.
Ng et al., 2014	Prevention approach – surveillance systems	Case detection and reporting for ebolavirus outbreak countries must be supported. Also, longitudinal serological and virological surveillance studies must be implemented to better understand ebolavirus transmission patterns.
Bunker et al., 2017	Prevention approach – early warning systems	It is important to develop early preventative measures to curb heat associated non-communicable disease deaths in Nouna, Burkina Faso.
Horn et al., 2018	Prevention approach –	Increasing access to oral rehydration in local health centres and increasing education on appropriate use

Author and year	Approach and key themes	Summary of suggested intervention
	early warning system	and handling of water and on sanitation practices can help reduce transmission of diarrhoeal pathogens and consequently the outbreaks of diarrhoea diseases in some areas in Mozambique. Furthermore, an early warning system for conditions that favour diarrhoea disease should be developed.
Thiam et al., 2017	Prevention approach – reduce the burden of diarrhoea through health intervention programmes	There is a need for effective preventative measures to reduce the high burden of diarrhoea in the health district of Mbour, Senegal. Health intervention programmes in the cold, dry season and in the rainy season focusing on morbidity control and prevention should be launched, particularly in urban settings where diarrhoea is most common, to reduce the incidence of diarrhoea in this context of climatic variability.
Scovronic and Armstrong, 2012	Prevention approach – urban planning	Interventions must focus on redesigning human settlements in informal settlements.
Engondi et al., 2012	Prevention approach – housing and clothing	The fact that children and the elderly are susceptible to weather mortality signifies the need for weather-mortality efforts, such as proper housing and clothing.
Engondi et al., 2015	Prevention – health education awareness	It is important to create better-targeted awareness campaigns to reduce the health burden from temperature exposure.

Table 2-2 shows that a few studies suggested either preventative or treatment-related interventions at individual, household and community levels (Dukić et al., 2012; Thompson et al., 2012; Thiam et al., 2017). Since most studies were location-specific, most of the suggestions made were also applicable to those localities. Several individual and household levels suggested preventative interventions were identified; for example, increased educational campaigns aimed at raising awareness about the association and effects of extreme heat events on human health (Tchidjou et al., 2010; Trærup et al., 2011; Thompson et al., 2012). Also, seasonal forecast-based vaccination campaigns aimed at reducing hospital admissions from acute respiratory infection and reducing exposure to extreme temperature, particularly among vulnerable groups such as young children and the elderly (Tchidjou et al., 2010; Azongo et al., 2012).

Importantly, since there is high mortality associated with meningitis during the dry season in the meningitis belt in Africa, the main suggestions were redesigning housing structures so that they have proper ventilation, changing sleeping arrangements, as well as reducing dust, smoke and carbon dioxide exposure (Dukić et al., 2012). Noteworthy, better ventilation may not necessarily mean providing air conditioning in the African context but constructing structures with larger and well-positioned windows and doors (Scovronick and Armstrong, 2012). To reduce smoke at the household level, cooking stoves with better combustion properties were suggested (Dukić et al., 2012).

A community-level preventative measure suggested was the proper allocation of resources, especially guaranteeing that vulnerable persons are protected against the effects of extreme heat. This suggestion was focused on governments as well as other persons with authority to distribute resources in Africa. In fact, reviewed studies focusing on South Africa – where there are extensive informal settlements – generally pointed out that informal settlements must be replaced, and new heat-adapted housing structures be developed (Scovronick and Armstrong, 2012). The same study pointed out that traditional round thatch huts – especially in the rural areas of Africa – should also be modified to adapt to extreme heat events and high ambient temperatures (Scovronick and Armstrong, 2012).

Studies focusing on diarrhoea and cholera incidence suggested the importance of strengthening household and community interventions for preventing weather-induced diarrhoea and cholera diseases in Africa (Reyburn et al., 2011; Trærup et al., 2011; Thiam et al., 2017; Horn et al., 2018). A study suggested the use of conditional cash transfers to deal with vulnerability related to heat exposure (Green et al., 2019), while another alluded to proper clothing (Egondi et al., 2012).

An intervention that was suggested several times was that early warning systems should be developed to ensure that the African populace is informed of impending extreme heat events before they occur (Heunis et al., 1995; McMichael et al., 2008; Reyburn et al., 2011; Amegah et al., 2016; Horn et al., 2018; Green et al., 2019). While being informed does not directly translate to action, early warning systems may enable the populations that will be affected by exposure to extreme heat to prepare in advance. This suggestion implicitly calls for the strengthening of climate information services for health on the continent. The few reviewed studies offering policy suggestions posit that better climate data are essential for better health-focused responses. Indeed, quality data from all relevant stakeholders are essential for heat-health planning efforts required. Surveillance systems are suggested in several studies reviewed (Trærup et al., 2011; Ng et al., 2014; Oloukoi et al., 2014).

e) Suggested policies: Studies that proffered concrete policy suggestions useful for extreme heat-health policymaking in Africa were few. Only nine out of 37 studies had some explicit policy suggestions, as shown in table 2-3.

Table 2-3: Key policy suggestions from the reviewed literature

Author and year	Summary of key policy suggestion
Amegah et al., 2016	Sub-Saharan African governments must take urgent steps to remove the bottlenecks to accessing institutional data for research.
Trærup et al., 2011	Integrated socioeconomic, climate and health policies that facilitate the provision of clean water and sanitation may reduce the costs of responding to outbreaks of cholera in Tanzania.
Oloukoi et al., 2014	Considering that local populations of the Oke-Ogun region of Nigeria use indigenous therapy encompassing the use of herbs and ash for residential vaccination against measles, in particular, the incorporation of indigenous knowledge into climate change policies may lead to the creation of effective adaptation strategies that are cost-effective, participatory and sustainable. Policies that promote the integration of health outcomes into development policies, especially focusing on the prevention of ill-health, are imperative. Policies that promote the involvement of various stakeholders and facilitate information sharing

Author and year	Summary of key policy suggestion
	on the health impacts of climate change are necessary for Nigeria and Africa.
McMichael et al., 2008	Effective preventative or adaptive policies based on an understanding of demographic, social and ecological determinants and sensitivities of the response pattern of the population of concern are important.
Bandyopadhyay et al., 2012	Policies that improve nutritional status, sanitation, maternal education and provide better access to health services are important to safeguard against diarrhoea.
Green et al., 2019	It is imperative to create policies that promote health networks for heat-health research and invest financial and human resources in these.
Scovronick and Amstrong, 2012	It is imperative to develop a development policy that prioritises the replacement of informal housing compared to one that emphasises the replacement of traditional dwellings in South Africa to deal with heat.
Thompson et al., 2012	It is important to create climate-health policies with a focus on children. The municipalities in Limpopo must provide the necessary legislative and administrative framework for good environmental practices such as regular environmental sanitation. It is important to create policies to reduce deforestation and soil erosion, especially in high-density areas of uneven terrain. Policies for mapping disaster risk areas and plans to target these areas must be developed.
Alexander et al., 2013	Locally acceptable and culturally appropriate public health strategies for reducing population vulnerability to climate change-related diarrhoea disease must be developed.

Three studies implicitly pointed out the importance of developing heat-health plans in Africa (McMichael et al., 2008; Scovronick and Armstrong, 2012; Oloukoi et al., 2014). However, not much detail was provided on the content of such plans. The cautionary advice provided was that because Africa is made up of diverse localities, developing a 'one-size-fits-all' heat plan may be misleading. Intrinsically, the findings of Scott et al., (2017) on urban heat-island effects in Nairobi were informative as they emphasised location-specific factors when assessing morbidity and mortality in Africa, particularly demonstrating that studies with extensive spatial coverage may not accurately illuminate the heat-morbidity/mortality relationships (Scott et al., 2017). Rather, more localised heat plans are imperative.

Another key policy suggestion is for authorities to formulate policies that target vulnerable populations that would be affected by exposure to extreme temperatures (Thompson et al., 2012). Heat plans must explicitly outline the different levels and categories of vulnerability in the communities they cover (McMichael et al., 2008). Therefore, data that explicitly show the vulnerable populations are essential for crafting an effective heat plan.

2.6 Discussion

In this review, the evidence published in English between 1 January 1992 and 30 April 2019 was summarised, focusing on the association and effects of extreme heat events and high ambient temperature on mortality and morbidity in Africa. To my knowledge, this is the most up-to-date Africa-focused systematic review on this subject, notwithstanding the existence of other studies that have included African countries in reviews largely encompassing studies from other continents (Burkart et al., 2014; Green et al., 2019). There has not been any review that exclusively examined the heat-health evidence from Africa. While a study focused on countries in sub-Saharan Africa and excluded those in North Africa (Amegah et al., 2016), a more recent study included only ten studies from Africa among many studies from other continents (Green et al., 2019).

The general pattern among studies that explored the heat-human health relationship in Africa was exclusionary (limited in coverage) and not exhaustive (referencing the continent in passing). Unlike these previous studies, this review consolidated available evidence on heat-human health in Africa without including content from any other continents and covered the whole continent. The review encompassed 20 primary studies and 17 secondary studies and importantly highlighted Africa-specific nuances on human mortality and morbidity arising from extreme heat exposure. This review underscores the fact that Africa has peculiar climatic and population health features that demand a focused and thorough exploration.

Overall, the key study finding confirmed the effects of extreme heat on human mortality and morbidity in Africa. This finding is in line with previous related studies. For instance, a study reported the dominance of heat effects in studies conducted in sub-Saharan Africa, with heat-related mortality observed in Burkina Faso, Ghana and Kenya (Burkart et al., 2014). Even though Green et al. (2019) included studies from other continents, they similarly point out that "the vast majority of studies found a positive association between heat and morbidity/mortality, and only nine either found no association or a negative association between the heat exposure and the health outcome of interest" (Green et al., 2019, p.84). Not many reviews provide unequivocal, continent-wide evidence on the effects of extreme heat exposure on human mortality and morbidity.

The results of this review further point out that the association between extreme heat and mortality or morbidity is complex. Indeed, the heat-mortality and heat-morbidity relationship were found to be linear or non-linear, with the latter showing U-shaped and J-shaped relationships. We suggest that the complexity in this relationship may result from the uneven geographic spatial distribution of climate elements and epidemiological heterogeneity of the continent.

Although extreme heat effects affect persons of all age groups, the African population most affected by exposure to extreme heat were infants (0-4 years), children (5-19 years) and the elderly (above 50 years). Similar findings have been reported in studies from South Asia where heat-mortality effects are more pronounced among children (Hashizume et al., 2007, Lindeboom et al., 2012, Ingole et al., 2017) and in Latin America and China, where heat-mortality effects were observed among the elderly (Goggins et al., 2013, Wu et al., 2013). Notably, Africa-specific studies generally classify persons aged 50 years and above as the elderly because of low life expectancy mainly caused by the HIV epidemic, among other diseases. The use of antiretroviral treatment has enabled many people on the continent to live longer than without antiretroviral treatment, and this will affect future age categorisation.

A few studies suggested some tangible interventions and policies to deal with the effects of extreme heat events, high ambient temperature and human health in Africa. Suggestions pertaining to preventative and treatment interventions as well as policies for early warning systems and heat-health plans were noted. The suggested interventions and policies lack depth and detail. More intervention and policy-oriented studies that focus on these study areas are encouraged. For studies to offer tangible programmes and policy suggestions, more Africa-specific intervention projects must be carried out.

There are some limitations to this study. The main limitation is that we did not evaluate the quality or potential biases of studies included in this review. The heterogeneity of included studies made it difficult to consider doing a meta-analysis for this review. The allocation of studies into those fitting primary or secondary analysis was not error-free. The general limitation of the realist review method that it may not be intrinsically reproducible and transparent, applies to this review (Petticrew et al., 2013).

2.7 Conclusion

While there is a growing body of evidence suggesting that Africa will be disproportionately affected by climate change, the effects of extreme temperature changes on human health on the continent have not been explored in detail to date. The systematic review aimed to establish the association and effects of extreme heat and high ambient temperatures on mortality and morbidity in Africa, as well as to explore the population sub-groups most vulnerable. The extreme heat exposure-health relationship is complex, and this review confirmed the effects of extreme temperature on mortality and morbidity, especially among children and the elderly.

African countries have a substantial mortality and disease burden. It is imperative to try to reduce extreme temperature related deaths and diseases. Future climate projections show increased temperatures across many countries on the continent. Therefore, policy and programmatic measures that curb future heat-health mortality and morbidities are urgently needed. Research that explores the economic costs of proactively and reactively acting on heat-health morbidities and mortalities must also be carried out to inform policymakers and practitioners.

A key objective of the review was to establish from available evidence the suggested interventions and policies to deal with the effects of exposure to extreme heat in Africa. Reviewed studies do not provide tangible heat-health policy and programmes suggestions. Further intervention and policy-focused research is encouraged. Based on this exploratory review, it is recommended that large-scale, Africa-specific transdisciplinary studies that examine extreme heat-human health relationships at sub-regional or continental scales be undertaken.

2.8 Chapter Postscript

In this chapter, the health effects of heat and heatwaves in Africa have been highlighted. Noteworthy, appendices 2.3 and 2.4 provide additional evidence on heat effects on human health. These appendices were published as separate chapters from the review and are presented in appendices to distinguish them from the review. The co-authored systematic review in appendix 2.3 is not Africa-specific but encompasses some studies from Africa. The systematic review shows that increased heat negatively affects pregnant women and their unborn children. The effects of heat are most pronounced among poor pregnant women. These findings are generalisable to Africa, where most women live in poverty.

The systematic review in appendix 2.4 examines the evidence on temperature changes, especially heat and diarrhoeal diseases in South Africa. The review found that seasonality affects the outbreak and spread of diarrhoeal diseases in South Africa. The study results further show that increased temperatures are likely to have a concomitant increase in cases of diarrhoea. In addition, the review reports that cases of diarrhoeal diseases may also increase during heatwaves. These findings are generally informative on the effects of heat and heatwaves on human health. Although the study in appendix 2.4 could be eligible for inclusion in the systematic review, its date of publication was out of the demarcated dates of the review.

In the next chapter, the heat-health effects in the Agincourt sub-district are presented, enabling a more context-specific interrogation of heat-health indicators.

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3 THE SELF-REPORTED HUMAN HEALTH EFFECTS ASSOCIATED WITH HEAT EXPOSURE IN THE AGINCOURT SUB-DISTRICT OF SOUTH AFRICA

3.1 Chapter Overview

The previous chapter dealt with the impact of heat on human health more broadly using a systematic review of published peer-review African studies. Two additional systematic reviews (Appendix 2.3 and 2.4) that buttress the findings were presented. This chapter focuses on the human health effects associated with heat exposure in South Africa's Agincourt sub-district using a number of international indicators. The assessment is qualitative, whereby a number of key informants and respondents were interviewed and their responses gathered. Like the previous chapter, this chapter highlights that heat is affecting people living in the Agincourt sub-district, especially the elderly, infants and outdoor workers. With projected increased temperatures for the sub-district, more people will be vulnerable to heat. However, responses targeting heat-health have not yet been established.

The chapter has been published as an article in the *Humanities and Social Science Communication* journal. The published article is reproduced in this thesis in its entirety with minor revisions and minor modification to its layout and formatting. The chapter overview and chapter postscripts sections did not form part of the original article. The structure of this chapter is as follows. Section 3.2 presents the chapter abstract or summary, followed by the chapter introduction. In section 3.4, the conceptual framework guiding the analysis of issues is presented, while the methodology is presented in section 3.5. The study findings are presented in section 3.6 and discussed in section 3.7, and the conclusion is in section 3.8. Following the ethical approval (3.9) and informed consent (3.10), the chapter postscript (section 3.11) provides a link to the next chapter. The interview guides used in data collection are provided in Appendices 3.1 and 3.2.

3.2 Chapter Abstract

Background: Exposure to heat and heatwaves are associated with mortality and may amplify morbidities. In a climate change context, projections suggest temperatures will likely rise in the foreseeable future. In this study, the current knowledge on human health effects of heat exposure and gathered local knowledge of heat-health effects in a rural area of the Agincourt sub-district of South Africa were assessed.

Methods: Existing, peer-reviewed published literature on heat effects on human health as well as heat-health indicators was reviewed. Semi-structured interviews and structured observations were used to collect data on heat effects on human health in the Agincourt sub-district. The *Lancet Countdown* heat-related indicators were applied as a framework against which the findings were discussed.

Results: Ninety-three participants who had lived in the Agincourt sub-district for five years and more were interviewed. Participants reported that temperatures, especially summertime temperatures, had been rising over the past years. Health effects of heat were deemed more apparent in relation to morbidity. Heatwaves were not easily comprehensible as singular "events", and their effects were poorly understood. The population groups deemed disproportionately affected by heat included infants, the elderly, those living with a disability and outdoor workers. High ambient temperatures were deemed to be associated with reduced labour productivity of outdoor workers.

Conclusion: Community-level perceptions of heat impacts on health were mainly related to illnesses and diseases, with no understanding of mortality risk. Future health awareness campaigns that encompass the full range of heat-health impacts are essential to reduce vulnerability, morbidity and mortality. This study provided location-specific, qualitative and indicator-aligned data for a geographic area expected to undergo significant heat stress in the future. The study findings have significant research, policy and practice implications in similar resource-limited settings.

Keywords: climate change; environmental health; heat-related indicators; heatwaves; labour productivity; vulnerability**.**

3.3 Chapter Introduction

The global average surface temperature is rising (Costello et al., 2009). The Intergovernmental Panel on Climate Change 2021 report states that the evidence of global warming due to human actions is unequivocal (IPCC, 2021). The five hottest years on record have occurred since 2015 (Watts et al., 2020). Rising global temperatures, directly and indirectly, impact human health. Directly, heat can cause excess mortality and morbidity, especially among vulnerable individuals such as children, persons with chronic illnesses, outdoor workers and the elderly (Gasparrini et al., 2017). Exacerbated by the heat island effect, persons living in urban areas are disproportionately affected by exposure to heat compared to those living in rural areas (Wichmann, 2017; Nana et al., 2019; Watts et al., 2019). Indirectly, hot conditions impact the spread and transmission rates of vector-borne and water-borne diseases, as well as nutrition (Niang et al., 2014).

Global research on the health effects of heat is increasing. Among others, the 2015 *Lancet* Commission on Health and Climate Change developed and progressively monitors key heat-health indicators, including vulnerability to the heat-related risks of climate change, exposure to temperature change, exposure to heatwaves, changes in labour productivity and the economic costs of heat (Watts et al., 2015; The *Lancet*, 2017; Watts et al., 2017). The 2020 report of the *Lancet* Countdown on health and climate change examines several dimensions of the effects of heat and heatwaves, covering exposure, vulnerability, labour capacity and mortality, resulting in a compendium of robust evidence for adaptation, planning and resilience for health (Watts et al., 2020). The *Lancet* Countdown Reports present comprehensive findings on heat anomalies and human health, summarised in Table 3-1. The findings show that global ambient temperatures are rising, and the frequency and intensity of heatwaves are increasing, adversely affecting labour productivity and human health worldwide.

Intrinsically, certain populations, including children, outdoor workers, people older than 65 years, people with chronic respiratory, cardiovascular, and diabetic diseases, as well as those living in urban areas, are more vulnerable to the health effects of heat than others (Watts et al., 2019). The heat vulnerability index includes indicators such as 'proportion of the population over 65 years, the prevalence of cardiovascular, diabetes and chronic respiratory diseases among population over 65 years and the proportion of the population living in urban (i.e. urbanization rate)' (Cai et al., 2020, p.1). These indicators exclude persons that are vulnerable to heat due to limited access to healthcare, poor health status, low socioeconomic status, the prevalence of cooling devices or green areas in cities and the existence of heat early-warning systems (Watts et al., 2020).

Table 3-1: Summary of the key findings on heat-health and adaptation indicators from *Lancet* Countdown Reports

Indicators	Year	Summary of findings
Vulnerability to the heat-related risks of climate change	2018	Rising ambient temperatures place vulnerable populations at increased risks across all WHO regions. Populations in Europe and the East Mediterranean are particularly at risk, with 42% and 43% of their populations older than 65 years vulnerable to heat exposure.
	2019	Vulnerability to extremes of heat continues to rise among older populations in every region of the world, with the Western Pacific, South-East Asia and African regions all seeing an increase in vulnerability of more than 10% since 1990.
	2020	Vulnerabilities to extreme heat continue to increase in every region of the world, led by populations in Europe, with the Western Pacific region, South-East Asia region and the African region all seeing an increase of more than 10% since 1990.
Health effects of temperature change	2017	Between 2000 and 2016, human exposure to warming was about 0.9ºC, more than double the global area average temperature rise during the same period.
	2018	In 2017, although the global mean temperature increase relative to the 1986 to 2005 reference period was 0.3°C, the increase in human exposure temperature (the temperature increase in populated zones) was more than double at 0.8°C.
	2019	Human populations are concentrated in the areas most exposed to warming, experiencing a mean summer temperature change that is four times higher than the global average. And, the global average population-weighted temperature has risen by 0.8°C from the 1986 to 2005 baseline to 2018, compared with a global average temperature rise of 0.2°C over the course of the same period.
	2020	Heat-related mortality in people older than 65 years increased by 53% and, in 2018, reached 296 000 deaths, the majority of which occurred in Japan, Eastern China, Northern India, and Central Europe.
Health effects of heatwaves/ex	2017	Between 2000 and 2016, the number of vulnerable people exposed to heatwave events increased by about 125 million, with a record 175 million more people exposed to heatwaves in 2015.

Indicators	Year	Summary of findings
posure of vulnerable populations to heatwaves	2018	An additional 157 million people (an increase of 18 million additional exposure events compared with 2016) were exposed to heatwave events in 2017 compared with 2000, and with the average person experiencing an additional 1.4 days of heatwaves per year over the same period.
	2019	In 2018, an increase of 220 million heatwave exposure events affecting older populations was observed, breaking the previous record set in 2015. Japan alone experienced 32 million heatwave exposures, the equivalent of almost every person aged 65 years and older enduring effects of heatwaves in 2018.
	2020	In 2019, 475 million additional exposures to heatwaves affected vulnerable populations, representing some 2.9 billion additional days of heatwaves experienced.
Change in labour capacity	2017	Global labour capacity in rural populations exposed to temperature change is estimated to have decreased by 5.3% from 2000 to 2016
	2018	In 2017, 153 billion hours of labour were lost, an increase of 62 billion hours lost relative to 2000.
	2019	In 2018, 45 billion additional potential work hours were lost due to rising temperatures, compared with the year 2000.
	2020	Rising temperatures were responsible for an excess of 100 billion potential work hours lost globally in 2019 compared with those lost in 2000, with India's agricultural sector among the worst affected.
Climate information services for health	2017	73% of the 100 responding WHO member states reported providing climate information to the health sector in their country.
	2018	The national meteorological and hydrological services of 55 countries providing climate services to the health sector.
	2019	The number of countries providing climate services to the health sector increased from 55 in 2018 to 70 in 2019.
	2020	The number of countries reporting that their meteorological services are providing climate services for health increased from 70 to 86 during the past 12 months.

Source: Watts et al., 2017, 2018, 2019 and 2020.

Extremes of heat do not lead to new vulnerabilities but rather amplify existing human health vulnerabilities on the African continent – a resource-limited continent already burdened with infectious and non-communicable diseases as well as the dual HIV-coronavirus pandemics (Agyepong et al., 2017). Despite these challenges, the national climate change adaptation plans of African countries such as Botswana, Chad, Ghana and Zimbabwe are less focused on heat and heatwaves (Woodruff and Regan, 2019). Several African cities have not implemented heat-focused risk assessments due to lack of capacity and resources to do so (WHO 2021). South

Africa is among the few African countries involved in a health system climate change assessment, preparedness and resilience reporting, and the country also has a draft national heat-health plan (Watts et al., 2020).

While global research on heat impacts on health is growing, few studies are specifically focused on Africa (Watts et al., 2018). Existing Africa-specific studies have examined the impacts of heat anomalies on various health outcomes, including inter alia mortality and morbidity; birth weight, still and preterm births; ebolavirus disease; cholera; and diarrhoeal diseases (Kynast-Wolf et al., 2010; Trærup et al., 2011; Azongo et al., 2012; Diboulo et al., 2012; Scovronick and Armstrong, 2012a; 2012b; Ng et al., 2014; Amegah et al., 2016; Scovronick et al., 2018; Boeckmann et al., 2019; Chersich et al., 2020). In trying to offset the gap in existing literature, this study investigated the perceived heat-health effects in the Agincourt sub-district of South Africa. This chapter summarises the study results.

3.4 Conceptual Framework

3.4.1 Framing the Study Through Human Health and Heat Indicators

While there are many topics that can be studied under human health and heat, this study is framed around existing indicators on human health and heat. These indicators specifically informed data collection tools as well as the study approach. Key human health-heat indicators from the European Centre for Disease Prevention and Control (ECDC), US-CDC Environmental Public Health Tracking, US-EPA, Public Health England, National Integrated Heat Health Information System (NIHHIS), the Global Heat Health Information Network and the World Health Organisation were searched. Existing literature on heat-health indicators from other countries also helped in framing this study (English et al., 2009; Cheng and Berry, 2013; Navi et al., 2017; Ebi et al., 2018). The human heat-health indicators from these institutions, as well as the 2020 *Lancet* Countdown Report, are shown in Table 3-2. Some indicators from the various institutions are comparable to those in the 2020 *Lancet* Countdown Report. The data collection tools were designed to provide information that informs the various indicators. Keywords were further defined *a priori* to data collection to avoid confusion and standardise understanding. For example, heatwaves were defined as the periods when the daily minimum temperature exceeded the 99th percentile of minimum daily temperature over the ten-year period (2009-2018) for three days or more.

Table 3-2: Summary of available/applied human-related heat-health indicators

Indicators from various institutions/organisations	**Indicator explanation**
Excess all-cause mortality	• Excess daily all-cause mortality due to heat
Heat-related mortality	• Number of summertime heat-related deaths by year • Annual rate for deaths classified by medical professionals as "heat-related" based on death certificate record
Heat-related illness	• Hospitalisation rates for "heat-related" illnesses such as heat exhaustion, heat cramps, mild heat oedema (swelling in the legs and hands), heat syncope (fainting) and heat stroke, based on hospital discharge records for patients who are admitted to the hospital for 23 hours or more • Age-adjusted rate of hospitalisation for heat stress per 100 000 population • Crude rate of hospitalisation for heat stress per 100 000 population • Number of hospitalisations for heat stress • Heat stress emergency department visits
Emergency department visits for heat stress	• Annual age-adjusted rate of emergency department visits for heat stress per 100 000 population • Annual crude rate of emergency department visits for heat stress per 100 000 population • Annual number of emergency department visits for heat stress
Productivity loss	• Working hours lost to heat stress • Percentage of gross domestic product lost to heat stress
Heat exposure measures	• Number of extreme heat days • Dates of extreme heat days • Number of extreme heat events • Dates of extreme heat events
Temperature distribution	• Daily estimates of maximum temperature for summer months (September – May)

Indicators from various institutions/organisations	Indicator explanation
	• Daily estimates of maximum heat index for summer months (September – May)
The 2020 *Lancet* Countdown heat-health specific indicators	
Climate change impacts, exposures and vulnerabilities	
Health and heat	
Vulnerabilities to extremes of heat	
Exposure of vulnerable populations to heatwaves	
Heat-related mortality	
Change in labour capacity	
Economics and finance	
Costs of heat-related mortality	
Loss of earnings from heat-related reduction in labour capacity	

Source: Watts et al., 2020; various sources

3.4.2 A Special Study Providing Information for Indicators

Given that the thematic areas on the data collection tools were premised on a wide variety of existing indicators, this study is conceptualised as a special qualitative case study (Yin, 2012). A qualitative study generally applies several methodologies, including interviews, observations, case studies and literature reviews, to collect information on a specific phenomenon, situation and/or population (Escobar, 1985). Such an approach also demands effective implementation of research methods and competent analysis of data for it to be credible. A detailed explanation of the study methodology demonstrates the fidelity to these aspects.

The use of the qualitative approach is innovative because quantitative data are usually used to inform indicators. The lack of existing data to inform the indicators demanded the application of qualitative research because it allows for data to be collected to fill in the gap. Therefore, the study participants' voices provide qualitative data necessary to inform the indicators. The Agincourt sub-district was purposely selected because of the existence of the SAMRC/ Wits Rural Public Health and Health Transitions Research Unit-Agincourt, which has been carrying out surveillance and other activities since 1992. The qualitative findings from this study could be assessed against the understandings and research outputs from the SAMRC/ Wits Rural Public Health and Health Transitions Research Unit-Agincourt.

3.5 Methods

3.5.1 Study Setting and Population

The study was conducted in Agincourt, a sub-district under Bushbuckridge Municipality in Mpumalanga Province of South Africa. Some of the areas under study, as well as Skukuza Airport, the source of the meteorological data, are shown in Figure 3.1. noteworthy, the map covers some areas that are not within the sub-district.

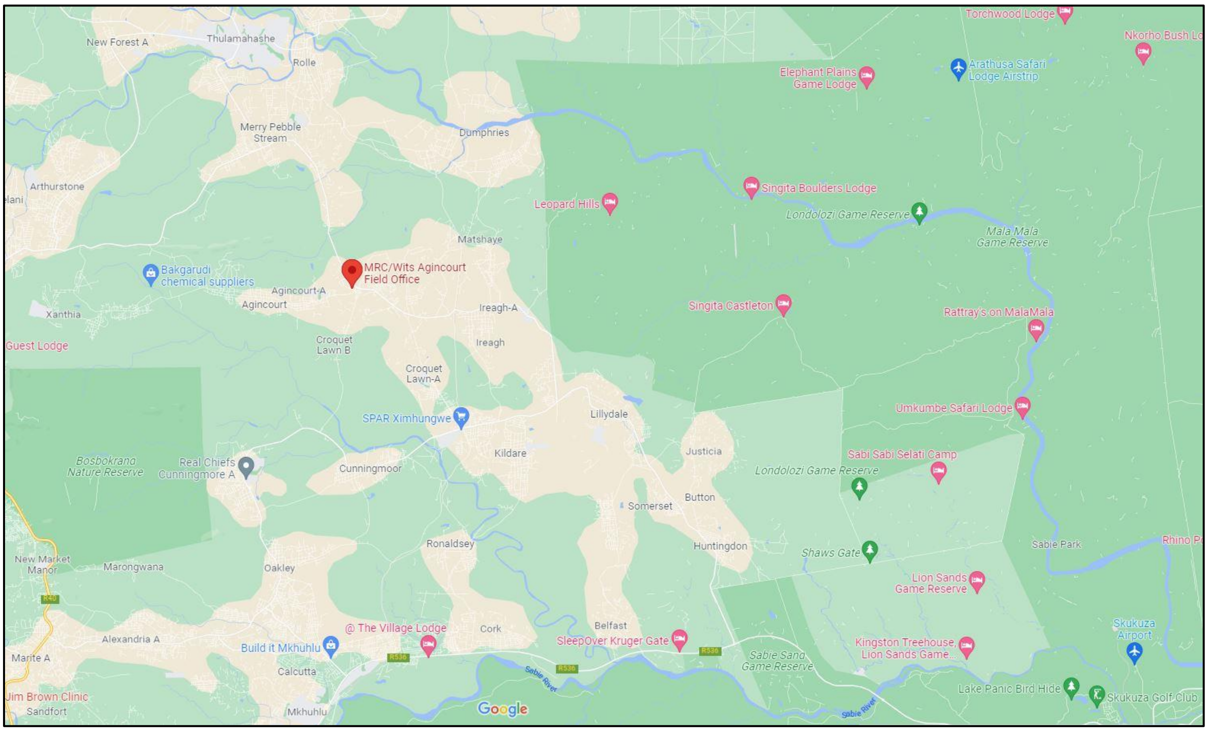

Figure 3-1: Map of the Agincourt sub-district and Skukuza Airport

The study covered areas that fall under the Agincourt Health and Socio-Demographic Surveillance System (HDSS) of the SAMRC/MRC/Wits Rural Public Health and Health Transitions Research Unit. Given the extensive track record of the HDSS and SAMRC/MRC/Wits Rural Public Health and Health Transitions Research Unit, our study was able to build on this track record with trust relations in place to undertake such research. The study area and population have been extensively described elsewhere, which precludes a repeat of the same information in this article (dos Santos et al., 2019; Kahn et al., 2012; Byass et al., 2010; Tollman et al., 2008).

3.5.2 Data Collection

Multiple methods of data collection were used in this research. Existing peer-reviewed published literature on heat, heatwaves, vulnerability to heat exposure and risks associated with heat events was comprehensively reviewed to get baseline data on the health effects of heat. Searches using the "advanced search" option were done on PubMed, Scopus and Science Direct applying the following phrases: Health effects of heat in Africa; Heat events and health in Africa; Vulnerability to heat in Africa; Vulnerability to heatwaves in Africa; Heat Extreme heat events and human mortality in Africa; Extreme heat events and human morbidity in Africa; Heatwaves and human mortality in Africa; Heatwaves and human morbidity in Africa; High ambient temperatures and human mortality in Africa; and high ambient temperatures and human morbidity in Africa. A total of 3 457 articles were screened, of which 3 365 were excluded and 92 full texts were downloaded and reviewed. References of downloaded full-text articles were further checked, and relevant articles were retrieved and reviewed, resulting in the exclusion of 49 articles and the inclusion of 43 articles.

An attempt to obtain a detailed set of meteorological variables from various sources was also made to explore climate trends and determine occurrence of EWEs in the area. Meteorological data were provided by the South African Weather Service (SAWS) to understand the meteorological climatology of the area. These data included temperature (minimum, maximum and average) and humidity (minimum, maximum and average) variables and were analysed to describe diurnal, seasonal trends. There is, however, no official weather station located in the Agincourt sub-district. Hence, data from the nearest official weather station at Skukuza Airport, bordering from the Agincourt area, were relied on. A previous study demonstrated minor temperature variations between the two sites and also used the station's dataset (Byass et al., 2010). Raw data, however, were not finally used for trend analysis and determination of occurrence of EWEs owing to gaps in the data. Notwithstanding the data difficulties, existing data compilations assisted in trying to verify respondents' recollection of heat waves and other EWEs as explained in section 3.6.2.

Primary data were collected through semi-structured interviews and structured observations. The data were collected between September and October 2019 and further updated in March 2020. These periods straddle the winter and summer seasons in the country and therefore enable some period of post-event reflection as opposed to undertaking any interviews during the peak of a heatwave that may dramatically influence perceptions and results.

With the public relations support of the SAMRC/MRC/Wits Rural Public Health and Health Transitions Research Unit staff, in-depth, face to face interviews were conducted. The interview guide for key informants and another for community members were used to gather data during semi-structured interviews. Key informants, that is, knowledgeable and experienced persons, including teachers, healthcare workers, and personnel from meteorological stations, Kruger National Park and research institutions, were identified and interviewed. Targeted interviews with recommended and non-referred community members, including inter alia traditional healers, faith healers, chiefs, outdoor workers, the aged, youths and the chronically sick, were also interviewed using the community interview guide. These interviewed community members are generally referred to as study respondents. Wherever the results from both key informants and respondents are reported, they are referred to as participants.

The interview guides covered several themes, including inter alia changes in ambient temperature over the past years, vulnerability to the heat-related risks of climate change, exposure to temperature change, the definition of heatwaves, exposure to heatwaves, heat-focused interventions, population groups most vulnerable to heat, heat-related mortality, heat-related illness, hospitalisation due to heat, costs of heat-related mortality and loss of earnings from heat-related reduction in labour capacity.

Participants were permitted to explore the study topics in detail, and follow-up probing questions were used to elicit further information on any issue that needed detailed attention or verification. Interviews were mainly carried out in English, with an interpreter used to translate a few interviews from Shangaan to English. The interpreter was trained so that he became more familiar with the process and when to probe for more information. Interviews lasted between 45 minutes and 60 minutes. All interviews were audiotaped using a handheld recording device, and notes were taken during the interviews.

Structured observations targeting schools, health facilities and other informal workplaces were also undertaken to ensure not only additional data but also much-needed verification and quality assurance. The personal and professional activities and interactions, as well as heat interventions at the different venues during the times when it was deemed too hot, were observed. For example, the activities, interactions and responses to midday heat by outdoor workers involved in brickmaking, farming, carpentry and construction were observed at several venues. The structured observations lasted about two hours. Structured observation reports were generated showing the venue, date and time of observation, main activities, potential heat effects to the venue occupants, heat-related interventions, general health conditions and the conditions of the general surroundings. Data saturation was reached when consistencies in data were achieved, and data related to specific themes became repetitive.

3.5.3 Data Analysis

Secondary data from the reviewed literature were analysed against the key heat-health research themes, including heat-related mortality, heat-related illness, hospitalisation due to heat, vulnerability to heat, exposure of vulnerable populations to heatwaves and change in labour capacity. Theme-based summaries were written and reviewed.

Historical meteorological data from the SAWS were analysed. All gaps in the existing meteorological data were dealt with through communicating with officials from the SAWS. The historical meteorological data were analysed to validate qualitative findings from key informants and other study participants.

Primary interview data were analysed using a thematic approach. Data analysis followed an adapted six-step process similar to that outlined by Braun and Clarke, (2006). The recorded audiotaped data were transcribed verbatim using *ATLAS.ti* software. Transcribed data were read and reread to ensure that details were being understood and correctly captured. Repeating patterns in the data were identified and analysed, followed by sorting and the creation of codes, that is, the assignment of labels to words or phrases that represented recurring themes in each interview. Themes were generated from these codes. The identified themes were refined and assessed. Summaries of findings were written under each theme.

All data sources were triangulated. Thus, theme-based summaries from secondary and primary data sets were collated and converged first and consequently analysed together with the meteorological data sets. Triangulation of the data sources helped in enhancing the rigour of the research, especially the trustworthiness of the research findings. Through triangulation of data sources, a comprehensive understanding of the perceived heat effects on health in the Agincourt sub-district was provided. Summaries of findings were written under each theme.

3.5.4 Data Presentation and Reporting

Although a variety of heat-health indicators from various institutions were reviewed (English et al., 2009; Cheng and Berry, 2013; Navi et al., 2017; Ebi et al., 2018) and these could have been used to report the data contained in the integrated theme-based summaries, reporting the findings guided by the indicators contained in the 2020 *Lancet* Countdown Report was considered more appropriate. The reasons for this choice include that the 2020 *Lancet* Countdown indicators are consolidated and easily accessible, internationally recognised, overlap with those from other institutions, from regular reviews done since 2015 and are the most updated. Therefore, only the theme-based summaries that could respond to the 2020 *Lancet* Countdown heat-health indicators were selected, and the findings are presented here.

3.6 Results on Human Health and Heat in the Agincourt Sub-District

In this section, the demographic composition of the participants, followed by the findings under the eight broad themes identified using thematic analysis, are presented.

3.6.1 Demographic and Socioeconomic Characteristics of Study Participants

Of the 93 study participants, 69% were South African citizens (21% were from Mozambique), and 54% were males (Table 3-3). Available literature shows that such participation is not unusual given that a significant number of persons resident in the area are migrants from neighbouring African countries who came in search of employment at farms and mines (Collinson et al., 2014; Kabudula et al., 2017). Most participants (59%) had matriculated (12 years of primary and secondary school education), while 24% had completed tertiary (colleges or university) education. About 29% and 33% of the Agincourt participants were employed in formal and informal sectors, respectively, and almost all respondents not residing in Agincourt were formally employed. Most participants (66%) had lived for a minimum of five years within 150 kilometres of the study area.

Table 3-3: Demographic and socioeconomic characteristics of the participants

Measure	Location: Agincourt sub-district (n=79)					Location: within 150km of Agincourt (n=14)			
	# Male	Male %	# Female	Female %		# Male	Male %	# Female	Female %
Gender	42	45	37	40		8	9	6	6
Age									
19-34 years	17	18	16	17		3	3	2	2
35-49 years	12	13	12	13		3	3	3	3
50-59 years	10	11	8	9		2	2	1	1
60 years^{+}	3	3	1	1		0	0	0	0
Citizenship									
South Africa	27	29	26	28		6	6	6	6
Mozambique	10	11	9	10		0	0	0	0
Swaziland	3	3	1	1		0	0	0	0
Other	2	2	1	1		2	2	0	0
Race									
Black African	42	45	37	40		6	6	5	5
White	0	0	0			2	2	1	1
Current student status									
Studying	11	12	10	11		1	1	1	1
Not studying	31	33	27	29		7	8	5	5
Highest education level completed									
Primary school	5	5	11	12		0	0	0	0
Matric	30	32	23	25		1	1	1	1
Tertiary education	7	8	3	3		7	8	5	5
Employment status									
Formally employment	15	16	12	13		6	6	5	5

Measure	Location: Agincourt sub-district (n=79)					Location: within 150km of Agincourt (n=14)			
	# Male	Male %	# Female	Female %		# Male	Male %	# Female	Female %
Informally employed	16	17	15	16		2	2	1	1
Unemployed	11	12	10	11		0	0	0	1
Duration of stay in the area									
11 months and less	0	0	7	8		0	0	0	0
1 to 4 years	11	12	10	11		2	2	1	1
5 and more years	31	33	20	22		6	6	5	5

There were 38 (41%) participants who were key informants with expert knowledge of the subject working in medical and educational facilities, airports, meteorological stations, national park and district and provincial offices, as shown in Table 3-4. The other 55 (59%) respondents were community members who could provide useful insights on the subject broadly categorised as shown in Table 3.4.

Table 3.4: Summary characteristics of key informants and respondents

Designation	Number	Summary of findings
Key informants		
Medical doctors	2	Two medical doctors residing and working close to the Agincourt sub-district were interviewed. They are involved in treating patients from the Agincourt sub-district.
Nurses	9	Nine professional nurses working at healthcare centres in the Agincourt sub-district were interviewed. They are frontline workers involved in clinical aspects of patient care.
Staff from meteorological stations	4	These staff members record meteorological data and work with some researchers. They provided information on how to access meteorological data.

Designation	Number	Summary of findings
		They verified some community perceptions against meteorological data and their experiences.
Airport staff	1	The staff member is involved in air traffic control and responded to how heat affects their operations.
Kruger National Park staff	5	Three staff members were mostly involved in game drives and managing tourist experiences. Two staff members were management staff of the national park.
Teachers and school principals	8	These respondents worked in schools within the district teaching primary and secondary school children. They are responsible for school-level responses to heat.
Researchers	3	These are researchers in agriculture and health. They work with community members and other stakeholders. They had some reports about climate and the socioeconomic situation of community members
Public health specialist	2	The specialists work in the area of public health and health research with a South African non-profit organisation.
District officials	2	These officials work at the district Department of Health and Environment. They shared district level insights.
Provincial official	2	These officials work at the provincial Department of Health and Environment. They shared provincial level insights.
Respondents		
Traditional healers/herbalist	4	These respondents provide community-based seasonal forecasting, and disease diagnostics and treatment services to community members.

Designation	Number	Summary of findings
Faith leaders	8	The leaders of various churches are consulted by community members when they are not feeling well.
Outdoor farmworkers	4	These respondents were men and women working on small farms in the community.
Outdoor brickmakers	5	These respondents were outdoor men involved in brickmaking and selling in the community
Chiefs/Village heads	4	Village heads (chiefs) are custodians of community customs and traditions. They also provide leadership to community members, especially during religious and cultural ceremonies.
Persons living with disability	4	These men and women reside in the community and have physical disabilities.
The elderly	4	Three males and one female, aged 60 years and above, are residents in the community.
Community youths	11	These respondents are informed youths residing in the community who were not formally employed or fit into other categories.
Chronically sick	5	These were persons with underlying respiratory, diabetic and renal conditions.
Community influencers	6	These are men and women who have influence in the community.

Having explained the study participants, in the next section, data from secondary sources as well as primary sources such as meteorological data are assessed and used to elaborate the climate background of the Agincourt sub-district.

3.6.2 Climate Background of Agincourt Sub-District

Existing literature generally shows that temperatures across South Africa are projected to increase at twice the global rate (Engelbrecht et al., 2015), and temperatures over the interior regions of the country are likely to increase by 2 to 3°C by 2050 and by 6 to 7°C by 2100

(Department of Environmental Affairs, 2011). However, few studies provide specific information about the climatic conditions of the Agincourt sub-district. dos Santos et al., (2019, p.4) state that 'no other studies concerning changes in climate and health, or mortality indicators have been conducted in the Agincourt sub-district yet'.

The Agincourt sub-district is located in the lowveld/bushveld region characterised by moderate summer rainfall of between 500mm to 700mm; warm to hot temperatures without any frost occurrences; high humidity, especially in summer; below-average sunshine duration during summer for a savanna climate, as well as a marked increase in minimum temperature during the summer and autumn months between 1960 and 2001 (Kruger et al., 2002).

The Agincourt area is generally hot during the summer months, from September to April. Importantly, 'since 1916, when regular observations began at Skukuza the temperatures have risen by about 0.05°C per decade' (Scholes et al., 2001, p.75). In addition, the number of hot days and hot nights in the area have been increasing (Kruger and Shongwe, 2004). Much recent literature shows that while the maximum normal temperature at Skukuza between 1981 and 2010 was 30°C, the highest average temperature recorded in 2018 was 32.6°C, and the hottest daily temperature from 1981 to 2018 was 48.3°C recorded on 10 February 2012 (South African Weather Service, 2019). These data confirm that the mean daily temperature in the Agincourt sub-district rose by 1.5°C between 1992 and 2013 (Byass et al., 2017). This long-term data shows that temperatures in the Agincourt area have been rising and will continue to rise in future unless drastic measures are taken to reduce global warming.

There is also evidence of increased weather events associated with climate change and variability around the area. The data from 1983 to 2012 shows that the Skukuza weather station recorded 21 heatwave occurrences over this period (Mbokodo et al., 2020). Although not specific to Skukuza, on 27 May 2018, a severe hailstorm hit the lowveld area of Mpumalanga, causing extensive damage in the area (South African Weather Service, 2019).

Existing literature indicates that climate change will impact the incidence and spread of vector-borne diseases, especially malaria (Byass et al., 2017). The 21-year Agincourt sub-district mortality data indicate relatively low mortality related to malaria, that is, about 180 deaths recorded in the area between 1992 and 2013 (Byass et al., 2017; dos Santos et al., 2019). Therefore, the Agincourt sub-district is a low-transmission malaria area, notwithstanding the association between malaria mortality and temperature established in existing literature (Byass et al., 2017).

3.6.3 Perception of Vulnerability to the Heat-Related Risks of Climate Change

In this section, the findings from primary data are presented. Participants stated that the Agincourt area is generally a 'hot' place. The summer season stretches between September and April. Those who have lived in the area for ten years and more stated that ambient temperatures are increasing, especially in summer. They noted that some water sources, such as wells, small natural pools and boreholes, are drying out much earlier every year than before, although they refill during the rainy season. They also reported that there is now a significant amount of dust and wind as well as dry air. For the respondents, the early drying of water wells and boreholes, dusty winds and dry air demonstrate that temperatures are much hotter than they were in the past decade or so. Participants reported that temperatures are usually above 30°C, and extremely hot days may go beyond 38°C during the summer months.

While the participants stated that the hottest months are October and November, the literature which reported meteorological data for the area suggests that January and February tend to be much hotter than these months (Kruger et al., 2002). A possible explanation for this difference may be that although January and February may be meteorologically hotter, the populations would have adapted to the heat over several months. In addition, January and February receive higher amounts of rain than October and November (Kruger et al., 2002), which can be associated with more cloud cover and may mediate the physical feeling of heat.

Since 66% of the participants have lived in or close to the area for at least five years, they highlighted that they have generally acclimatised to the high ambient temperatures experienced in the area. One respondent stated:

> *'I arrived in Agincourt in August 2007. The temperatures were unbearable for me. Then in October and November 2007, it became very hot and very uncomfortable. I could not sleep. I would force myself to go to work. But after that season, the body adapted. Right now, I only feel very hot days. Most of the time, I sleep and work without feeling the heat.'*

For both key informants and respondents, climate change appeared to be interpreted more readily as being linked to rainfall. They noted that they have not really reflected on increasing temperature changes in the area in relation to climate change and variability. One respondent explained:

> '*We usually discuss climate change in relation to a good or bad rain season. We accept that temperature increases may be associated with climate change. But we have not investigated this much. Unlike rainfall which affects everyone, temperature changes are usually an individual affair. It is hot for a day or some hours. Therefore, we do not pay much attention to this. Since temperatures are on the increase, we are all vulnerable.'*

Some respondents stated that while humans are vulnerable to heat associated with climate change, animals and infrastructures are also vulnerable. One respondent stated:

> *'For me, there is a cycle of vulnerability. Heat will affect animals, water, plants and infrastructure such as our shelter. This will, in turn, affect what humans eat, drink and where they stay. Human health is also affected. To adapt, humans will change the environment, and the cycle repeats itself.'*

Overall, the various quotes highlight the different perspectives on vulnerability to heat, especially emphasising that the community is adversely affected by heat, albeit some people can acclimatise to high ambient temperatures over time.

3.6.4 Perception of Exposure and Vulnerability to Extreme Temperature Change

Key informants demonstrated a clear understanding of the effects of exposure to heat compared to study respondents. They highlighted that heat would cause vulnerability by reducing the availability of clean water sources for humans and animals and facilitating the spread of water-borne and vector-borne diseases. Both key informants and respondents, however, stated that it would be impossible for heat to cause deaths in the area. One respondent stated:

> *'I don't think high temperatures will result in deaths here. Other people will intervene before the deaths happen. I think it is acceptable to say extreme temperatures can cause diseases.'*

Some respondents stated that heat affects many persons living in sub-standard dwellings in the Agincourt area. A respondent noted that:

> *'While we are affected by very high temperatures in one way or the other, I think the houses we live in differ. Bigger houses allow for air to circulate. Smaller houses make it difficult for air to circulate and are very hot to live in. Unfortunately, it is the poor*

such as the old people and orphaned children who are living in these sub-standard houses. They suffer more from very high temperature.'

Similarly, key informants highlighted that vulnerability arose from the lack of air conditioners in the villages. One key informant stated:

> *'We suffer from hot conditions because we don't have air conditioners. If we had air conditioners and electricity is uninterrupted, we would not be vulnerable to heat. We will just switch on the air conditioner and stay in cool places.'*

Another respondent stated that most villagers are vulnerable to heat because they must work to survive. The respondent noted:

> *'We are vulnerable to hot weather because we have to go out there to work. We need money for us to survive daily. We mostly work in outdoor settings, especially farms and mines. Our working time is predetermined. It does not change because it is too hot. If you are lucky, you can take a break when it is too hot. We often work without rest to finish the work and get money. These circumstances make most villagers vulnerable to extreme temperature changes.'*

Some participants reported that vulnerability to heat could also differ based on individual physical characteristics. A respondent noted that persons who are overweight, taking chronic medication and with skin problems, such as albinos, suffer more from changes in temperature, while a key informant suggested that nearly everyone in the Agincourt area is vulnerable to temperature changes. He noted:

> *'For me, vulnerability to temperature changes is both an environmental and personal matter. For instance, as soon as one feels hot and they regularly take water, they will not suffer much from the heat. However, without regular water intake, a person dehydrates. Persons most vulnerable to extreme heat are newcomers, old people, children, 'those disabled', the chronically ill and homeless. Also, everyone is vulnerable as extremely hot weather cause water bodies to dry up, and animals and humans to compete for fresh water.'*

Several participants included religion and beliefs in reflections in their responses to vulnerability to extreme temperature changes. These views are well represented by one respondent who commented:

> *'Vulnerability to extreme events, including heat and the effects on people depend on God. I believe humans are as vulnerable as God wants. If God wants us to be sick from heat, then we will be. If God does not permit that, then nothing will happen.'*

Most of the quotes in this section emphasise that heat exposure mostly affects the poor and those who go out to work for local livelihood support. The conditions of housing, social capital and socioeconomic conditions are emphasised as factors that predispose persons to heat vulnerability.

3.6.5 Understanding and Perception of Exposure and Vulnerability to Heatwaves

Existing South African regular weather updates allude to heatwaves without clearly defining a heatwave. Most participants did not understand the concept of a heatwave. Most argued that it was impossible for three or more consecutive hot days to occur. One key informant noted:

> *'Here, temperatures soar during the day, and they lower at night. We have never experienced three consecutive extremely hot days and nights. I can give you several days when it was too hot, but the days were not consecutive. Maybe we would have adapted by the second day, or we would have found ways to protect ourselves from the heat. Given this, we do not feel the heat anymore after the first day. Meteorological data may prove whether I am right or wrong.'*

However, a key informant working in the education sector stated:

> *'There are weeks when it becomes too hot. We stop lessons or change the venues where we deliver the lessons. Sometimes we allow children to go back home early…We may have experienced heatwaves during such weeks…but this is just my speculation. I cannot truthfully say there were three consecutive days that were extremely hot, even though I have been teaching here for nine years.'*

Because participants generally had a limited understanding of heatwaves/heat spells, it was impossible to explore, in detail, issues such as exposure and vulnerability to heatwaves, although much of what has been gathered could be included in such investigations in future. However, meteorological data suggests that there are certain days when the area may be considered to have experienced heatwaves.

3.6.6 Changes in Labour Productivity

Outdoor engagement in productive labour is a key factor that is usually impacted by increased periods of heat stress (Pogačar et al., 2018). In this study, most working people in the Agincourt area are engaged in outdoor, short-term informal employment. Both key informants and respondents pointed out that labour productivity reduces during extremely hot days. One respondent noted:

> *'On a very hot day, the body is tired, even in the morning. There is nothing much that one can do when the body is already tired. Unless one works in air-conditioned environments, it is difficult to push the body to work in extremely hot weather…In general, people are present at work, but they achieve less.'*

A key informant further pointed out:

> *'Most people here work outdoors. When it is too hot, some good employers allow them to take longer breaks. Hence employees work in the morning and late in the afternoon. Despite this, they do not achieve the same results that they usually achieve when it is not too hot. Even teachers sometimes stop teaching and make children return home.'*

The times for effective teaching and learning are also impacted by heat stress. Just as noted in other cases (Puteh *et al.*, 2012; Goodman *et al*., 2019), participants noted impacts on teaching and learning. A teacher highlighted that the decision to continue with lessons when it is very hot is not an easy decision to make. It depends on whether students remain attentive, if there is water available of, the possibility of students taking water breaks and advice from the Department of Basic Education. The teacher further noted:

> *'Lately, weather advice sometimes clearly state that teaching institutions must stop or change lessons times because it will be extremely hot. We use such weather advice to decide whether to suspend lessons or change the lessons delivery times.'*

Study participants also pointed out that labour productivity can be viewed as an individual rather than a community issue. One respondent stated:

> *'The issue of labour productivity is closely related to personal circumstances. While some people would like to work, even during extremely hot days, they have some medical conditions that make it impossible for them to work in hot weather…When we exclude these people, already the overall output is reduced. Some circumstances force people to work even if they should take a rest. There are many situations where you get paid only when the assigned task is completed. In these situations, productivity is not usually reduced.'*

3.6.7 Existing Interventions Focused on Heat and Human Health

The study further investigated the existence of any current health interventions for heat in the Agincourt area. Most participants stated that the most known intervention is drinking more water to avoid dehydration. In addition, community members sit in a shaded area, reduce outdoor work, minimise walking under direct sun, do not use blankets and may sleep outside of their dwellings during very hot evenings.

Although traditional healers highlighted that there are some traditional remedies for dealing with the effect of heat on people in the area, especially children, they were not willing to disclose the remedies. Further probing revealed that traditional healers provided medication to deal with heat-induced diarrhoea. A few males stated that they take herbal concoctions that boost their immune system against many ailments, including heat-related illnesses. Some female participants disputed these claims stating that the herbs do not solve the effects of heat.

To explore the role of interventions further, the study investigated how medical facilities in the area responded to periods of heat stress and related impacts. One doctor observed:

> *'We generally provide oral rehydration solutions to patients that are dehydrated…at this stage, we do not have any community awareness programmes focusing on the health effects of heat, even though campaigns are necessary.'*

Other clinical staff highlighted that clinician treat the symptoms that the patient presents without carefully interrogating the origin and or "driving factors" that may be giving rise to the patient's condition that would then exclude any further interrogation of any causal links between the effects of heat and the patient's symptoms. Except for cases of dehydration, diarrhoea and headaches, if a person visits a health facility with other illnesses, the medical staff prescribes the medication that cures the diagnosed sickness. Medical staff do not explore the social and environmental conditions that may be leading to the illness unless the patient details these during initial contact. Time constraints for medical staff is a major barrier that limits a detailed presentation of a patient's history.

3.7 Discussion

The subject of health and climate change in general and heat effects on human health is topical considering that the evidence of global warming is unequivocal, and many studies show that African countries are already experiencing increased temperatures over the past decades. Future projections are showing that the patterns of warming and increased temperatures are not going to change, and adaptation and mitigation measures must be taken at all levels.

The current special study collected qualitative data on self-reported heat effects on health in the rural Agincourt sub-district from local participants, and the findings were reported against internationally evolving heat-health indicators, specifically those highlighted in the 2020 *Lancet* Countdown Report. With this investigation, facets of heat and health have been identified that may deepen and broaden the international evolution and use of indicators. Importantly, the empirical evidence reveals the effects of heat and heatwaves/spells on human health in the Agincourt area.

Exiting literature show increased temperatures of about 0,05°C every decade from 1916 and an increase of 1,5°C between 1992 and 2013 specific to the Agincourt sub-district (Byass et al., 2017; Kruger et al., 2002). These increases in temperature are significant, and the responses provided in this study show that community members in the Agincourt area were aware of changes in climatic conditions, especially changes in rainfall. Existing projections demonstrate that the area is amongst the places in South Africa that will experience increased heat in future unless current trajectories are consistently altered (Engelbrecht et al., 2015).

The impacts of the increased heat on human health were clearly articulated by the respondents and key informants: heat exposure has serious effects on morbidity. The community showed an understanding of heat effects on persons with underlying medical conditions and vulnerable population groups such as the elderly and children. Despite this, current community actions to adapt to the effects of heat are simple, for example, drinking water and finding shade. There were no clear, sustained coordinated community responses to how to manage heat. This should be of concern because our study shows that some community members are vulnerable to heat exposure.

In addition, exposure and vulnerability to heat have a strong relationship with economic outcomes (Lim and Skidmore, 2020). Heat will curtail the economic activities of many community members, especially those predominantly working outdoors, such as farms, open cast mines and in the informal sector activities, for example, street vendors. Increased heat weakens the economic base and, in the absence of a clear intervention plan, exposes populations to heat.

The current situation and future projections underscore the need for heat-health interventions and programmes. Focused heat interventions are essential to reduce the risks associated with exposure to heat. It is important to provide essential heat-climate services for the region to achieve adaptation to heat and community resiliency. There is a particular need to invest in heat-health interventions for the poor and most vulnerable. In addition, the confluence of factors associated with poor heat-health outcomes underscores the need for intersectoral actions.

Of concern is that the study showed community reliance on existing structures and social capital to mitigate mortality arising from heat and extreme heat events. Study participants' contention that people will not die before they are helped demonstrates this. However, this overdependence on community structures and systems is misplaced because studies from other settings show that extreme heat events damage physical infrastructure and disrupt community systems as people are displaced (Otto et al., 2012; Russo et al., 2015; Smith et al., 2016; Mbokodo et al., 2020). With the projected increase in heatwaves and heat, deliberate efforts to strengthen the capabilities of community systems to respond to heat is essential.

In this study, evidence of community members coping with the changes in temperature was provided. Such information can inform researchers and policymakers. The finding that community members reportedly gradually adapted to heat demonstrates that there are complex mechanisms and intricate factors, including biological, social, environmental and economic, that should be considered before attributing death and illness to heat and heatwaves (Vanos et al., 2020). In most settings, the detailed physiological mechanisms for human adaptation to heat and heatwaves are not well established, and this study did not detail these either; future studies should consider doing so.

The finding on heatwaves provides new insights for heat-health response. Participants could not easily understand our definition of heatwaves, which is closely related to the internationally used definition. Participants failed to comprehend and agree to the fact that three consecutive, extremely hot days were required for a "heatwave" to have occurred. The community did not recollect experiencing three consecutive days of extremely hot weather. The failure to define heatwaves/spells made it impossible for participants to provide explanations on the effects of heatwaves on human health, specifically vulnerability to heatwaves. This finding points to the need for more careful articulation of how concepts pertaining to heatwaves are being used both by scientists and policymakers but also by communities.

As previously stated, the research of South African weather updates and existing literature showed that the term is loosely used without any consensus and elaborating the definition. Therefore, the role of language and meaning-making is critical in such efforts and requires further research. Communities, health officials and policymakers have to understand the issues and more critically offer inputs; for example, wording that may be in the vernacular but may better capture what the "science" is trying to express. Despite this, our findings relating to the population groups most vulnerable to heat events revealed that children, the elderly and outdoor workers are most exposed, confirm the findings in existing literature (Azongo et al., 2012; Thompson et al., 2012; Amegah et al., 2016; Green et al., 2019).

Previous findings linked to heat periods and labour productivity, especially among outdoor workers, were corroborated in this research (Ngwenya et al., 2018). Indeed, the Agincourt sub-district is already experiencing periods of heat spells or heatwaves, and these are projected to increase in future. Such periods of heat stress, without any appropriate mitigating interventions, can negatively impact outdoor workers, particularly those engaged in agriculture, and indirectly on their dependents.

3.7.1 Monitoring Heat-Health Indicators in Future

In this study, the foundation for further research on understanding community-informed heat effects on health within African contexts has been provided. Evidence exists on the impacts of heat on health and the effectiveness of interventions to potentially reduce heat-health stress impacts. While studies on heat and health in South Africa exist, some of them are not aligned to internationally recognised indicators, as undertaken in this study. The continued expansion and refinement of heat-health related indicators is a priority to many national and international agencies such as WHO, the Global Heat Information Network and the *Lancet* Commission on Health and Climate Change, among others. Specifically, studies on costs of heat-related mortality and loss of earnings from heat-related reduction in labour capacity in rural settings such as the Agincourt sub-district are imperative. Work is underway, albeit still unpublished, to define some key concepts such as heatwaves as well as to investigate the most relevant and applicable temperature variables for heat, particularly querying the use of minimum, maximum and average or diurnal temperature, the humidity measures, duration of sunshine and the role of metrics for wind speed and direction in the South African context. A key area of future work relates to the translation of the draft South Africa heat policy into practice and the examination of policy implementation against interventions and actual health outcomes.

In the present study, an innovative approach of gathering qualitative data and reporting it against the 2020 *Lancet* Countdown heat-health related indicators was applied. The qualitative method does not explicitly allow for any attributions to be made on heat effects on health. A more quantitative analysis of the same indicators using internationally recognised modelling approaches but focusing on the same area is currently under development as part of the heat effects on health in the Agincourt sub-district study. Future work proposes to evaluate the quality of the studies focusing on heat and health in South Africa separated into quantitative and qualitative studies using a standardised approach so that an overall evidence summary is produced. Furthermore, our plan is to analyse gender and age as well as rural and urban dimensions in the existing evidence.

3.7.2 Strengths

There are some propositions underlying this special study. Our view is that there is a more fundamental philosophical question about the presentation of heat-health risk information. Should decision-makers only pay attention to risk factor quantification for those heat-health risks supported by the strongest causal evidence? Or do notions such as the precautionary principle recommend that we should be mindful of risking quantification and explanations and even consider inconclusive evidence? The argument presented here is that response to heat-health risks, which are emerging risks in the African context, can take considerable time and ignoring less definitive evidence may lead to worse health outcomes for society.

A number of strengths exist for this study. The triangulation of data sources, that is, primary and secondary data sources, enhanced the validity and reliability of the study results. Apart from this, the inclusion of 93 persons, of which 83% completed 12 years of primary and secondary as well as tertiary education, with equitable gender age participation, with at least five years in the area and inclusive of the diverse migrant and non-migrant statuses, are core strengths of this study.

Reporting the study findings against internationally evolving heat-health indicators is innovative. The *Lancet* Countdown indicators are internationally renowned and evolving with a global monitoring framework in place. The yearly revisions and expansion of these indicators make them dynamic and topical in the health and development agenda. Notably, continued improvement in indicator measurement is facilitated through studies that encompass them, and the current special study is one of these. A key issue is to ensure that the indicators are downscaled and tracked at national and sub-national levels. Our study contributes to the currently limited country-level and location-specific understanding that exposure to extreme heat is associated with serious health implications, especially in rural settings in Africa. This study thus provides invaluable empirical evidence for policy and practice, including enhancing the health of citizens given current and future climate stresses.

3.7.3 Limitations

The study presented here begins to trace some of the community-perceived links to periods of heat stress and its impacts. Study findings are based on self-reported responses, and social desirability bias may have affected the participants' responses. All attempts were made to avoid leading questions, and short and clear questions were always used to minimise bias. Intrinsically, the study findings have limited generalisability. The study reported findings against the *Lancet* 2020 Countdown Report heat-health indicators and excludes other existing indicators reported in other reports. Whether the study findings would provide similar insights against the non-*Lancet* Countdown Report heat-health indicators has not been explored.

3.8 Conclusion

Understanding the effects of high ambient temperatures and heatwaves on human health is essential to assess risk, prioritise public health action and evaluate the success of different interventions and policies. This study provides a comprehensive assessment of eight heat-health indicators from a resource-limited African setting. Our findings show that community members believe that rising temperatures exacerbate the spread of diseases, that is, morbidity, but have played a relatively unknown part in mortality. It is essential for public health actions to focus on the major heat-health risks in communities. Some of the morbidity related risks are known by community members. Meteorological data, as well as seasonal and short-term forecasts, can complement the local knowledge, which is usually short-term, seasonal forecasting.

The findings provide empirical evidence that reinforces the crucial need for robust monitoring of the risks to human health of heat. These findings support the need for raising awareness and the creation of early-warning systems that strengthen community resilience to rising temperatures. These early-warning systems must be integrated into the healthcare system to ensure preparedness at primary healthcare facilities and clinics, especially in rural areas. Further location-specific research that informs the internationally evolving heat-health indictors, including those highlighted in the *Lancet* Countdown Reports, are encouraged.

3.9 Ethical Approval

The study was approved by the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand, Johannesburg, South Africa (proposal R14/49) This study further complied with the existing relevant ethics protocols for the Wits Agincourt Unit's surveillance and research work in the communities. Although the study was supported by the Global Change Institute (GCI) of the University of the Witwatersrand, the funding and technical partners of the GCI played no part in the study design, data collection, data analysis, data interpretation, or writing of the article.

3.10 Informed Consent

Written informed consent was obtained from all study participants. All participants provided written informed consent for recording and participating in the interview before the start of the interview. To ensure confidentiality, identifiers such as names of workplaces, health facilities and personal identifiers have been removed from the data presented in this study.

3.11 Chapter Postscript

In this chapter, the impact of heat on human health in the Agincourt sub-district was presented using some internationally acclaimed indicators. It did not address in detail the issues around decision-making at continental or community levels. In the next chapter, I start a discussion on climate services, that is, the use of climate information in decision-making on the African continent. While it seems obvious that increased extreme weather events such as heat should facilitate the development of climate services, the evidence in the context of Africa shows this is not the case, as will be elaborated in subsequent chapters.

3.12 References

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4 CLIMATE SERVICES IN AFRICA: RE-IMAGINING AN INCLUSIVE, ROBUST AND SUSTAINABLE SERVICE

4.1 Chapter Overview

The previous chapter focused on heat effects on human health in the Agincourt area using international heat-health indicators; it did not examine the related issue of the decision-making process for changing climate. In this chapter on climate services, the state of climate services in Africa is critiqued, and suggestions for inclusive, robust and more sustainable services are proffered. The main point worth highlighting is that while Africa is facing a changing climate, with increased frequency and intensity of extreme weather events, the use of climate information for adaptation is not institutionalised, as will be highlighted in several sections in this chapter. This chapter was published in its entirety in *Climate Services* journal.

4.2 Chapter Abstract

Africa is one of the most vulnerable continents to climate change because of its heightened sensitivity to climate variability and inadequate institutional adaptive capacity. Notwithstanding these challenges, Africa, and its inhabitants, have been confronting the vagaries of climate for centuries, including severe droughts and floods. Given this context, this chapter provides a commentary on the efforts to ensure and enable climate services on the continent, as well as a critical, reflexive assessment of activities in this varied landscape. A special focus on the institutional frameworks and the underlying knowledge systems that support and interface with climate services will be examined. A central question underpinning the chapter is: To what extent is the expanding landscape of climate services being endogenously driven in Africa? Finally, some recommendations for future efforts to enhance effective institutions and knowledge brokering and facilitate better climate services in Africa are suggested.

Keywords: Knowledge creation; Knowledge brokering; Climate services; Climate information and knowledge; Africa.

4.3 Chapter Introduction

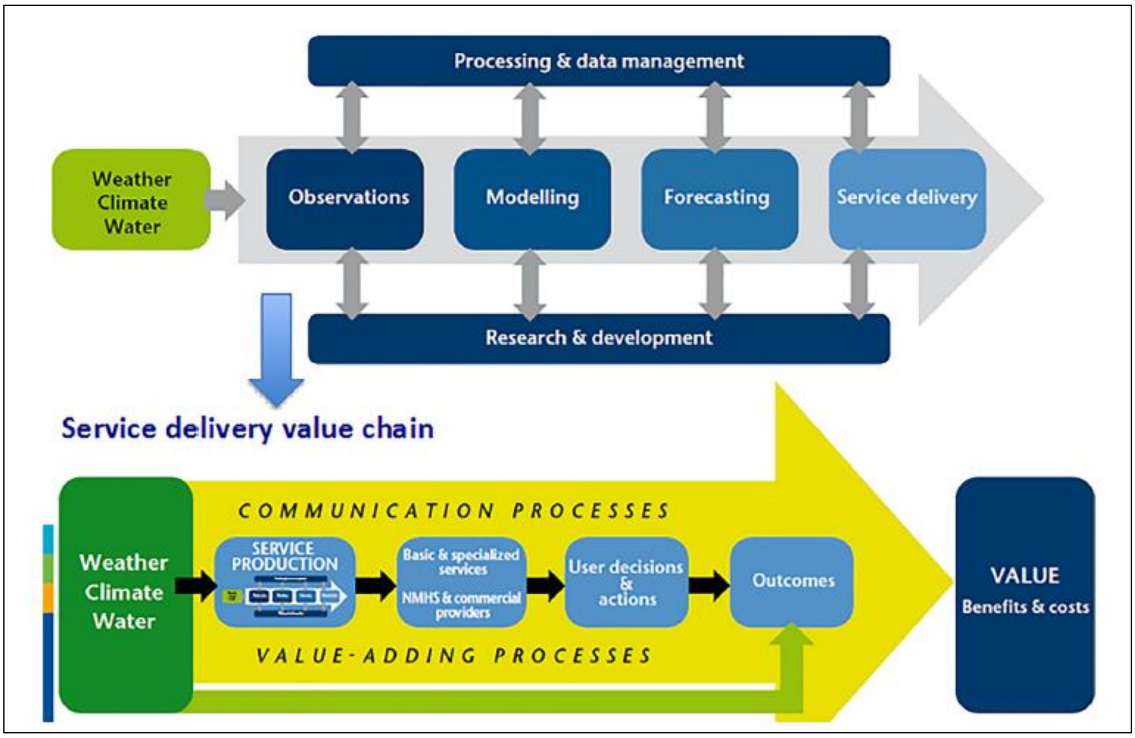
Climate change and variability are global, super-wicked challenges confronting all countries, peoples and ecosystems (Rayner and Okereke, 2007, FitzGibbon and Mensah, 2012, Adelle and Russel, 2013). African countries have been projected to be highly vulnerable to and will be severely and disproportionately impacted by changing climatic conditions, ultimately affecting the continent's development (IPCC, 2007; 2014). However, Africa, and many Africans, have been living with climate challenges, such as droughts and floods, for centuries.

Notwithstanding remarkable local and traditional coping capacities to various climate challenges, many African countries are hampered by a lack of access to context-relevant climate information. The barriers and challenges to climate information "suitability" are not unique to Africa, and several others have noted the constraints and barriers to climate information uptake and use (Dilling and Lemos, 2011; Lemos et al., 2012; Kirchoff et al., 2013). Barriers to uptake have been accentuated by how knowledge is conceptualised, framed and encountered (Moser and Ekstrom, 2010; Moss et al., 2013; Kalafatis et al., 2015). One barrier, for example, includes a "linear mode of knowledge production" in climate services where the user is viewed as, often, lacking in "climate knowledge" relevant for services and applications. This so-called "deficit" model is premised on the notion that all that is required is to "fill-up" the deficit knowledge gap with information, or to "bridge [sic] the knowledge divide" between producers of climate information and "end [sic] users" (Vogel and O'Brien, 2003; 2006; Tall, 2010; 2013). The model is also anchored to notions that the users are "end" users, a term we argue runs counter to co-production notions of co-design, with little attention to the contexts in which users operate and live their lives (Jasanoff, 2010):

> 'Living creatively with climate change will require re-linking larger scales of scientific representation with smaller scales of social meaning. How, at the levels of community, polity, space and time, will scientists' impersonal knowledge of the climate be synchronized with the mundane rhythms of lived lives and the specificities of human experience?' (Jasanoff, 2010, p. 238)

Recently, there have been efforts to rectify this model of knowledge production, and attempts are now being made to, more explicitly, include users in the knowledge production process, mostly through an iterative interactional lens (Bremer and Meisch, 2017). These engagements are often (but not always, however) still superficial, usually strongly driven by the producer of climate information (e.g., the scientists) and undertaken at a point in the process when the fundamental knowledge production decisions have already been made and without a very deep assessment and understanding of the "mundane rhythms of lived lives" As such, it often serves to tailor an existing product rather than fundamentally involving the users, understanding their "frames of reference" and lived realities in the knowledge production process (Bremer and Meisch, 2017) from the very outset. A successful climate service is provided not '…when the delivery reaches the last mile', (Youcef Ait-Chellouche, 2017, p.23), but when the delivery is co-planned in the very first mile.

Figure 4-1: The value chain approach to climate services showing various actor engagements along a chain



(Source: WMO-World Bank-USAID handbook on valuing weather, water and climate).

Efforts among many engaged in climate services are now also focused on a "value-chain approach" (see, for example, Figures. 4.1 and 4.2 showing value chain flows). The climate services value chain is underpinned by a basic system called the "Climate Services Information System" (CSIS, top graphic). The full value chain for climate services encompasses user decisions and actions and outcomes, and the evaluation of socio-economic costs and benefits (second graphic). Thus, there are non-hydro-met elements in the value chain that require WMO/NMHS engagement with other non-hydro-met stakeholders. In the climate context, guidance for this is provided by the Global Framework for Climate Services (Maxx Dilley pers. comm, 2019).

Such efforts include attention to greater interactions between users and producers of climate information (Harvey and Singh, 2017) (advances shown in Figure 4.2 with a closed feedback loop between producers and users of climate information). Notwithstanding the efforts to include inputs from users along the chain, the starting point for engagement is, however, usually still with the producers of climate change information and remains rooted in the information that is shown proceeding down a chain with some points of engagement along the way. The actual messiness of such engagements, the real world of political economy negotiations of climate services and the complex asymmetrical power plays involved in such engagements and daily lived realities are still not well captured in such a conceptualisation.

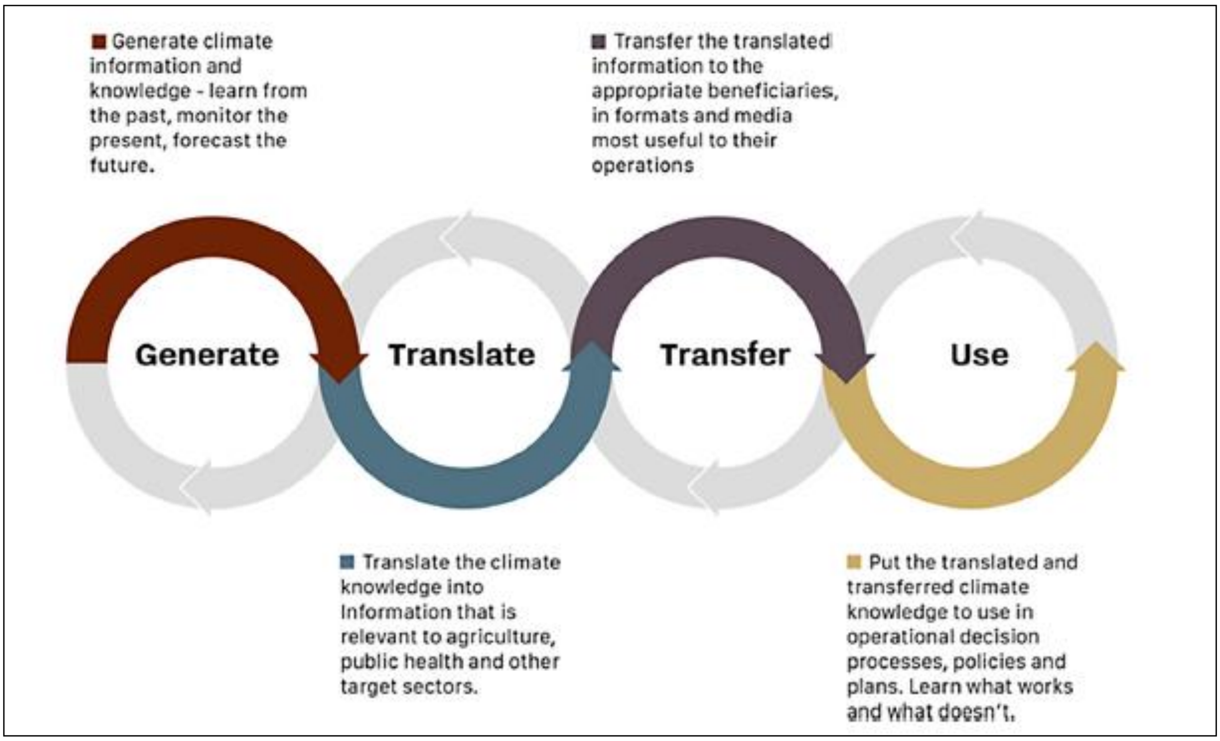


Figure 4-2: Linear value chain approach to climate services showing loops of interaction that link users to producers, with the grey loops showing engagement at the generation phase (IRI).

The argument in this chapter is against such a strong linear dominance that has become entrenched whereby a singular, producer-focused (iterative, albeit somewhat interactional) approach is the guiding operational mode of engagement. In this chapter, a call for a more decentralised knowledge production process that is sensitive to the lived realities of various users and is more reflexive of the messiness in the climate information user landscape, recognising the decision and risk context as the starting point for knowledge production. Whether and how climate change information and knowledge are currently brokered in Africa, especially the engagement processes involved, what information is brokered and whose knowledge counts are also specifically examined. Finally, some of the practical and ethical challenges for climate information and knowledge services in Africa are explored.

4.4 What, Who and Why Climate Services?

As the urgency of the climate change challenge has risen up the political agenda, the need for actionable climate information to inform policy and practice has similarly emerged as a priority. This demand led to the implementation of the Global Framework for Climate Services (GFCS) in 2009, which has since become a prominent mechanism for addressing the identified gap between the societal need for climate information and producer supply (Hewitt et al., 2012).

A wide range of definitions of climate services exists, including some more "circular" ones. The existing definitions predominantly suggest that climate services range from a climate data delivery activity with some movement towards a more nuanced form of user interaction and capacity development in climate information use. For the purposes of this chapter, I adopt the definition of Street (2016: 3), who broadly defines climate services as:

> 'The transformation of climate-related data - together with other relevant information - into customised products such as projections, forecasts, information, trends, economic analyses, assessments (including technology assessments), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large.'

Climate services generally try to enable countries and various users and actors, through informal and formal institutions and networks, to better manage the risks of climate variability and change at all levels. Through these interactions, the development and incorporation of science-based climate information and prediction services into planning, policy and practice are fostered.

Effective climate services are, thus, increasingly being understood as involving the co-production and co-engagement of knowledge by both producers and end [sic]-users that should elicit and provide the various actors with climate information of relevance to climate-sensitive sectors. Such engagements, ultimately, should also facilitate adaptation and mitigation to climate variability and change (Steynor et al., 2016; Moss et al., 2013).

4.5 Evaluating and Enhancing Climate Services in Africa

Climate services have been growing worldwide, with the proliferation of several initiatives directed at developing the capabilities for climate information. Notably, existing studies generally point out that there has been an uneven proliferation of climate services (Reinecke, 2015), with the majority being funded and supported by initiatives from developed nations. Climate services frameworks and initiatives, availability of climate services in Africa, and the disconnect and dissonance between information supply and use are further investigated below.

4.5.1 Climate Services Frameworks and Initiatives

The growth and development of the climate services landscape worldwide have been characterised by a number of different actors, agencies and interests, some of which are noted here. The WMO co-sponsors a range of initiatives, including the World Climate Research Programme (WCRP), the Global Climate Observing System, the Intergovernmental Panel on Climate Change, the GFCS and the United Nations Convention Framework on Climate Change (UNFCCC). These global agencies collaborate with National Meteorological and Hydrological Services (NMHS) in developing and delivering climate services. These well-meaning efforts merit more interrogation, particularly in this chapter, where a call for an investigation into the nature and value-add of co-engaged efforts in climate service production processes is made.

The global institutions that promote climate services have been explored in existing literature (Medri et al., 2012; Máñez et al., 2014; Vaughan and Dessai, 2014). In their comprehensive assessment, Vaughan and Dessai (2014, p.595) note that, notwithstanding the progress and development of technical development, the ‘truth is that, in many contexts, the strongest impediments to forecast adoption are contextual or institutional’. Investigating such institutional dimensions has mainly been in the form of single or multiple case studies (e.g., Dilling and Lemos, 2011; Kalafatis et al., 2015).

Africa-focused institutions for climate information services have also evolved over time. Detailed assessments (Snow et al., 2016) of such collaborations included progress being made with some of the national hydrometeorological services for eleven countries (including Benin, Uganda, Tanzania, amongst others), illustrating the roles that data, climate information, accessibility and uptake of climate information play in enhancing climate services in Africa. Barriers and constraints, particularly in connection to public-private partnerships that can be seen as key to progress climate services in the continent, are also explored. Besides the NMHS that are found in all countries on the continent (e.g., Snow et al., 2016), a number of regional institutions have existed for several years, such as the African Centre of Meteorological Application for Development and the Intergovernmental Authority on Development Climate Prediction and Application Centre. The recently created or restructured climate services institutions on the continent include the Southern African Development Community Climate Service Centre, West African Science Service Centre on Climate Change and Adapted Land Use and the Southern African Science Service Centre for Climate Change and Adaptive Land Management. A number of development and science councils have also aided the promotion of climate services and engagement with users in the African context. There are several large-scale climate information initiatives, including the Future Climate for Africa, Weather and Climate Information Services for Africa and ClimDev-Africa programmes that exclusively focus on Africa-centred climate information. Severe shortages of climate and weather information and weather station data have been confirmed in these projects, as well as the need for appropriate climate and weather information linked to urban city planning, water, energy and adaptation. The climate data and information landscape has grown significantly with many new actors entering the arena.

In addition to these efforts and those of the meteorological services, an expansion in actors is also being noted with the non-governmental organisation sector, the private sector (e.g., mobile phone companies and index-based insurance schemes, for a good review of African cases see Snow et al., 2016) and farmers unions adding to the enterprise. The role of climate knowledge brokers and boundary organisations have also arisen, “filling in spaces” in the value chain (Kirchoff et al., 2015a; 2015b).

Brokers and boundary organisations, including the role of climate outlook forums, have also grown globally and in Africa and have had mixed reviews (Kirchoff et al., 2015a; 2015b; Daly and Dessai, 2018). A good example (despite a few shortcomings mentioned above) of the collaboration, spearheaded by international agencies (Daly and Dessai, 2018) is the Regional Climate Outlook Forums in Africa, where consensus is reached on seasonal forecasts with data and technical support from international partners (Patt et al., 2007).

In their detailed assessment of outlook forums, for example, (at least seven, including the Greater Horn of Africa and the Southern Africa Region Climate Outlook Forum), Daly and Dessai (2018) note that there are three models of users' engagement ranging from a linear "hands on" approach where forecasts are disseminated to users, followed by one that enables some user feedback to producers of information and finally the active partnership and engagement approach usually referred to as a co-engaged, co-designed approach. The future and sustainability of the forums have always, however, remained a challenge. The suggestion of the possibility of more formal architectures and activities on climate information for regions (International Science Council et al., 2018, p.13) may go some way to improving the less permanent institutional arrangements of the forecasting forums. Notwithstanding the future of the forums, the engagement processes between and with users and producers of climate information remain constrained:

> 'Nonetheless, all models of user engagement …engage users "downstream" of the production of the forecast … according to interviewees, only a small number of RCOFs have embraced more collaborative models of user engagement' (Daly and Dessai, 2018, p. 700-701).

In response to this enduring challenge, it is posited that rather than the producer generating information based on assumptions of how users may perceive and include climate into their lived reality and possibly use the information, there is a need for very early and ongoing engagement processes, linked to understanding the contexts and lived local realities of the people one is interacting with. Such an approach argues against entrenching the ideas of "value chains" and unidirectional flows of information. How, whose and which knowledge forms are being "valued" in the process of climate information production and uptake and use thus remain central challenges (Dilling and Lemos, 2011, Kirchoff et al., 2013, Vincent et al., 2018a; Vincent et al., 2018b).

4.5.2 Availability of Climate Services in Africa

Sector-specific information on climate services, such as climate services for water and agriculture, tend to dominate the climate services research focus in Africa. The water and agriculture sectors are important sectors related to the vagaries of climate of African countries' economies prompting increased research. A few studies have explored other sectors such as health, energy and infrastructure and local services wherein the Africa specific context is key. Cholera outbreaks following floods, heat stress cases, nutritional concerns linked to prolonged droughts, large infrastructural damages incurred during flash floods, etc. (Holloway et al., 2013; Selvaraju, 2013; Troccoli et al., 2015; Terradellas et al., 2015), as well as other concerns such as the ethics of climate services and interrogating whose knowledge counts and why (Hewitson et al., 2017) are all being researched as part of "climate services".

The science of climate change and variability, as encapsulated in the various climate projection models used, has also been variously advanced on the continent but without much deep and critical due regard to use and application in the political, socio-economic and general decision and policymaking contexts of the continent. While the various models have remained relatively clear to the scientific community (although even this could be debated), there has been very little assessment of the value and uptake amongst the praxis members of the community, particularly the value-add to overall social wellbeing (Vaughan and Dessai, 2014).

There has also been little attention to the user's framing of climate change; What does climate variability and change actually mean to a user? Attention to power differentials in contexts where users are interested in climate information is raised as a challenge, but there are very few detailed assessments of what asymmetries of power may mean in the context of user engagements with climate information (e.g., Lahsen, 2016; Van der Hel, 2016; Nost, 2019). Much of the research remains rooted from the perspective of the scientist's world view and "business", for example, climate monitoring, data acquisition and the like.

Challenges in accessing good quality data, commercial data and climate information are therefore noted to persist in climate services (see, for example, a good overview by Georgeson et al., 2017). Commentators also note that evidence points to '… a persistence in many of the main trends relating to interpreting and communicating climate information' (Harvey and

Singh, 2017, p.16). Other persistent challenges (Harvey and Singh, 2017) are also noted, which are arguably not only related to African engagements. These are linked to notions of trust and engagement, which are often viewed as the "soft" side of climate services when compared to the "hard, more techy" nature of climate services. The framing, engagement and interaction in climate services are still driven from the scientists' perspective (physical, social and or biophysical scientists). The blindspot, it would seem, is that the worldviews, imaginaries and daily lived realities of the users, and indeed, civic or community epistemologies (Jasanoff, 2010) are not really being considered. Several authors, including Harvey and Singh (2017), Porter and Dessai (2017), Daly and Dessai (2018), Bremer et al. (2019) note, for example:

> '…scientists still treated users as if they were a mirror image of themselves or highly numerate like them' (Porter and Dessai, 2017, p.12).

4.5.3 The Disconnect and Dissonance Between Information Supply and Use

Experience derived thus far shows that, in general, unless climate data are developed in response to the context and with whom it is intended, it often has very little value (Stern and Easterling, 1999, Vogel and O' Brien, 2003). Understanding the practitioner decision context and how user knowledge related to climate is/is not being created, valued and used is, therefore, central to co-designing and co-creating climate services that are both useful and usable (Clayton et al., 2015). Failure to be fully aware and cognisant of belief systems, values and perceptions held by users in climate services can ultimately fracture trust-building relationships that are critical to the success of climate services. This point is made explicit in the white paper on Climate Services Ethics which states, 'We believe that the value systems and decision frameworks of users should be central to climate service delivery' (Adams et al., 2015, p.1).

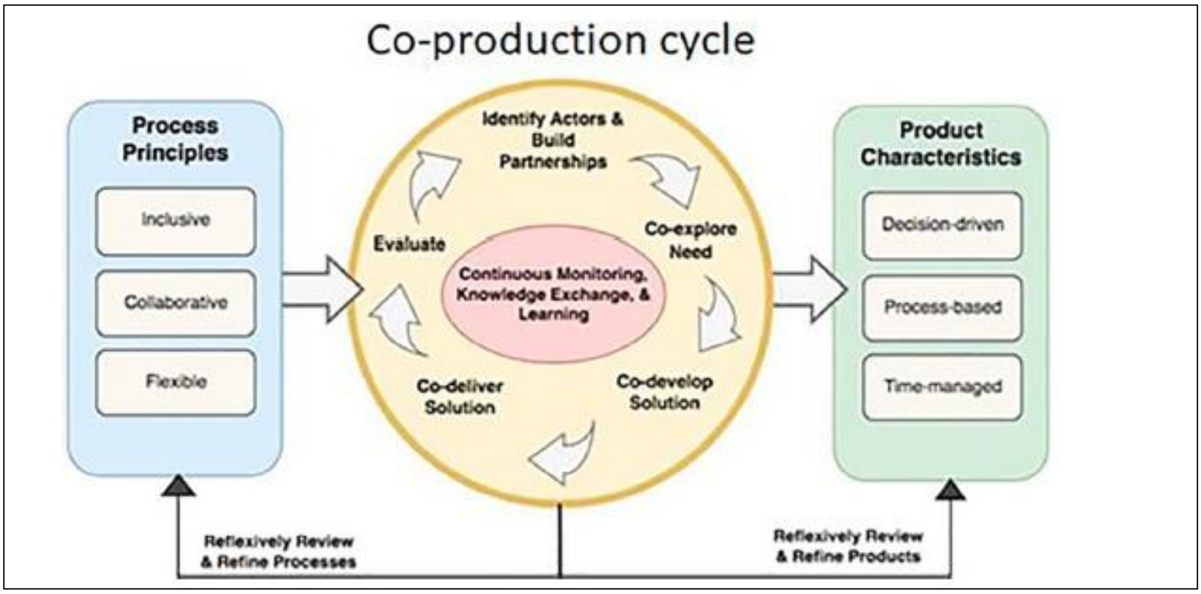
The involvement of practitioners (e.g., decision-makers and other actors) in climate services is enhancing more meaningful understandings of adaptation to various climate stresses. However, the persistence of a "value chain" approach (Figure 4.3) and the notion of a "service", it can be argued, are failing to result in a step-change in climate information use in planning and decision-making in the African context. This is evidenced through the slow pace of adaptation implementation on the continent (Shackleton et al., 2015) and infrequent integration of long-term climate information into policy and/or decision-making (Jones et al., 2015; England et al., 2018). Weichselgartner and Arheimer (2019, p.393), in their recent review of climate services, further endorse the shared views of more detailed attention that needs to be given to the engagement of users (in our case African users) when they note about Climate Change Adaptation Services (CCAS):

> 'The challenge of designing effective CCAS has two dimensions: first, bringing users into the front end of service production, an arena from which they have been so far mainly excluded; and, *second, institutionalizing polycentric, interactive, and multipartite processes between knowledge and decision-making, among actors that have worked so far largely discretely' (emphasis added)*.

The current producer-driven iterative interactional approach (Bremer and Meisch, 2017) to practitioner engagement falls short of "servicing [sic]" the needs of African practitioners and wider civic society. There are three main disservices that result from this approach to knowledge production. The main disservice is the potential damage that can be caused through extractive engagement techniques that are often inherent in a hierarchical, iterative, interactional approach. The primary intention of these engagements is often to elicit feedback for the purposes of meeting funding obligations or meeting the needs of the producers (Steynor et al., 2016). The value of practitioner engagement is strongly dependent on the way in which engagement is undertaken, including who is engaged, when they are engaged, how they are engaged and the context in which they are engaged. If practitioners gain little, if any, value from the process and are left with little to show for the time they have invested then these types of engagements can, over time, sour producer-practitioner relationships and have a detrimental effect on the overall climate services project.

While the iterative interactional approach results in products that are nuanced towards the needs of practitioners, the final products often do not meet the use requirements of the practitioners. For instance, most African National Meteorological Services still present consensus seasonal forecasts as tercile maps of "below-normal," "normal" or "above-normal" rainfall. This convention was adopted in response to consultations during the Regional Climate Outlook Forums and is still widely used today. However, practitioners express difficulties with using these forecasts, such as a lack of local interpretation (Patt and Gwata, 2002) and the arbitrary thresholds often provide a lack of decision-relevant information (Klopper et al., 2006).

Figure 4-3: Conceptualisation of the co-production process



Source: Vincent et al., (2018a) (permissions from the authors).

Finally, superficial engagement that does not fully recognise the democratisation of a diversity of knowledge and perspectives in a knowledge development process can result in communities, policymakers and even national agents/actors disassociating themselves from "owning" and effectively using the resulting services (Steynor et al., 2012; Vincent et al., 2018b). Reflexive considerations of more local and traditional knowledge about climate and its impacts and civic epistemologies about the lived environment, and not "the environment" as driven and presented by technocentric models, are also often not front and centre of the production of climate information (Roncoli, 2006, Roncoli et al., 2011).

Some of these aforementioned concerns about climate services in Africa have been raised since the early 1970s (e.g., Glantz, 1977). Initial investigations on climate information in Africa explored whether more and better information would lead to its use and also identified some of the conditions where such engagements could be enhanced (Hulme et al., 2001, Vogel and O'Brien, 2006). Vogel and O'Brien (2006) indeed caution against the approaches whereby climate information is produced "in silos" (e.g., for enhanced food security) that is not fully recognising and value the contexts in which the intended users are embedded.

Vogel and O'Brien (2006), for example, observed, over a decade ago, that expecting people who were not involved in the production of climate information at the very outset and who are expected to just "eat" or consume the information (in contexts of enhanced drought risk reduction and food insecurity) because it has been produced and transmitted by experts, may be a misguided approach. Climate information producers, they argue, have to consider the users of the information throughout the whole knowledge production process. While, certainly, some attention has been paid to the voices that caution against the 'let the Africans just eat climate information' approaches (Snow et al., 2016:10), this is not yet widely appreciated within the wider climate services community. Practitioners are often engaged relatively late in the process of information production, with the purpose of nuancing or tailoring the final climate product to better meet the needs of the recipients (Bremer and Meisch, 2017; Vincent et al., 2018a). As such, the direct, early co-involvement of the users of climate services in an immersive extended science approach (Bremer and Meisch, 2017) (as opposed to an iterative interactional approach) has remained largely unrealised, with only a few committed researchers and practitioners attempting to pursue more engaged processes early on in the knowledge production process (Weichselgartner and Arheimer, 2019).

The logic and current framing in the climate change discourse, while noting the emerging need for partnerships amongst many engaging in climate services, is still also often framed as that of "bridging" science to policy and society, but actual co-creation is still not surfaced or very evident. Even some of the sponsoring bodies perpetuate the notion of more linear engagements (e.g., International Science Council et al., 2018: 15, emphasis added):

> 'WCRP should build pro-active bridges to the WMO's Global Framework for Climate Services *and other science-to-service initiatives*.'

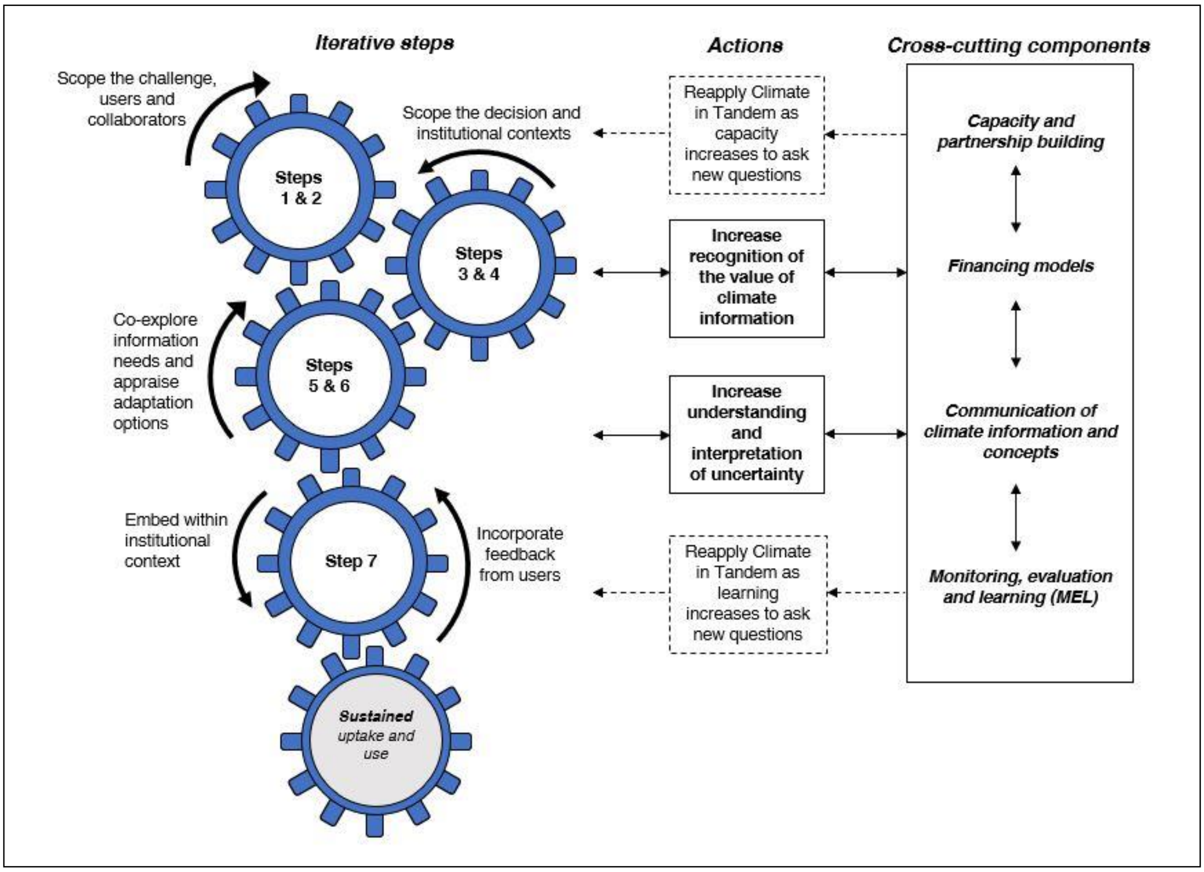
We caution against a "bridging" conceptualisation calling, rather, for a framework that illustrates the complex and, usually, messy and interactive "spider webs" of daily, real-world engagements (e.g., Vogel et al., 2007), including investigating the role that various shadow networks play in the wider climate services landscape, either internationally or more locally (e.g., Pelling et al., 2008).

Some authors have recently attempted to begin to capture these more participatory and "messy" co-production frameworks in a graphical manner (see, for instance, Figure 4.3 taken from Vincent et al., 2018a and Figure 4.4 from the Stockholm Environment Institute [Daniels et al., 2019]). These conceptualisations, many of them borne from intense engagements in African contexts and experiences, are valuable in furthering the discourse around a more participatory approach to climate services. However, it should be acknowledged that these simple conceptualisations can never adequately capture the complex reality of the context-specific process (Vincent et al., 2018a; Daniels et al., 2019).

In combination with this recent advancement in the theoretical discourse, some more practical successes have been realised where comprehensive engagements have been undertaken at the very outset of the project process in the African context. These projects have demonstrated the value of early participatory engagement. For instance, in the recent Building Resilience and Adaptation to Climate Extremes and Disasters programme, a co-production process was undertaken in Burkina Faso to strengthen the capacities of the national meteorological service to jointly develop forecasts with agro-pastoralists.

In approaching this project, significant resources and time were allocated to building partnerships, developing common ground and developing principles for working together. Some of the partners had no prior experience of working together, so a number of engagements were facilitated with the purpose of gaining a common understanding amongst actors before any attempt at co-development took place. As a result of taking this immersive approach to co-production (Bremer and Meisch, 2017), increased access and use of climate information were reported. But, almost more importantly, the actors involved in the project (working both ways between producers and users) reported a notable change in learning, knowledge, attitudes, capacities and skills. This translated into a continuation of interest in climate services post the project, and budget lines were introduced to continue creating the spaces for shared interactions (Carter et al., forthcoming).

Figure 4-4: The "Climate in Tandem" co-production framework from Stockholm Environment Institute



Source: Daniels et al., 2019.

4.6 Questionable Endogenous Growth and Ownership of Climate Services

In combination with the shortcomings highlighted in the predominant iterative interactional approach to "climate services" in Africa and some successes with more immersive approaches, there are additional dynamics, we would argue, that are also potentially limiting the effectiveness of climate services in an African context. These shortcomings centre around the issue of ownership and growth of climate services from within the continent.

Africa has become a major focus for international aid to address the impacts of climate change because of the disproportionate impact that climate change and variability are likely to have on the continent, as well as the recognition that many African countries lack in-country resources and may have limited or unrealised capacity for a sustained and sustainable response. A number of climate services initiatives and programmes, as shown above, are being implemented on the African continent. The recent focus on programmes to deliver climate services for Africa is undoubtedly making a positive impact in some cases, not only on learning about climate change (between scientists and citizens) but also in grappling with how to include relevant and appropriate climate information in decision-making and practical climate adaptation initiatives. Several sources of funding aid provide a critical role in facilitating climate change activities on the continent (e.g., Department for International Development, Deutsche Gesellschaft für Internationale Zusammenarbeit, Swedish International Development Cooperation Agency, Norwegian Agency for Development Cooperation amongst others) many through programmes and initiatives for climate services delivery, implementation and use as well as capacity building, particularly strengthening capacities to deliver and use climate services – although the learning and feedback loops between citizens, scientists and funders are still weak and not well understood.

These funding efforts are, however, not without their own challenges. There are occasions, for example, when funding and technical support from international partners can create a situation where climate services so-called "for and in" Africa can exacerbate the complex environment in which multiple actors/funders/agents are already trying to operate in. The different support partners, for example, can impose a number of implementation and accountability conditions for the implementation of the various initiatives and programmes. These implementation and accountability conditions can sometimes conflict with the priorities or values of the recipient country's policy or even the practicalities of implementation on the ground. For instance, the upgrades to the Lusaka water and sanitation system, driven by international aid, are focused on the macroscale issues of delivering water to Lusaka. While these infrastructure upgrades are tremendous assistance to the water and sanitation project in Lusaka, it diverts the focus from the practicalities of delivering water at a household level, which remains a challenge for the city. This tension between city processes and development aid are documented in interactions at the city scale (Blantyre, Harare and Lusaka) through the Future Resilience of African Cities and Lands project, where a partner from one of the cities expressed that 'The problem comes from development partners as they come with success stories from elsewhere which do not work in [city A]'. Another partner reiterated the statement by saying, 'Development partners should come and support already existing visions' (Nchito et al., 2019, p.2).

Despite excellent intentions, the nuances of the African context, particularly the political economy and power relations in climate services production, have yet to be fully explored in the design and intention of climate services initiatives and programmes (Webber and Donner, 2016; Hewitson et al., 2017; Nost, 2019). Climate services, in their current form of designing, framing and implementation may fail to gain traction in the long term because of issues of trust, recognition of varying forms of knowledge and climate information, political understanding and support, and transparent processes that are clear at the very outset of engagement processes (see similar conclusions that Snow et al., 2016 draw with climate services in many African countries).

Finally, many programmes often neglect to consider sustainability plans for their interventions, leaving few (or no) resources to maintain or expand on the investment. This results in reliance on ongoing international aid to maintain programmatic interventions (Harvey et al., 2019), often rendering African countries beholden to international partners. Given the above scenarios, one main question about the delivery of climate services in Africa is whether there is indeed endogenous growth and evolution of these services? There is no easy answer to this question, and, as has been shown with some of the issues and concerns raised above, this requires further detailed investigation.

4.7 Re-Imagining Climate Services in Africa

In this chapter, the manner in which climate services are implemented in Africa have been presented. It is argued that greater attention needs to be given to how knowledge related to climate and climate variability and change is currently being factored into current and future planning (Webber and Donner, 2016). Of those cases where climate information is being sought after and used, what suggestions can be made to re-engineer and enhance the effectiveness of the delivery of climate services in Africa and enable feedback and knowledge inputs from users to producers of climate information? The suggestions advanced are two-fold: first, emphasising more engaged approaches (e.g., transdisciplinary approaches to climate services) delivery along the lines of Bremer and Meisch's (2017) extended science lens, and second, an interactive learning and knowledge brokerage approach. A departure from the "let them eat information" approach requires taking both an invigorated science approach (e.g., for better forecasting across scales) and a transdisciplinary approach (Austin et al., 2018) to climate services delivery premised on various forms of knowledge production, including mode 2 forms of knowledge production (Gibbons et al., 1994).

First, transdisciplinarity can help to explore and begin to unravel the underlying cultural and contextual factors that influence the framing of climate by users and, if the goal, the uptake and use of climate services (Lee et al., 2015). This is imperative, especially if all agents involved in delivering climate services attempt and aspire to be honest brokers of knowledge as well as aim to advance ethically-informed services.

Second, sustained transdisciplinary research and actions in the climate services space in Africa can help demonstrate the complexity and "messy realities" of the decision-making arena, allowing for a more context-specific and context-sensitive understanding of the role of climate information in the decision-making process. Intrinsically, an enhanced understanding of the decision-making space does not only allow for climate information to be designed to better fulfil the requirements of the intended users but also facilitates the identification of gaps in how we all become users of climate information by:

> 'Living creatively with climate change …by …. *re-linking larger scales of scientific representation with smaller scales of social meaning*' (Jasanoff, 2010, p.238, emphasis added).

The shift towards an iterative interactional approach to climate services has resulted in an increase in user-engagement activities. This has led to a substantial increase in both virtual and face-to-face contact between researchers and African practitioners. For instance, most attempts at user engagement and capacity building work have inevitably taken place in the form of workshops or meetings. While these mechanisms are often appropriate engagement techniques, the number of one-off engagements that abound in climate service development is leading to a form of "engagement apathy" in Africa (CSAG et al., 2014). This is compounded by a perceived lack of progress on the part of the researchers, with some practitioners engaged repeatedly on the same issue but by differing teams of researchers (FCFA, 2017). This is rapidly leading to fatigue towards superficial engagements that result in little output and provide scant change in daily functioning.

Whether this increased engagement is leading to changes in knowledge brokerage requires more detailed investigation. In fact, increased numbers of engagements without changing the knowledge "processes" of engagement may just perpetuate the same "let the African eat information" perspectives. Given this, it is critical that transdisciplinary engagements embrace the principles of considered co-production, particularly with regard to process. A set of principles are outlined by Vincent et al. (2018a) and include that the co-production process should be inclusive, collaborative and flexible. In practice, this means that the co-production process should include all relevant actors at the very outset of the design of the project with an emphasis on humility, including funders and potential lead institutional actors, the expectations of the engagement should be clearly communicated from the outset, the contribution of all knowledge holders (scientists, practitioners and intermediaries) engaged in the project should be budgeted and accounted for upfront (Steynor et al., 2016, FCFA, 2017), there should be a focus on relationship building that is sustained beyond a single project and the process should remain open to emergent issues that may change the course of the interaction.

Funding agencies, research councils and various programmes, thus, have a very important role to play in facilitating the adoption of these principles, promoting a more co-learning approach. The current balance of power lies with the funding agencies as they allocate budgets (including individual budget quotas), project focus, timeframes and deliverables of programmes/projects. We suggest here that this often dominates the climate services discourse that then flows from such engagements and becomes entrenched over time. Therefore, funding agencies should also be re-imagining how they engage in climate services and document their principles of action; for example, limiting short cycles of project funding and one-off or temporary transdisciplinary engagements (Steynor et al., 2016) to include longer cycles of funding, building in flexibility in budget allocations and reporting requirements (Gaziulusoy et al., 2016), remaining open to emergent issues that may change the course of the project, focusing on building local institutional capacity and refocusing attention on the success of a process rather than solely on the project outcome (Steynor et al., forthcoming).

An important consideration in the delivery of climate services in Africa is for external agents to acknowledge that there is a great deal of learning that should take place among parties and that the "producers" and "funders" of knowledge are also learners. In effect, therefore, there is no END user. To date, not enough focus has been placed on how local level (municipality, district and provincial levels) and community-based institutions can actively engage and indeed lead in knowledge about climate variability, change and risk reduction. The reason for this is that those involved in institutional capacity building and implementing some interventions have often not taken an interactive learning approach (Lundvall, 1992). Through an interactive learning approach, there is an acknowledgement that all systems and institutions are important in solving “wicked” global change problems. In fact, local and community-based institutions are often more informative and knowledge rich and thus usually can strengthen the “science” and “policy” contexts because they have evolved over time in the locality, thus making them adapted and adaptable to the locally prevailing conditions (another additional argument to rethink the Figures 4.3 and 4.4 showing a dominant “linear” model).

4.8 Conclusions

In this chapter, an examination of climate services in Africa, focusing on the approaches and institutions involved in climate services delivery in Africa, as well as the knowledge that is encapsulated in the climate services was done. The discussion makes it clear that the delivery of climate services in Africa has some serious constraints, namely that there seems to exist a lack of honest understanding of how and if climate knowledge is framed and used in local contexts. The departure points for engagements are still tethered to the “scientist” as the expert who is “communicating” and trying to embed climate information and knowledge into the daily realities of people. The brokerage of knowledge thus becomes the driving feature of the engagement process with a focus on communicating science that is then unfurled through a value-chain type of approach to climate services. Attempts at more iterative, interaction co-production efforts are being tried, but initiatives from the “ground up” and the hearts and minds of Africans, it is argued, are not being adequately considered in the processes. In short, there remain few endogenously African driven efforts. This is at a time when decolonisation is a sensitive and pressing issue on the continent. Rather climate change “adaptation and climate services” are being created externally and therefore lack local ownership.

The previous and ongoing contributions made by the international community to support fundamental climate services research and build essential capacity on the continent to enhance adaptation to current and future climate risks should be applauded. These interventions have had a positive impact on Africa’s preparedness to tackle the climate change challenge, although the value-add needs more investigation. Given the likelihood of impacts coupled to climate change, a call for urgency in evaluating the approaches to climate change engagements in Africa, including climate information used for effective risk reduction.

In this chapter, some of the challenges in the current approach to climate services have been outlined. It is, therefore, suggested that it is time to re-imagine climate services implementation in Africa through embracing more participatory and polycentric approaches that can more closely begin to map onto and be informed by the daily realities in Africa. The considered view is that these changes in framing and the ways in which such engagements are captured and visualised may lead to climate services being considered as a valued service rather than an obligation by many interested and affected parties who currently only "interact" with the services.

4.9 Chapter Postscript

This chapter presented a detailed literature survey and critique of climate services in Africa. The partially explained aspect of holistic approaches which will be made more elaborate in the next chapter, which presents a systems conceptual framework for climate services, especially climate services for health in Africa.

4.10 References

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5 SYSTEMS APPROACH TO CLIMATE SERVICES FOR HEALTH

5.1 Chapter Overview

In the previous chapter, the climate services theme was introduced with a special focus on Africa. The key message highlighted was that climate services in Africa must be re-imagined to be robust, inclusive and sustainable to ensure more resilient societies in the face of climate change. The subtle and implicit point highlighted in this chapter is that climate services should also be context-specific to be suitable and actionable. Therefore, the chapter cautions against theorising universal services without considering the context of the services.

This chapter narrows the discussion on climate services by suggesting a new approach for more specific types of climate services, namely climate services for health. The chapter presents a novel conceptual framework for guiding analysis for climate services for health. To my knowledge, the systems approach to climate services for health has not been clearly articulated or presented in existing literature. The systems approach to climate services for health is advanced as a holistic and comprehensive way to view the services. Conceptualising climate services for health in a holistic way enables policymakers, researchers and practitioners to understand the importance of the feedback loops that must exist for co-delivery of an effective and optimal service. The Ethiopian case study presented in this chapter partially grounds the systems approach to the African context. The Ethiopian case study demonstrates the evolution of climate services for health in a country with 'over 1000 active observation stations. The NMA is one of the strongest national meteorological services (NMS) in Africa and has demonstrated a leadership role in a number of key developments. For instance, ten years prior to the development of the Regional Climate Outlook Fora in Africa (RCOFs), the NMA was disseminating national seasonal climate forecasts' (Dinku et al., 2014a, p.2).

This chapter is presented in its entirety as has been published in *Climate Services*, with the exception of sections 5.1 and 5.8, which were not part of the original article. The chapter is structured as follows. In sections 5.2 and 5.3, the abstract and introduction are presented, followed by the justification for the approach as well as its application in sections 5.4 and 5.5. In section 5.6, suggestions to enhance the conceptual framework are provided, while section 5.7 concludes the chapter. The chapter postscript in section 5.8 recaps the main points raised in this chapter and links it to chapter 6.

5.2 Chapter Abstract

Climate change and variability remain pressing global challenges directly and indirectly affecting human health. This has increased the demand for usable climate information for adaptation to climate-related health challenges and for building effective response strategies. Climate services for health can help to enhance human well-being and, in extreme cases, can save human lives by reducing morbidity and mortality. Very little has been done and understood about how we can enhance climate services for health. The main aim of this chapter is to bring empirical evidence, conceptual clarity and interdisciplinary approaches to policymakers and practitioners dealing with this crucial issue. The article explores the application of a holistic, broadly termed “systems” approach to climate services for health in the context of adaptation and resilience. It uses illustrative examples from Ethiopia, Bhutan and Germany to demonstrate and elaborate the application and merits of the systems approach to emerging climate services for health. The systems approach improves conceptual thinking about climate services for health. In addition, it is a valuable analytical framework that unifies the diverse stakeholders involved in health adaptation and resilience planning, interventions and policymaking. This chapter fills in the existing gaps in the scientific literature on the subject and enhances the conceptualisation of climate services for health. It makes suggestions to improve understanding of climate services for health.

Keywords: Adaptation Climate change and variability, Climate services, Health system, Climate system, Climate information.

5.3 Chapter Introduction

There is growing and incontrovertible evidence that climate change and variability can, directly and indirectly, act as an amplifier of threats to human health globally (Costello et al., 2009). The World Health Organization (WHO) estimated that 12,6 million or 23 per cent of all deaths worldwide in 2012 were attributable to environmental factors mainly related to climate variability (Neira and Prüss-Ustün, 2016). Human health outcomes are largely impacted by both EWEs and gradual changes in weather and climatic conditions. EWEs, on the one hand, can affect physical and psychosocial well-being, influence access to healthcare and cause vulnerability (Aadil Gulzar et al., 2021). Gradual climatic changes, on the other hand, can trigger exposure to harmful or beneficial health conditions (Whitmee et al., 2015). Recent scientific models and predictions show that the global effects of climate change are more pressing than ever (IPCC, 2021). The evidence demonstrates the increasing health effects of variations in climatic conditions. It also shows that non-integrated (climate information alone or health information only) is inadequate for decision-making on diseases and illnesses related to climate variability. Rather than only focusing on "climate change" as the central issue, the overall system in which climate change is occurring and playing itself out is needed for informed climate action. Transdisciplinary approaches that integrate actionable climate information, observations and models, we argue, are required for actionable knowledge about the health impacts of climate exposure (Hewitt et al., 2021).

Integrating climate and health information and making it actionable is, however, a very difficult task. Nevertheless, increased mortality and morbidity has intensified the urgency for responding decisively to the health impacts of climate change. A holistic, robust and sustained climate-health response requires the effective deployment of accurate and tailored climate information and dedicated climate services (Watts et al., 2015).

One arena for action is what has been termed "climate services", that is,

> 'transformation of climate-related data – together with other relevant information – into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other services in relation to climate that may be of use for the society at large' (European Commission 2015, p. 10, in Street, 2016, p. 3).

They encompass timely provision of tailored climate information and knowledge working with and for decision-makers (Vaughan and Dessai, 2014).

Dedicated climate services, that is, climate services for health, are vital for enhancing human health adaptation and resilience to the health impacts of climate change. Climate services for health are defined as 'the entire iterative process of joint collaboration between relevant multidisciplinary partners to identify, generate and build capacity to access, develop, deliver and use relevant and reliable climate knowledge to enhance health decisions' (WHO/WMO, 2016: 15). They encompass the use of climate and environmental information in healthcare decision-making. Underpinning them is a realisation that climate is a key variable in managing the overall burden of disease and excess mortality, and increasing life expectancy (Tadese et al., 2008).

This chapter examines the application of a systems approach to climate services for health. The systems approach to climate services for health can be defined as a holistic and transdisciplinary framework for understanding the dynamic and complex interconnectedness and non-linear feedback loops that exist between health and climate information, as well as other social, economic and environmental dimensions that affect health outcomes. It also elaborates the merits of the systems approach to climate services for health. It aims to provide conceptual clarity on climate services for health as well as fill in existing gaps in the literature on the subject. Conceptual clarity is important for a diverse range of stakeholders making policies and planning for health adaptation and resilience. The insights presented are derived from selected examples and case studies. With this background, we firstly explore why the systems approach is necessary for climate services for health.

5.4 Reasons for the Systems Approach to Climate Services for Health

The systems approach articulates the importance of viewing health adaptation and resilience responses holistically. This is in line with the WHO definition of health ‘as a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity’ (Sartorius, 2006, p. 662). Climate services for health symbolise a “messy” set of interactions that, if explored and understood, can begin to facilitate the use of actionable climate information in concrete health decision-making. The application of the systems approach to climate services for health, we argue, can help to facilitate the integration of climate and health information in climate-health responses.

5.4.1 Health Systems Adaptation Through Climate Services for Health

Climate services for health can inform health adaptation interventions, planning and policy processes and outcomes. The IPCC (IPCC, 2014, p.118) report defined adaptation as ‘the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.’ While public health practitioners and policymakers need climate information to effectively plan for health adaptation, the uptake of climate information has been underwhelming (Goosen et al., 2014;

Boon et al., 2021). Policymakers and practitioners assess the salience, credibility, legitimacy, “actionability” and usability of the information (Prokopy et al., 2017). They often consider and use co-produced and co-delivered, adaptable, targeted and context-relevant climate services for health (Vollstedt et al., 2021). Therefore, we suggest that health adaptation interventions require climate services that understand and can demonstrate risks and impacts at various spatial and time scales.

The variety of adaptation responses require further clarity and are not a “one-size-fits-all approach”. As indicated above, climate services for health are essential for reactive adaptation or coping, that is, diminishing the deleterious impacts on health during and after extreme climate events. *Reactive adaptation* is a “wait and see” approach whereby decision-makers postpone actions on climate change effects until the negative effects have materialised (Yousefpour et al., 2017). Reactive adaptation may be a result of a deliberate policy position based on a cost-benefit analysis of acting or not acting. Where the benefits of not acting outweigh acting and the climate change impacts are reversible, policymakers can apply reactive adaptation. Similarly, practitioners may implement interventions after the low impact adverse climate change event has occurred. Decision-makers operating within resource-constrained settings may take a reactive adaptation position because of a lack of resources to deploy before or during the occurrence of negative health impacting climate events.

Incremental health adaptation can also be enhanced through climate services for health. Incremental health adaptation encompasses proactive health interventions aimed at preventing the negative effects on physical and social systems. The incremental health adaptation approach is preventative. Interventions that fall under this approach include raising awareness on climate change health impacts among health and allied workers, integrated climate-health risk monitoring systems, and early warning systems anchored on integrated climate-health information.

Climate services for health, using such approaches, can promote “Health in All” policies, which acknowledge that health outcomes are affected by all explicit and implicit public health policies. The systems approach emphasises effective production and delivery of climate services for health by promoting strategic co-ordination of health and other sectors that affect health. Furthermore, it includes influencing non-health sectors to promote policies and interventions that produce positive health outcomes. Climate services for health can also try and facilitate a more radical and "transformational health" form of adaptation, that is, proactive approaches that aim to address the main reason for vulnerability to climate risks promote sustainable development and resilience. To be transformative, the institutional context needs to be "shaken" and changed, and the uptake of information seriously addressed (Lotz-Sisitka et al., 2016). The application of the systems approach can assist in identifying populations most vulnerable to the health impacts of climate change. In most settings, persons most vulnerable to the impacts of climate change and variability include children, women, the elderly and persons living with disabilities. The delivery and mechanisms for uptake of information of climate services for health can transform the lives of these vulnerable groups for the better and guarantee better health outcomes for them. The WHO guidelines for climate-resilient health systems do not articulate climate services explicitly. However, the guidelines highlight important activities that are dependent on and related to climate services for health (WHO, 2015). These include vulnerability assessments, comprehensive monitoring of threats and early warning systems and developing climate-informed health programmes, among others (Ebi, 2016).

It is worth pointing out that our presentation of three distinct adaptation categories simplifies the complex reality that include overlaps among categories. Health adaptation actions and policies can thus encompass reactive, incremental and transformational aspects together; therefore, being a messy approach rather than a simple set of actions that bridge science to policy and action. While the WHO published some guidelines on how health systems can be protected through adaptation planning and how countries can transition to climate-sensitive policies and programmes, the importance of climate services for health in guidelines is not very explicit. Given this, innovations that 'make climate services [for health] far more useful and valuable to users, and to allow the services to address specific, complex adaptations' are necessary (Hewitt et al., 2021: E584). Applying the systems approach to climate information for health displaces 'the dominant tradition on adaptation … [which] primarily takes an actor-centred view, focusing on the agency of social actors to respond to specific environmental change stimuli and emphasizing reduction of vulnerabilities' (Nelson et al., 2007: 395).

5.4.2 Health Systems Resilience Through Climate Services for Health

Climate services for enhanced health and well-being can provide valuable information for enhancing resilience against health risks. 'Health systems resilience can be defined as the capacity of health actors, institutions, and populations to prepare for and effectively respond to crises; maintain core functions when a crisis hits; and, informed by lessons learned during the crisis, reorganise if conditions require it' (Kruk et al., 2015, p.1910). Resilient health systems can protect and save human lives and guarantee quality health outcomes in the immediate, short-term and long-term. They comprise of five elements, namely they need to be integrated, are aware, diverse, self-regulating and adaptive (Kruk et al., 2015). Within the systems approach, health systems resilience is also usually examined and interrogated at the micro-, meso- and macro-scale (Lyng et al., 2021).

Resilience of health systems through climate services for health is also premised on two propositions. First, climate services for health can help maintain the health system in a more desirable and functional state during and after being affected by climate extremes. Climate services for health enable the delivery of comprehensive, beneficial and positive health outcomes as well as facilitate the development of a more responsive health system. Overall, climate services for health enhance the capacity of health systems to withstand climate change impacts.

Second, climate services for health can facilitate the identification and "crossing" (transgressing) of broad thresholds by stretching the boundaries at which health systems reach a tipping point. The generally acknowledged effects of climate variations on health systems are mostly disruptive, and hence, health systems with a greater threshold can withstand climatic threats, risks and actual shocks (Lotz-Sisitka et al., 2016). The role of climate services for health is to fortify health systems and make them more complex systems that include non-linear changes and non-linear feedback loops, self-organisation and learning (Ziervogel et al., 2021). The complex systems, inclusive of and strengthened by climate services for health, do not easily reach tipping points.

The systems approach allows for a more integrated approach to climate-health responses. The main advantage of the systems approach is that it guides decision-makers to move beyond only adopting linear approaches of management and helps them to begin to think through what more adaptive, complex and transdisciplinary management of climate-health impacts may entail. Despite these merits, has the systems approach to climate services for health been applied or implemented in practice and with what outcomes?

5.5 Application of the Systems Approach to Climate Services for Health

5.5.1 Status of Application of the Systems Approach

Our assessment of the available and existing literature shows that publications on climate services for health emerged less than three decades ago and have increased rapidly over the last decade. The increased publications arise from increased collaborative research focusing on this subject, scientific reports by the IPCC and other institutions as well as the availability of journals that are publishing articles on the subject. The application of the systems approach to climate services for health is, however, very limited even though the approach has been widely used in public health; for example, the WHO developed a health systems framework with six building blocks that encompass service delivery, health workforce, health information systems, access to essential medicines, financing and leadership or governance (WHO, 2007). The key outcomes of the systems framework are improved health, responsiveness, social and financial protection and improved efficiency (WHO, 2010). Although the WHO systems framework is informative, it has not been widely adopted in conceptualising climate-health issues.

Currently, health and climate systems are not integrated. Ebi (2016, p.4) observes that 'current policies and programs for managing climate-sensitive health outcomes were established without considering climate variability and change, resulting in a significant gap for achieving resilience' and adaptation. Health and climate systems currently generate data and information for their own independent use and purposes. In practice, National Meteorological Services (NMS) independently generate climate information, while health systems separately generate health information with little to no interactions taking place between the two systems.

Despite this, climate services for health require blending a 'range of techniques to integrate spatial and time-scaled weather and climate information in combination with clinical, epidemiological and other health data to understand and apply knowledge about how climate in the past, present, and future influences health outcomes, health risks and health service delivery' (WHO/WMO, 2016, p.15). Co-production and co-delivery of the services are imperative for effective and robust climate services for health. In addition, transdisciplinary approaches that help health professionals understand the impacts of climate variability and change on health and mobilise them to take appropriate action are essential. The following section provides some emerging examples of the application of the systems approach to climate services for health.

5.5.2 Illustrative Examples of the Systems Approach to Climate Services for Health

Three illustrative examples (Ethiopia, Bhutan and Germany) based on a review of the literature are provided that demonstrate some emerging use of a systems approach to climate services for health. These examples are purposely chosen to demonstrate different facets of the application and merits of using the systems approach to climate services for health. Noteworthy, the examples are not perfect prototypes of the application of the systems approach to climate services. They provide some important information that can inform the content of the systems approach to climate services for health.

The first example is from Ethiopia, a country located at the horn of Africa with a long history of climate services compared to other countries on the continent. The collaboration between the Ethiopian Ministry of Health (EMoH) and the National Meteorological Services of Ethiopia (NMSoE) shows an attempt towards applying a systems approach to climate services for health. Ethiopia is among the early adopters of the WHO health systems framework in Africa (Manyazewal, 2017). The country made serious attempts to operationalise the six building blocks of the WHO health systems framework. However, the initial use of the WHO health systems framework excluded environmental metrics, especially climate change information (Teklegiorgis et al., 2016). Yet, Ethiopia has been adversely affected by climate change. Some disease outbreaks in Ethiopia may be associated with EWEs and climate variations (Ermert et al., 2012). The use of the WHO health systems framework alone meant that the country could not effectively respond to diseases associated with climate variations such as malaria.

In a typical non-integrated fashion, the NMSoE independently generated and delivered weather and climate information, while the EMoH generated and delivered health information separately (Del Corral et al., 2012). Through international partnerships and support, the NMSoE and EMoH were introduced to how they could use climate information in health decision-making (Dinku et al., 2014b). The NMSoE and EMoH created a Health-Climate-Working Group to provide leadership and co-ordinate the efforts of synergising climate information and health information for health decision-making (Dinku et al., 2016).

Ethiopia's Health-Climate Working Group has influenced the evolution of climate services for health in general through facilitating the exchange of information, analysing and interpreting the information, training and capacity building health workers and enabling decision-makers to focus on diseases generally affecting the populace (Tadese et al., 2008). An example where Ethiopia's Health-Climate Working Group has been effective is in co-ordinating the country's malaria response using climate services for health.

In terms of malaria response, Ethiopia's Health-Climate Working Group ensures that the NMSoE timely provides national climate information (Dinku and Sharoff, 2011). The climate information provided shows the climatic conditions and areas favourable for mosquitos that cause malaria to proliferate. The climate information also forecasts how seasonal weather changes will affect the spread of malaria. The EMoH also provides routine malaria surveillance data from the different areas in Ethiopia. Iterations and interactions co-ordinated by the Health-Climate Working Group facilitate the integration of climate and health information.

The Health-Climate Working Group helps in interpreting the integrated climate-health information and ensures evidence-based decisions ensue. The climate services for health specifically focusing on malaria response enable decision-makers to plan for malaria prevention activities, including awareness campaigns. It also enables treatment actions to take place, including distributing mosquito nets, spraying some parasite breeding areas, as well as providing malaria medication in areas affected or predicted to be affected by malaria.

Overall, Ethiopia's Health-Climate Working Group has somewhat promoted the systems approach in the delivery of climate services for health in the country. It has helped integrate the previously independent climate and health information systems. It provides a national-level platform for information exchanges and shared decision-making (Dinku et al., 2016). It involves transdisciplinary teams working on data analysis, interpretation and translation. In the area of malaria intervention, it has helped translate empirical evidence into concrete responses with beneficial lifesaving health outcomes (Dinku et al., 2011). The processes and outcomes of Ethiopia's Health-Climate Working Group demonstrate how climate services for health that are fit for purpose can be co-produced (Thomson and Woyessa, 2011).

Despite these merits, Ethiopia's Health-Climate Working Group still has some areas to improve to make its attempt towards a systems approach to climate services more impactful. It must involve more local communities in co-generating and co-delivering the climate services for health. Obtaining more support for its activities must come from domestic actors, especially the government or the users of the climate services for sustainability, which is not the case at the moment. Capacity building of the diverse actors so that they can actively and meaningfully contribute to the discussions are important (Simane et al., 2016). There are reported climate data gaps because of inadequate weather stations that need investments to make data more complete and coverage of the data less spatial, which is imperative for context-specific or more localised decision-making (Bhopal et al., 2021). And finally, since the health impacts of climate change are not limited to Ethiopia, promoting a regional systems approach to climate services for health may result in the country realising more benefits.

The second example is from Bhutan, a landlocked country in Asia (Ebi and Otmani del Barrio, 2017). Climate change is variously affecting human health in Bhutan. Climate change has been associated with increasing heatwaves, EWEs, heat and extreme variations in precipitation. The health effects of these changes in climate include temperature-related illnesses and deaths, extreme weather-related health impacts, air pollution-related health effects, water and foodborne diseases, mental, nutritional, infectious and other health effects (Tshering and Sithey, 2008). Increased incidence and spread of vector-borne diseases, especially malaria and dengue, as well as waterborne diseases, including diarrhoea, have been attributed to climate change in Bhutan (WHO/UNDP, 2014). Heat and heat events are projected to reduce labour productivity and cause increased mortality by 2080 (WHO/UNDP, 2016).

The WHO/UNDP funded the Climate Change Adaptation to Protect Human Health project in Bhutan that promoted the delivery of climate services for health. The project's specific objective was to strengthen Bhutan's capacities to identify and prevent the deleterious effects of climate change on health outcomes in the country. The project was executed by the Department of Public Health of the Ministry of Health (MoH), while the Environmental Health Programme was mandated to implement and co-ordinate other agencies. To ensure involvement of transdisciplinary teams, a Project Steering Committee with representatives from relevant agencies was set up to provide advisory and management oversight to the project (WHO/UNDP, 2014).

To deliver climate services for health, Bhutan created national-level committees for cross-sector integration of climate-health work. These committees ensured that climate change interventions were aligned with development goals (Ebi and Otmani del Barrio, 2017). The national co-ordination was also cascaded to lower tiers of government, especially those working directly with communities. Local health committees were established to co-ordinate climate-health responses at local levels. Nevertheless, the country's efforts aimed at building institutional and technical capacities on climate change and health have not been satisfactory and proportionate to the prevailing challenge (WHO/UNDP, 2014). This means more institutional building work still needs to be done.

To facilitate access to climate services for health at local level, the country developed educational materials on health adaptation to climate change impacts used by all health personnel (Ebi and Otmani del Barrio, 2017). Through capacity building activities, village health workers were trained to understand climate-health risks as well as carry out disease surveillance work. This enabled climate services for health to reach the most vulnerable and most at-risk populations in the country (Ebi, 2016).

The application of the systems approach to climate services for health in Bhutan is evolving. Climate services for health are informing health adaptation interventions. Climate services for health have been applied in activities aimed to increase the climate resilience of infrastructure in the country. And finally, the country has 'climate information included in the Integrated Disease Surveillance and Response System, including the development of early warning and response systems for climate-sensitive health risks' (WHO, 2015, p.7).

Bhutan's emerging capabilities to deploy the systems approach to climate services for health through integrating data and information from the MoH and NMS to develop early warning systems at national and local levels is impressive and informative (Ebi, 2016). However, the current activities are mainly funded by international partners. There is a need to ensure increased local funding and ownership of the services for them to be sustainable.

The last example is from Germany, a European country with advanced climate services that comprise producers, brokering institutions and users (R¨osner, 2012). However, Germany's climate services are normally conceptualised using a value chain approach which emphasises a linear delivery of the services and mapping actors involved in the services (Frisch, 2012). The ethos of co-production of climate services have been applied in some cases in Germany (Vollstedt et al., 2021).

The Deutscher Wetterdienst (DWD), whose activities are nationally legislated and include providing meteorological services to different users, including those in public health, for a fee, is at the centre of driving climate services in Germany (DWD, 2016). However, in this chapter, we elaborate on climate services for health, particularly the German Heat-Health Warning System (HHWS) that has been conceptualised using a systems approach (Matzarakis et al., 2020).

Scientific projections show that Germany is experiencing a warming trend (WHO, 2018). The intense and frequent summer heat extremes occurring in Germany are mainly affecting the health of persons living in urban areas (Mücke and Litvinovitch, 2020). The main health risks in the country are morbidity and mortality caused by inter alia EWEs, such as heat waves and cold spells.

In 2003, Germany recorded 7,000 heat-related deaths, and these are projected to increase to 8,500 per year by 2100 (Mücke and Litvinovitch, 2020). Germany may experience an increased incidence of cardiovascular diseases associated with heat and skin cancer due to increased exposure to ultraviolet radiation (Wetterdienst, 2003). Economically, 'the estimated monetized losses range from €6m to €43 m per hot day for an entire nation with a GDP of €2.5 trillion and 82 million population' (Karlsson and Ziebarth, 2018, p.115).

The specific negative health effects on health in Berlin, including the increase in summer morbidity and mortality as well as respiratory diseases, have been reported in existing literature (Mahlkow and Donner, 2017). Among other reasons, the urban heat island effect exacerbates heat-related diseases and deaths in Germany's cities, especially Berlin (Gabriel and Endlicher, 2011). Given the health effects of heat on the German population, the country operationalised the HHWS in 2005 (Matzarakis et al., 2020).

Germany has developed several explicit policy and institutional mechanisms to respond to heat under its National Adaptation Strategy on Climate Change (Deutsche Anpassungs Strategie, DAS). Operationalisation of DAS has happened since 2011, with the government providing nine million Euros for community adaptation projects for the period 2011 to 2017, of which 10% was specifically allocated to the public health sector (Mücke and Litvinovitch, 2020). As part of the climate change adaptation institutional framework, Germany created a Working

Group under the auspices of the German Conference of Environment Ministers that comprised ministries of health and environment as well as state authorities with a mandate to study and provide empirical evidence on the climate-health risks. The German MoH is the heat co-ordination agency, but it collaborates with other ministries (Baeker and Stutzinger-Schwarz, 2017).

The DWD plays a pivotal role in the delivery of climate services for health, especially the HHWS. It takes into account all relevant meteorological and non-meteorological, physical (infrastructure and location), socio-economic and demographic parameters influencing the thermal state of the human body to inform the HHWS. (Matzarakis et al., 2020). The DWD issues heat-health warnings to authorities and the public using the radio and television, internet, newsletter, smartphone application or email. Federal governments often set up telephone hotlines and information campaigns (Baeker and Stutzinger-Schwarz, 2017). While the information shared normally includes a map with textual explanations, specific information for the elderly and cities is emphasised as well.

In 2016, several stakeholders working under a Working Group on Adaptation to the Impacts of Climate Change in the Health Sector reviewed, analysed and communicated information on the health effects of heat in the country. The Working Group helped in the creation of the Heat-Health Action Plan (HHAP) published in 2017. The HHAP is a master plan for the country and is used to guide further development of regional plans.

Overall, the main aim of the HHWS is to reduce morbidity associated with heatwaves by issuing heat and health warnings, facilitate heat-planning in other non-health but relevant sectors, integrate health into all policies, mobilise resources to respond to heat and raise public awareness on heat (WHO, 2018). The HHWs emphasises the most vulnerable groups such as the elderly, chronically ill or obese people, infants, outdoor workers, the poor and persons vulnerable to heat due to social factors.

While the implementation of the heat plan happens at municipal level, the DWD is mandated to issue heat warnings that enable authorities and the public to introduce preventative and protection measures. The heat-health services encompass information on how to reduce indoor heat to care for vulnerable population groups and inform employees in health, education and social care settings what to do during heat waves. In Berlin, for example, the heat response intervention includes providing drinking water and sun protection products (Baeker and Stutzinger-Schwarz, 2017).

What is apparent is that heat-health services in Germany are evolving positively with institutional and policy support. Climate services for health are delivered by public and private as well as national, regional and local actors. Specific agencies involved include aid organisations, hospitals, pharmacists, medical professionals, the Red Cross, schools, kindergartens, care homes, among others (Vanderplanken et al., 2021). However, the federal nature of the German government minimises the centralisation of the services.

Having detailed these three examples, we turn to discuss some key points arising from these in the next section.

5.6 Enhancing the Systems Approach to Climate Services

There are five important points arising from the examples provided in the previous section and some merits and limitations of the emerging systems approach to climate services, elaborated in the following sub-sections.

5.6.1 Structural Aspects of the Emerging Systems Approach to Climate Services for Health

Our three illustrative examples demonstrate different aspects related to the application and merits of the emerging systems approach to climate services for health. The example of the Health-Climate Working Group in Ethiopia demonstrates a centralised systems approach to climate services for health. In this centralised system, the Health-Climate Working Group integrates, interprets and disseminates climate-health information to policymakers and practitioners throughout the country. While the merit of the centralised systems approach is that it ensures that climate services for health are prioritised and have support from higher levels of government, it is a top-down approach that limits feedback and interactive learning. It also limits the delivery of climate services for health to public institutions and provides limited space for private actors as well as services brokering institutions to evolve.

In contrast, the Bhutan example shows a decentralised systems approach to climate services for health. While Bhutan has a national system that integrates climate-health information, the country built the capacities of cadres located at various levels to interpret and disseminate climate services for health to local communities. The local cadres contextualise and localise climate services for health so that they are usable by community members, including the most vulnerable members of the community. The main advantage of the decentralised systems approach to climate services demonstrated by the Bhutan example is that it allows for interactive learning, contextualisation of the services and continuous development of the service. It also allows for brokering institutions as well as private actors to flourish.

The German example illustrates a devolved systems approach to climate services for health. In this case, the national system vertically interacts with the regional and municipal level service providers and users while simultaneously allowing horizontal interactions between regional and municipal level users. The system permits municipalities to make decisions on interventions and policies that benefit local communities under their jurisdiction. The system has permitted private actors and brokering institutions to get involved in the delivery of the HHWS.

5.6.2 Niche Areas and Systems Approach to Climate Services for Health

The three examples presented demonstrate that services tend to focus on certain niche areas rather than being all-encompassing. The main factor determining the niches is the priority given to actual, perceived or projected negative health outcomes, especially illness or disease associated with climate change and variability. Ethiopians are affected by malaria, which justifies climate services for health that focus on the malaria response. The embryonic and evolving systems approach to climate services for health in Bhutan has explored responses to dengue, malaria and diarrheal diseases. These are climate-sensitive diseases with a high negative impact on population health. Heat and heat waves have caused many deaths in European countries, including Germany. Hence, the country’s focus on a heat-health response system is reasonable and rational.

The evolving niche-focused service provision within the systems approach to climate services for health makes practical sense and has several merits. First, niche-based services direct resources towards responding to the greatest health needs of the community. This is important because resources are always inadequate to respond to all the health needs of communities. Second, it enables capacity building actions to be focused. The Bhutan example demonstrates how high-quality cadres that could understand and respond to climate-health matters emerged from training and capacity building. Third, it allows for learnings, including policy and practice learning. In terms of practice, niche interventions can be scaled up once proven effective and transferable knowledge is used to develop other interventions. New policies in other areas can incorporate learning insights from one niche area. All the examples somewhat demonstrate the importance of interactive learning, albeit in different degrees, for the production and delivery of climate services for health.

Given this, the application of the systems approach to climate services for health must be viewed as niche-focused rather than all-encompassing. Thus, the systems approach promotes the provision of differentiated services.

5.6.3 Importance of Feedback Loops in the Systems Approach

As stated before, the systems approach to climate services for health challenges a linear conceptualisation of services. It promotes conceptualisations that value backward and forward feedback loops (Pongsiri and Bassi, 2021). The German case is illustrative of this. The creation of the HHWS involved public participation processes. There are also evaluation processes that have commenced in several cities, including Berlin, to get information on the efficacy of the HHWS. The Ethiopia service also has some elements of feedback loops at the top level. This happens through iterations and interactions within the Health-Climate Working Group. The systems approach to climate services, therefore, must be conceptualised as non-linear and comprised of feedback loops (Stern, 2016). A system with strong feedback loops enhances the sustainability and robustness of climate services for health (Whitmee et al., 2015).

5.6.4 Furthering the Systems Approach to Climate Services for Health

This chapter mainly explores the application and merits as well as demerits of the application of the systems approach to climate services for health at national level. The illustrative examples show that the systems approach is applicable at national and lower tiers of the country, including provincial, municipal and community levels. An analysis at regional level was not done. This is a limitation because climate change effects on health are not limited to national boundaries. Therefore, we encourage further analysis of the application and merits of the systems approach to climate services for health at regional and international levels.

The examples also demonstrate that the systems approach to climate services for health demands integration of different systems, especially the health and climate systems. Through that integration, “Health in All” policies can be promoted. Despite this, the examples presented should not be interpreted as the best examples of what type of a system must exist. They should be considered as providing existing options on applicable systems that can be adopted and adapted by countries assessing ways to deliver climate services for health. The examples show that there is no “one-size-fits-all approach” to the application of the systems approach to climate services for health.

An explicit key point demonstrated by all the examples is that the involvement of high echelons of government in co-ordinating some processes and policies facilitate the creation of a conducive environment for the delivery of climate services for health. In all cases, the government is involved at the ministerial level, which ensures co-ordination of the service. Given this, government involvement in policymaking and co-ordination is recommended as an essential aspect for the effective delivery of climate services for health through a systems approach.

The German and Bhutan examples show that the systems approach to climate services for health promotes prioritisation of interventions focusing on the most vulnerable populations. The German example showed a focus on the elderly who are the most vulnerable to heat, while the Bhutan case focused on persons vulnerable to dengue and malaria. Given this, it can be said that the application of the systems approach can lead to greater inclusion of the marginalised populations. It enables focused interventions that promote resilience amongst populations whose health will be disproportionately affected by climate change effects. Since the systems approach allows for a focused intervention for the vulnerable populations, it may be an approach most suitable to many countries, especially those with many vulnerable persons such as African countries.

5.6.5 Reconsidering Policy and Practice

Another key point that implicitly arises from the examples presented is that the application of systems approach to climate services for health somewhat calls for regular reconsideration of policy and practice. Two forms of policy and practice reconsiderations can be drawn from the examples. First, a review of existing policies and institutions so that they are realigned to the demands of delivering climate services for health. Second, continuous assessment and adaptation of policies and institutions so that they can respond to the most pressing health needs of the population. The German example showed institutional and policy changes made to deliver an effective HHWS. Similarly, the Ethiopia Health-Climate Working Group changed the operations of some agencies so that they could deliver climate services for health.

Overall, rigid and inflexible policies and institutions will not be amenable to the application of the systems approach to climate services. Similarly, failure to regularly assess and review policy and institutional frameworks and adjust them accordingly would not promote the application of the systems approach to climate services for health. As such, an adaptive, interactive learning approach enhances the effective application of the systems approach to climate services for health (Vogel et al., 2019).

5.7 Conclusions

The human health effects of climate change and variability are well established in existing literature. Therefore, climate services for health that facilitate decision-making and effective responses to the health impacts of climate change are urgently required. In this chapter, we used examples from Ethiopia, Bhutan and Germany to examine the application of the systems approach to climate services. We drew some insights from the examples and highlighted the merits of applying the systems approach.

Overall, the application of the systems approach to climate services for health can promote the integration of climate-health information, effective institutional and policy co-ordination, capacity building activities, adaptive and interactive learning, as well as the evolution of contextually relevant climate services for health, focused on the most vulnerable populations. The approach can ensure timely review of policies and adaptive adjustment of institutions necessary for an effective response system. It can help inform policy and practice decisions. It also furthers a transdisciplinary ethos in policy and practice and can help bring together information from diverse sources towards a robust service. The application of the systems approach is necessary to enhance health adaptation and resilience.

The empirical evidence presented showed that the systems approach to climate services for health encompasses various dimensions. Regardless of this, the governments have a greater role to play in promoting the delivery of effective climate services for health. This chapter importantly provided new insights on how the systems approach has been applied to climate services for health and filled in knowledge gaps on this subject. It also proffered some suggestions on how to enhance the application of the approach in future. Future studies that focus on the application of the systems approach to climate services for health at regional and international levels are encouraged. While this chapter provided an initial conceptual framework and rationale for its use, testing and using the framework in other settings will help refine the framework. As such, we recommend some case studies that further refine the conceptualisation and application of the systems approach to climate services for health.

5.8 Chapter Postscript

In this chapter, the systems approach to climate services for health was elaborated. It was noted that the systems approach to climate services provides a holistic conceptual framework that can guide analysis of the services even in Africa. By applying the systems approach to climate services, decision-makers would shun parochial conceptions of the service and view the service holistically, which may broadly inform their actions. In the next chapter, this conceptual framework is deepened through an articulation of the importance of inclusive climate services for health.

5.9 References

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6 CLIMATE CHANGE AND HEALTH: THE CASE FOR MORE INCLUSIVE CLIMATE SERVICES FOR HUMAN HEALTH AND THEIR CHARACTERISTICS

6.1 Chapter Overview

The previous chapter commenced a discussion on climate services for health. A conceptual framework, namely the systems approach to climate services for health, was explained. The main argument advanced in the chapter is that the application of the systems approach to climate services for health can help decision-makers aim for holistic decisions and more appropriate approaches for health adaptation and resilience to the effects of climate change and variability.

This chapter deepens the conceptualisation of climate services for health. It defines inclusive climate services for health as well as their characteristics. Inclusive climate services for health can be defined as climate-health information that is equitably co-delivered to facilitate adaptation and resilience among all members of the community with appropriate considerations for the concerns and needs of persons most vulnerable to climate change and variability. The key characteristics of inclusive climate services for health include that services must be people-centred, include multilevel/co-operative governance, involve interactive learning, encompass transdisciplinarity and be delivered as public goods. This chapter provides the rationale for why inclusive climate services for health are needed. The deepening inequalities in health services delivery and responses to the deleterious effects of climate change amply justify the need and necessity for a rethink of the nature and content of existing climate services for health and promotion of inclusive climate services for health. An example of the inequalities relating to heat-health services is presented to bolster the case for taking an inclusive approach to climate services.

6.2 Chapter Abstract

The IPCC recently reported that the evidence of anthropogenic climate change is unequivocal. There is growing global interest in understanding the health effects of climate change. Existing evidence shows that global population health will be adversely affected by changing climatic conditions. Tailormade and actionable climate information targeting the health sector may

enable health systems to adapt and be resilient to climate change. Thus, the importance of evolving climate services for health cannot be underestimated. However, inequalities necessitate deliberate transformation and calibration of climate information for health adaptation and resilience to serve the most vulnerable populations. As such, climate services for health must be inclusive to be effective, robust and responsive.

6.3 Chapter Introduction

The latest report by the IPCC shows indisputable empirical evidence of climate change (IPCC, 2021). The gradual changes in climatic conditions and current and projected frequent occurrence of intense EWEs will directly and indirectly affect human health (Watts et al., 2020). Unfortunately, climate change impacts on health are happening when most health systems have been weakened by the coronavirus pandemic (Lal et al., 2021). The COVID-19 pandemic demonstrated that many lives could be lost when a pandemic strikes ill-prepared and fragile health systems. Similarly, EWEs and extreme climatic variations may cause excessive loss of lives and exacerbate morbidity across many countries lacking an effective adaptation and resilience plan and intervention (Nimako and Kruk, 2021). This chapter proposes a framework for inclusive climate services and the characteristics that define them. The content presented is transdisciplinary in nature (Ziervogel et al., 2021) and emphasises services for responding to heat.

Climate services, defined as the ‘transformation of climate-related data - together with other relevant information - into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices development and evaluation of solutions and any other services in relation to climate that may be used for the society at large’ are important for decision-making in the context of climate change (Street, 2016: 3). Climate services are intended to improve climate-sensitive decision-making by making climate information actionable. They promise better decision-making in climate-sensitive sectors such as water, health, infrastructure, agriculture, energy and transport.

Climate services for health are a specific or dedicated type of service that encompasses the use of climate and environmental information in decision-making for health and well-being. They are defined as ‘the entire iterative process of joint collaboration between relevant multidisciplinary partners, including communities, to identify, generate and build capacity to access, develop, deliver and use relevant and reliable climate knowledge to enhance health decisions' (WHO/WMO, 2016). Climate services for health can help save lives before, during and after a climatic crisis. The delivery of climate services for health is uneven across the world, which is a great cause of concern.

6.4 The Case for More Inclusive Climate Services for Health

The governance and delivery of climate services for health must be inclusive. They must equitably enhance health systems' outcomes and responses for all populations before, during and after climatic crises. Inclusive climate services for health promote positive health outcomes for populations most vulnerable to climate change and variability, especially infants, the elderly, outdoor workers, persons living with disability, persons with chronic conditions, persons living with mental health challenges, urban dwellers and persons living in abject poverty (Watts et al., 2019). Inclusive climate services for health can enhance the global agenda on universal health coverage (Lozano et al., 2020) advance the health in all policy strategy (Kokkinen, 2015). Governing and delivering climate services for health inclusively enhances user participation in decision-making processes. Delivering climate services for health in an inclusive manner can empower communities.

Climate-related crises generally affect the physical and social infrastructure for health. A surge in disease outbreaks, deaths, trauma and stress raises demand for healthcare during and after the crisis. Responding to a climate-related crisis requires effective mobilisation and deployment of inter alia financial, infrastructural, technological and human resources to affected areas populations. Another invisible ingredient for an effective response is information – particularly actionable meteorological, socio-economic and health information delivered at the correct resolution, geographical scale and timeframe, as well as through the right channel and targeting the right persons. Usable climate-health information and products enable communities to prepare for and respond, for example, to climatic crises. Actionable climate-health information facilitates an understanding of the nature and extent of the crisis, the population groups affected, the capacity to adapt and be resilient, the economic costs, and mortality and morbidity numbers associated with the crisis.

The health effects of extreme heat demonstrate situations where climate services for health are important but usually lacking. Global average temperatures have risen by 1.2ºC from pre-industrial times (Romanello et al., 2021a). Rising temperatures and extreme heat events pose substantial health risks in most parts of the world. Globally, about 475 million heatwave events were recorded in 2019 and heat exposure disproportionately affected vulnerable populations. It is reported that 'during the past 20 years, there has been a 53.7% increase in heat-related mortality in people older than 65 years, reaching a total of 296 000 deaths in 2018. In Europe in 2018, the monetized cost of heat-related mortality was equivalent to 1.2% of regional gross national income, or the average income of 11 million European citizens' (Watts et al., 2020, p.1). In the WHO Europe region, estimates indicate an increase of 33% in heat-related mortality in 2018 compared to 2000, with vulnerability to heat associated with ageing populations, urbanisation and a high prevalence of chronic diseases (Romanello et al., 2021a).

Furthermore, the 2021 report of the *Lancet* Countdown on health and climate change reports that 'looking to 2021, people older than 65 years or younger than 1 year, along with people facing social disadvantages, were mostly affected by the record-breaking temperatures of over 40 ºC in the Pacific Northwest areas of the USA and Canada in June, 2021—an event that that would have been almost impossible without human caused climate change' (Romanello et al., 2021b, p. 1619). Likewise, heat is affecting Africa, a continent warming much faster than the global average temperature increase. A recent report pointed out that 'near surface air temperature averaged across Africa in 2020 was between 0.45 ºC and 0.86 ºC above the 1981-2010 average' (WMO, 2020, p.7). The north-west, western equatorial areas and some parts of the Greater Horn of Africa show the largest temperature anomalies on the continent. At country level, the year 2020 was the third hottest year since 1950, with a mean temperature of 20.2ºC and a positive anomaly of 0.9ºC in Tunisia (WMO, 2020).

The health effects of the heat and temperature anomalies in Africa are also becoming clear each year. About 34% of the global disability-adjusted life year attributable to the effects of climate change are found in Sub-Sharan Africa (Amegah et al., 2016). In South Africa, about 3.4% or 290 000 deaths between 1997 and 2013 were attributed to non-optimal temperatures, with vulnerability more pronounced among the young and elderly populations (Scovronick et al., 2018). Another South Africa specific study reported an increase of 0.9% in mortality per 1ºC increase in daily ambient apparent temperature for all age groups and a 2.1% increase in mortality among the elderly aged 65 years and above in Cape Town, Durban and Johannesburg, South Africa (Wichmann, 2017).

Apart from these experienced health effects of heat, the projected increased intensity and frequency of heat and heatwaves are of great concern. One report observes that 'record temperatures in 2020 resulted in a new high of 3.1 billion more person-days of heatwave exposure among people older than 65 years and 626 more person-days affecting children younger than 1 year' (Romanello et al., 2021b). Heatwaves often increase the number of persons requiring healthcare, including hospitalisation. This puts pressure on national governments to mobilise resources for lifesaving interventions.

The health effects of heat and heat events are complicated because they are related to and are usually driven by and expose inequalities. Existing evidence shows that 'although heat can kill anywhere, the risk is greater in cities' compared to rural areas (*Nature* Editorial, 2021, p.331). And even within the urban areas, 'extreme heat exposure is highly unequal and severely impacts the urban poor' (Tuholske et al., 2021, p.1). In general, extreme heat and heatwaves take a disproportionate toll on people of colour and those in lower-income communities (Witze, 2021). Inequalities also affect responses to heat. While it is known that creating green and cool corridors by planting trees and building swimming pools, painting roofs white, providing air conditioners, raising awareness on heat-protection interventions, creating an early warning system, training health workers on how to treat heat-related ailments, communicating heat information in social media and through short text messaging and strengthening community care systems, resources are not equally available to carry out the desired transformations *(Nature* Editorial, 2021; Witze, 2021).

The case of COVID-19 response, especially access to and allocations of vaccines, shows that developed countries can respond using nationally available resources, whereas most developing countries depend on international support to deliver the necessary healthcare (Burki, 2021; Sen Crowe et al., 2021). This same situation may recur with regards to responses to heat and heatwaves – developed countries will be able to respond better than developing countries. Heat and heatwaves usually affect regions and are not limited to national boundaries. However, co-ordinating such complex responses at regional level in resource-limited settings is a daunting task. Most poor and vulnerable regions lack a regional co-ordination mechanism that facilitates a response to the health effects of heat across borders or supports national efforts to respond to life-threatening extreme temperature events. Given this, strengthening the international policy and institutional frameworks so they can help create and co-ordinate national and regional responses is essential. Climate services for health can inform decision-makers on how to respond to climate-related crises at various levels. Therefore, the services must be inclusive and focus on alleviating the health effects of climate change among the most vulnerable populations. Deepening inequalities in effects and responses makes inclusive services essential. But what are the characteristics of inclusive climate services for health?

6.5 Characteristics of Inclusive Climate Services for Health

For climate services to be inclusive, a human rights approach that focuses on the most vulnerable populations is dialogic, promotes participation and constructive engagement, and is premised on the systems approach with feedback loops is essential (Manyuchi et al., 2021; Samuel and Jacob, 2021). Inclusive climate services for health can be defined as climate-health information that is equitably co-delivered as a public good to facilitate adaptation and resilience among all members of the community with appropriate considerations for the concerns and needs of persons most vulnerable to climate change and variability. Inclusive climate services for health are characterised by the following five elements.

First, they are *people-centred*. This is an explicit recognition that climate services for health are for the people, and participation of the people in their delivery is important. People-centredness encompasses providing climate-health information that is respectful of and responsive to the needs, preferences and values of individuals, families and communities. The delivery of the service targets diverse populations and population sub-groups. The services are co-created with the persons who will be adversely affected by the crises. This includes exploring the populations' demand, concerns and needs for climate-health information. The perspectives and world views of the populations are highly valued and integrated into the service. Co-creation and co-delivery of the service are based on a common understanding established between the populations and professionals. The service thrust includes enhancing prevention, treatment and health promotion outcomes among populations and population sub-groups. People-centredness emphasises that all people, especially the most vulnerable members of society, must be included in co-creation, co-delivery and co-evaluation of the service. The engagements between the professionals and populations using the services create a continuous relationship with some feedback loops essential for refining the content of the service. The underlying principle for co-delivery of climate services for health is that individuals, families and communities are active partners in the service and not merely passive and obedient recipients of the service provided by knowledgeable and powerful professionals. The principle is closely aligned to that of universal health coverage, which promotes broad-based provision of health services, protection of vulnerable persons and active response to health crises (Connell et al., 2013). People-centredness combined with universal health coverage generally lead to better access to necessary climate-health information, efficient and effective health responses and improved population health, with the largest gains accruing to the most vulnerable marginalised people (Moreno-serra and Smith, 2012).

Second, they should include *co-operative/multilevel governance*. This results from the undeniable fact that climate change has made governance for health more complex. Governance for health encompasses efforts by governments, private actors and citizens to guarantee population health at national, regional and international levels (Kickbusch and Gleicher, 2012). Governance for health within the context of climate change must promote collaborative action of health and non-health sectors, public and private institutions and citizens. Co-operative governance of climate services for health requires structures and mechanisms that facilitate collaboration between health and non-health sectors. This is an intersectoral action for health approach (Spiegel et al., 2012). Actors belonging to climate-sensitive sectors collaborate with those from the health sector to co-deliver actionable climate-health information. Co-operative governance of climate services for health further requires synergised health and non-health policies. This can be achieved through adopting a “health in all” policies approach. This is ‘an approach to public policies across sectors that systematically takes into account the health implications of decisions, seeks synergies, and avoids harmful health impacts in order to improve population health and health equity’ (WHO, 2014, p.2). climate-health information must be shared between health and non-health sectors and health and non-health professionals.

Since the health effects of climate change know no borders or race, responses require a multilevel governance approach, including complementary vertical and horizontal interactions between stakeholders at international, national and community levels. The international and national frameworks for health governance in the context of climate change are elaborate, while sub-national level mechanisms are not clearly understood. Reforming the mechanisms and frameworks for health governance at community level and empowering communities to respond to crises is crucial. A decentralised and devolved system of delivering climate services for health is imperative (Samuel and Jacob, 2021). For climate services for health, local-level climate information must be at the fore of driving local-level health interventions. Rigid bottom-up or top-down frameworks for climate information governance must be avoided. An agile system that facilitates dialogic two-way communication flows must be adapted for the delivery of effective climate services for health.

Third, they encompass *interactive learning* (Lundvall, 2007). Interactive learning in relation to climate services for health is a process in which agents dialogue and collaborate in the co-creation, co-delivery and co-utilisation of usable climate-health knowledge (Lundvall and Lema, 2014). Interactive learning occurs among individuals, communities and institutions as well as between institutions and individuals sharing climate information. In practice, interactive learning can take place among national meteorological services, health institutions and communities when they exchange climate-health information. Interactive learning includes an iterative dialogue between multiple actors exchanging actionable information. This eschews linear approaches that suggest producers exist separately from users and puts great effort on scientific information and communicating the scientific information to policymakers without acknowledging the messy world of politics as well as complexity inherent in the climate-health relationship and attributions (Friend et al., 2014).

The use of appropriate language and acceptable channels of information dissemination promotes interactive learning among all interested and affected parties involved in generating, providing and contextualising the climate services for health. Social media platforms are increasingly enabling vertical and horizontal information exchange at micro- and macro-levels. While integrating indigenous knowledge may enhance the content of climate services for health, realising this is a complex task. In most traditional communities, indigenous seasonal forecasts and climate-health information tend to be produced by a few knowledgeable individuals and spread by word of mouth. Likewise, a few professionals are involved in generating scientific climate forecasts using meteorological and satellite instruments, but the data is recorded and mostly exchanged in writing. Interactive learning closes the divide between scientific communities that advance scientific climate-health services and indigenous communities that verbally disseminate traditional climate-health information. Through interactive learning, scientists and indigenous populations will value each other’s contribution to climate services for health.

Fourth, they are *transdisciplinary* in content. It is an established fact that climate services for health depend on many actors and sectors co-producing and co-delivering actionable information for decision-making. As such, an inherent aspect of the services is that they integrate diverse knowledge, transcend disciplinary boundaries and promote the application of new knowledge to respond to threats and risks of climate emergencies denoting transdisciplinary ethos (Pineo et al., 2021). Inclusive climate services for health ingrain a broader ethos of transdisciplinary collaboration, that is, facilitating respectful interactions and linkages between professionals and non-professionals. This is an acknowledgement that responses to health crises in most developing countries are not only carried out by trained healthcare workers. There are many persons that provide alternative healthcare in communities. Community-based traditional and faith-based healthcare providers play a significant role in responding to diseases, ill health and injuries in communities. Trained healthcare workers and non-trained alternative healthcare providers bring different and eclectic knowledge bases. Sometimes they respond to different population groups or to the health needs of populations at different times. Creating platforms for trained healthcare workers to interact with non-trained alternative healthcare providers is more imperative in the context of climate change. When appropriately managed, transdisciplinary engagements facilitate the delivery of context-relevant and inclusive climate services for health.

And finally, they are a special type of *global public good*. Public goods are defined as goods that are non-excludable and non-rival in consumption (Samuelson, 1954). To elaborate further, 'a good is non-rival if consumption by one person does not diminish the quantity remaining for others, and non-excludable if others cannot be excluded from consuming it' (Moon et al., 2017, 196). Climate services for health are a special type of public information primarily for the health sector. However, consumption of climate-health information by decision-makers and health workers does not diminish their availability to others. Hence, perceiving climate services for health as public goods means the following. They can be co-produced through collective choice of the public to fulfil a public need. They can be paid for collectively. They may not be supplied only through the market since they can be supplied without charges or at a subsidised cost. And they are a population-wide health service comprising non-clinical, surveillance, research and risk assessment, and disease outbreaks control interventions (Gupta and Gostin, 2009). Since climate services for health aim to protect the whole population from the deleterious health effects of climate change and complement clinical services for prevention and treatment of climate-related and sensitive diseases, they constitute a public good. Inclusive climate services for health are affordable for populations living in poverty and delivered to advance public health interest, including for the most vulnerable populations. To achieve inclusive climate services for health undergirded by global public goods ethos, it is important to promote focused investments targeting their co-production, co-delivery, utilisation and co-evaluation. Such investments by international, regional, national and subnational agencies must be made with urgency given that 'climate change is the biggest health threat facing humanity' (WHO, 2021, p.15).

6.6 Conclusion

Having conceptualised inclusive climate services for health, it is important to state that the highlighted framework requires testing and application. Refining the elements that constitute an inclusive climate service for health will help inform policy and interventions aimed at reducing inequality and vulnerability to the health effects of climate change. Case studies from different settings, especially resource-limited countries, that explore the framework will enhance adaptation practice and policy effectiveness. We suggest that the framework be used to explore the understudied topic of the health effects of heat. The framework must be used to guide, for instance, heat-health responses in countries that may not have such systems in place. While the framework is globally informative, it may be more informative in the context of many developing countries, particularly African countries, that are bedevilled by high levels of inequalities and exclusions. In the African context, the framework may guide African practitioners and policymakers towards building inclusive policies and interventions that will facilitate adaptation and resilience to the health effects of climate change.

6.7 Chapter Postscript

This chapter explained the inclusive climate services for health as an imperative to solve the deepening inequalities related to the health effects of climate change and variability. It also highlighted some inequalities relating to responding to the health effects of climate change that warrant a deliberate focus on the marginalised and most vulnerable members of the community. The health effects of heat are elaborated to demonstrate the effects of inequalities on mortality and morbidity. Unequal capacities to respond, causing more vulnerability to exposure to heat and heatwaves, was also highlighted. The chapter explained the characteristics of inclusive climate services for health. It was highlighted that the inclusive climate services for health framework has not been tested and applied in practice to demonstrate its efficacy. Hence, the next chapter applies the inclusive climate services for health to guide analysis of issues in the context of the Agincourt district case study.

6.8 References

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7 CLIMATE SERVICES FOR HEALTH IN THE AGINCOURT SUB-DISTRICT IN SOUTH AFRICA

7.1 Chapter Overview

The previous chapter presented a framework that can guide the analysis of climate services for health, namely inclusive climate services for health. It presented a discussion on heat-health effects and information for decision-making and responses to heat. This chapter charts a new discussion on climate services in general and climate services for health presented through a multiple embedded case study. For brevity, a multiple embedded case study involves cases that systematically fit within a particular case study. As such, cases focusing on climate services, climate services for health and heat-health service are collated and then explored in the context of a case study focusing on these themes in the context of South Africa and the Agincourt sub-district.

The main purpose of this chapter is in part to apply the conceptual framework highlighted in the previous two chapters, namely the systems and inclusive frameworks to climate services for health in "practice" and provide evidence on climate services, climate services for health and heat-health services that reflect the African context. Except for sections 7.1 and 7.9, all other sections of this chapter have been submitted to the *Climate Services* journal for consideration for publication. The title of the manuscript still under review is "*The status and content of climate services and climate services for health in Agincourt sub-district in South Africa*". Minor edits have been made to this original manuscript submitted for publication.

This chapter is structured as follows. In sections 7.2, 7.3 and 7.4, the abstract, introduction and conceptual and methodological aspects are presented, respectively. The study results are presented in sections 7.5 and 7.6. While section 7.5 presents findings on climate services in South Africa, section 7.6 presents the results of climate services, climate services for health and heat-health services in the Agincourt sub-district. The conclusion is presented in section 7.8 and a chapter postscript in section 7.9. As stated in chapter 3, the interview guides used for data collection are presented in appendices 3.1 and 3.2.

7.2 Chapter Abstract

Climate services for health can facilitate health resilience and adaptation to climate change, particularly if they are well-calibrated to promote wellness and save lives. In this study, the status of climate services for health in South Africa's Agincourt sub-district, Mpumalanga province, was assessed. A qualitative case study methodology encompassing multiple methods of data collection was used. The results show that climate services for health in the Agincourt sub-district, albeit essential, are fragmented and underdeveloped. Scientifically informed heat-health services are non-existent. Healthcare and allied professionals are, however, aware of the importance of climate services for health. The main barrier to climate services delivery is paucity of interagency co-ordination; for example, co-ordination to plan and respond to climate-health information between the SAWS and Departments of Health and Education is lacking. Inclusive systems of climate services for health encompassing health in all climate policies, resiliency and sustainability are essential for positive prevention and treatment outcomes. Future studies must provide an investment case for climate services for health, demonstrating the benefits of acting and costs of inaction.

Keywords: Adaptation; Climate applications; Extreme temperature; Inclusive climate services for health; Health outcomes; Public health risk.

7.3 Chapter Introduction

The past decade or so has witnessed a remarkable surge in interest in climate services worldwide (Tall et al., 2018; Vaughan et al., 2018; Gumucio et al., 2019). The creation of the GFCS and other collaborating institutions helped internationalise climate services research, programmes and policies (Tall et al., 2018).

But what are climate services? The notion of climate services broadly refers to the conversion of climate data and related information into knowledge and customised products, including tools, websites, forecasts, information, trends, economic analyses, assessments, counselling and other information that then has the potential for context-specific and transformative decisions to reduce adverse climate change effects and ultimately promote sustainable development (European Union, 2016).

Existing global research on climate services has emphasised climate-sensitive sectors. These are sectors that will be disproportionately affected by the vagaries of climate change and variability. They include water resources, agriculture and food security, health and energy (Patt et al., 2007). To develop adaptation and mitigation strategies for these climate-sensitive sectors, high quality, context-specific, easily accessible, affordable, usable and ethically delivered climate information is required (Adams et al., 2015; Lemos, 2015; Prokopy et al., 2017).

Africa-specific research on climate services is increasing. Most African countries, however, have limited capabilities to convert climate data into strategic climate information for decision-making (WMO, 2019). Africa-focused climate services research, for example, has not fully explored several themes found in global literature. To date, the status of climate services in some African countries is also not known (Vaughan et al., 2019). Few studies have focused on climate services in certain economic sectors. Yet, sector-focused studies importantly bring to the fore sector-specific issues about climate services (Nkiaka et al., 2019). An examination of climate services by sector is perhaps the most appropriate way to expose, in a nuanced manner, the key themes on climate services. In addition, case studies that shed light on the status of climate services in a given locality and sector are necessary to advance climate services research, practice and policy.

With this as background, climate services for health and heat-health services in the Agincourt sub-district of South Africa are explored. The study expands on knowledge from a previous related study conducted in the Agincourt sub-district (dos Santos *et al.*, 2019). The main aim of this study was to assess the status of climate services for health and heat-health services in the area. The subsidiary objectives were to: explore the gaps in the delivery of climate services, climate services for health and heat-health services in the area; provide directions for better climate-health outcomes; provide empirical evidence for climate services for health, heat-health services and health adaptation policy and practice; and finally, highlight key areas for future research.

In section 7.4, a conceptual framework and the study methodology are presented. The section highlights the inclusive systems of climate services for health framework and case study approach, as well as qualitative methods deployed to gather data. In section 7.5, a summary of climate services for health in South Africa is presented. The section scaffolds the study findings on climate services for health and heat-health services in the Agincourt sub-district presented in section 7.6. A discussion is presented in section 7.7. In this section, the various implications of the study findings are elaborated. The last section is the conclusion.

7.4 Conceptual and Methodological Issues

7.4.1 Inclusive Systems of Climate Services for Health

The conceptual framework guiding the analysis of issues in this study is called inclusive systems of climate services for health (see chapter 5 for systems approach to climate services for health and chapter 6 for the more inclusive framework for climate services for health). As stated before, climate services for health are defined as 'the entire iterative process of joint collaboration between relevant multidisciplinary partners to identify, generate and build capacity to access, develop, deliver and use relevant and reliable climate knowledge to enhance health decisions' (WHO/WMO, 2016:15). Climate services for health are important components of a well-functioning health system. Intrinsically, climate services for health are delivered within a system – a system of health services delivery. They enhance prevention, care and treatment outcomes.

Globally, National Metrological and Hydrological Organisations play a critical role in climate services through generating and disseminating weather and climate data (van den Hurk et al., 2016). In addition, information brokers, that is, institutions and actors that translate the meteorological data into strategic information for decision-makers on a number of scales, crucially facilitate the provision of climate services (Boari and Riboldazzi, 2014; Lemos et al., 2014). Climate information brokers can translate forecasts and other climate information into actionable information for the health sector. Some of the cases studies in chapter 5 demonstrated that the international and national architecture for climate services delivery could be centralised (Tarhule, 2007). Notwithstanding this, delivering climate services for health through a centralised model may not be the most optimal approach in Africa. Many African countries have inherent systemic institutional weaknesses that will affect the smooth delivery of the services. In addition, centralised delivery of climate services may facilitate exclusion and unequal delivery of climate services for health, resulting in unequal health outcomes, as argued in chapter 6.

Notwithstanding the caveats mentioned above, inclusive systems of climate services for health are imperative. These are an integrated people-centred, dynamic system of linkages and interactions that take place among health and climate information actors at various levels, which result in interactive learning, distribution of knowledge throughout the system, appropriate delivery of relevant information products, evidence-informed policies and timely decisions that strengthen health systems and enhance population health outcomes.

Inclusive systems of climate services for health can promote health in all climate policies and ensure that all people have equal access to co-produced climate information. Inclusive systems of climate services for health aim to achieve adaptation, resiliency and sustainable delivery of services. Noteworthy, 'a climate resilient health system is one that is capable to anticipate, respond to, cope with, recover from and adapt to climate-related shocks and stress, so as to bring sustained improvements in population health, despite an unstable climate' (WHO, 2015: 8).

As highlighted in chapter 6, the characteristics of inclusive climate services for health include people-centredness, multilevel/co-operative governance, interactive learning, delivery as public good and transdisciplinarity. The fact that delivery in the form of public good relates to investments necessary for climate services, that is, the provision of capital and human resources for co-production and co-delivery of the services for health, was not fully explained in chapter 6 and is therefore worth elaborating in this section.

To be more inclusive, investments must be made towards three key aspects of the climate-health information system. First, capacity building of healthcare workers and environmentalist/climatologists empowers them to adequately discharge their duties. Second, investments must be made for empowering community members and other relevant stakeholders to "engage" with climate services for health. Community members "engage" with climate services for health when they apply their minds, decide and articulate various aspects of the service relevant to individuals and the community. And thirdly, investments must be made to build quality institutions with capabilities for policy development and enforcement, leadership and co-ordination of the climate services for health. Delivery of climate services may be based on commercial terms, whereby users pay for specific services. However, inclusive climate services may require government subsidies for those unable to pay to get the climate-health information they require. The private sector may complement governments by investing in climate services for health. Having summarised this conceptual framework that will guide analysis of issues in this chapter, the next section explains the study methodology.

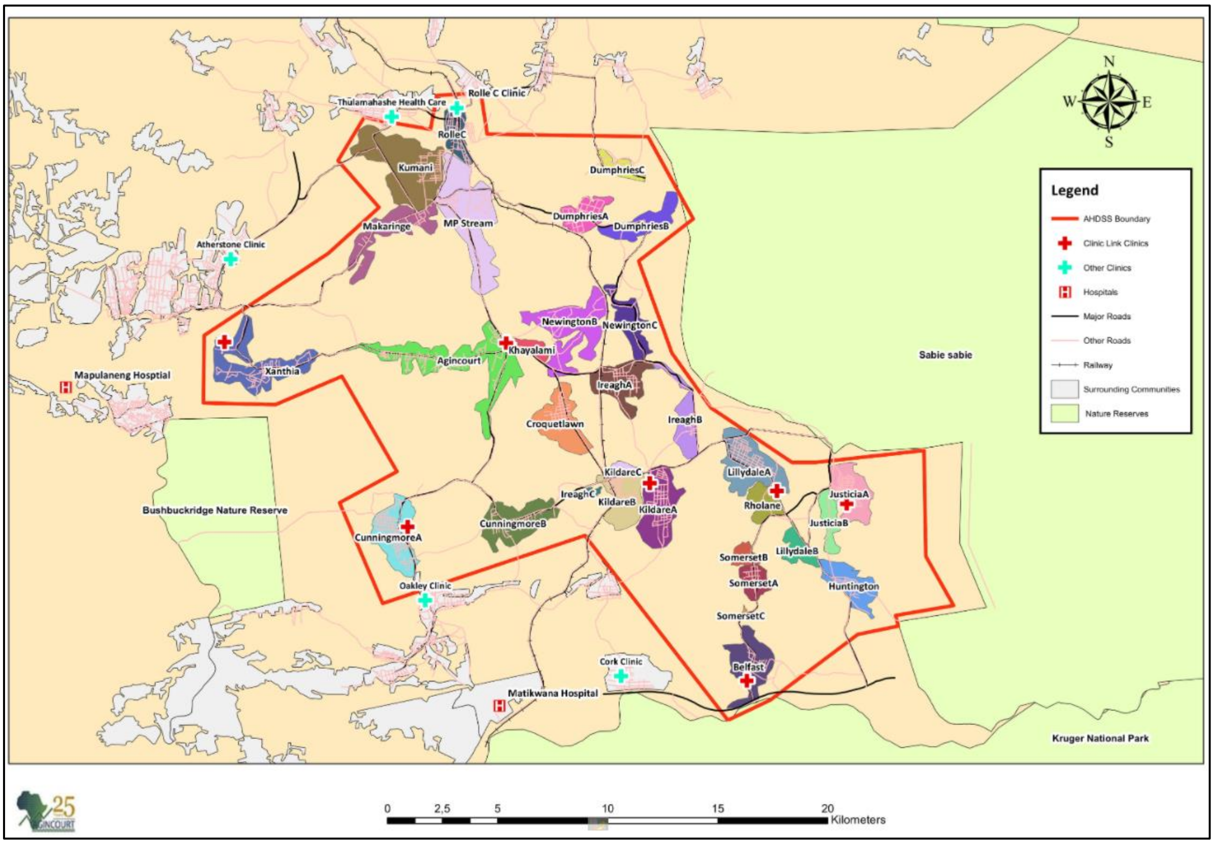
7.4.2 Methodology

A qualitative case study methodology was used for this study, and some of the aspects related to the study methodology have also been presented in chapter 3. This methodology 'provides tools for researchers to study complex phenomena within their context' (Baxter and Jack, 2008: 544). It enabled the use of a variety of data sources and enabled the exploration of complex interactions and relationships between individuals, communities and organisations involved in delivering climate services and climate services for health. It also facilitated an understanding of the meaning, experience and interpretations of the delivery of climate services for health from the viewpoint of the community. Finally, it promoted a broader transdisciplinary perspective by allowing inclusion of professionals and non-professionals in the research. Research participants were able to elaborate the subjective meaning, actions and social contexts relating to climate services for health as they perceived and understood them.

The qualitative case study methodology, involving various participatory actions, was chosen because it enabled the investigation of how and why questions without manipulating the behaviour of study participants, cover and highlight relevant contextual conditions associated with climate services in South Africa and climate services for health in the Agincourt sub-district, and unravel the blurred and unclear boundaries between phenomena and context (Yin, 1993).

The Agincourt sub-district was purposefully selected as a single case study area. It falls under Bushbuckridge Municipality in Mpumalanga province of South Africa, as shown in Figure 7.1. As explained in chapter 3, the case study covered areas that fall under the HDSS of SAMRC/Wits Rural Public Health and Health Transitions Research Unit-Agincourt. The study area and population have been extensively covered in existing research (Kahn et al., 2003; 2007; 2012; Byass et al., 2010a; Collinson et al., 2014; Kabudula et al., 2017; Tollman et al., 2008).

Figure 7-1: MRC/Wits Agincourt Unit HDSS Study Area-Research Villages 2020



Source: https://www.agincourt.co.za/?page_id=1896

The Agincourt sub-district case study importantly provides empirical evidence on climate services for health in a typical rural setting of South Africa. Other reasons for selection include support from the SAMRC/Wits Rural Public Health and Health Transitions Research Unit-Agincourt, easy access to key informants and communities and research costs, all factors that further influenced the choice of the case study. The study also benefited from leveraging the extensive and intensive track record of the HDSS and SAMRC/Wits Rural Public Health and Health Transitions Research Unit-Agincourt.

Through a desktop review, existing literature, such as peer-reviewed articles published in journals, reports and policy documents provided information on climate services, and particularly climate services for health in South Africa. The reviewed literature additionally provided baseline information on climate information for health in the Agincourt sub-district.

Data were collected through an interview guide administered during interviews with key informants and community members. The interviews were carried out between September and October 2019 and updated in March 2020 (fortunately before the onset of COVID-19 that may have thwarted ongoing face-to-face assessments). The key informants interviewed were persons knowledgeable about the area as well as the subject of climate services. The key informants provided names of other key informants and community members who could voluntarily respond to the research questions. Recommended persons were followed-up and interviewed. All study participants gave written informed consent for interviewing and recording. Interviews lasted between 45 and 60 minutes. Structured observations were conducted at specific venues and sites to verify information from reviewed literature and interviews. Structured observation sessions lasted about two hours.

In terms of data analysis, secondary literature was reviewed against themes that were aligned to the interview guide and research questions. Thereafter, theme-based summaries from reviewed literature were written. Data from interviews were analysed electronically using the Atlas.Ti software package. The data were transcribed verbatim and reviewed several times. The data were then coded, and themes were generated from the codes. Theme-based summaries were then written and reviewed. Structured observation reports were also analysed electronically. Structured observation data were coded, and themes were generated. Theme-based summaries from the structured observations were written and reviewed. The various data sources were triangulated.

The study fully adhered to ethical standards for scientific research. Ethical approval for this study was provided by the Human Research Ethics Committee (Non-Medical) of the University of the Witwatersrand, Johannesburg, South Africa (proposal R14/49). The (SAMRC)/Wits Rural Public Health and Health Transitions Research Unit-Agincourt's HDSS and other research work in the communities has existing ethical approvals with which this study complied.

The study was financially and technically supported by the GCI of the University of the Witwatersrand. Although two members of staff of the GCI were involved in this study, the funding and technical partners of the GCI played no part in the study design, data collection, data analysis, data interpretation or writing of the chapter. All study participants provided written informed consent prior to participating in an interview. To ensure confidentiality, identifiers such as names of workplaces, health facilities and personal identifiers have been removed from the data presented in this study.

7.5 An Overview of Climate Services in South Africa

In this section, the key findings from a literature survey on climate services in South Africa are outlined. South Africa created the National Climate Change Response Policy in 2011. This policy articulates the country's roadmap towards a lower carbon economy and climate-resilient communities. South Africa's implementation of climate services is intricately linked to the GFCSs' Implementation Plan approved by the WMO in 2012. The Plan requires all WMO member states to establish supporting frameworks for climate services at national level. To comply, South Africa developed the Road Map for the National Implementation of the GFCS in 2013 and the National Framework for Climate Services (GFCS, 2013; Government of South Africa, 2014). These documents laid the foundation for the national implementation of climate services in the country.

South Africa's climate services are also linked to the Regional Climate Centre, namely the SADC CSC. The SADC CSC implements several climate services programmes. South Africa participates in the Southern Africa Regional Climate Outlook Forum and the South-West Indian Ocean Climate Outlook Forum. These are forums that bring together national, regional and international climate experts on a regular basis to produce regional climate outlooks based on data from NMHS, regional and global weather and climate agencies.

South African institutions have been involved in several climate services initiatives over the past decade. Some institutions participated in the Future Climate for Africa initiative through the FRACTAL project (Pretorius et al., 2019). South African metropolitan cities of Durban, Cape Town and Johannesburg funded their participation in the FRACTAL project. The project explored decision-making processes and enhanced capacities of the three metropolitan cities to respond to climate change risks. The Universities of Cape Town, KwaZulu-Natal and the Witwatersrand were involved in the FRACTAL project. Most recently, South Africa has been involved in the Full-Value chain Optimized Climate User-centric Services for Southern Africa (FOCUS-Africa). The FOCUS-Africa programme aims to deliver tailored climate services agriculture and food security, water, energy and infrastructure in the SADC CSC.

Another initiative on climate services for water management is the HydroNet Water Control Room project implemented by the Inkomati-Usuthu Catchment Management Agency (IUCMA) through a partnership between HydroLogic, eLeaf, the SAWS, Winejob, the University of Twente and IUCMA. It used climate data to improve river and reservoir operations through data-informed decision-making. Another initiative is the collaboration between the University of KwaZulu-Natal and Umgeni Water under the Copernicus Climate Change Service (C3S) programme whereby climate data is used by Umgeni Water to manage eutrophication and water supplies to eThekwini and Msunduzi municipalities.

Various other South African institutions are involved in exchanging climate information and consequently advancing climate services. These institutions usually facilitate the supply-side of climate services. These include Departments of Environment, Forestry and Fisheries; Agriculture, Land Reform and Rural Development; Science and Innovation; Cooperative Governance and the Ministry of Higher Education, Science and Innovation. The SAWS, Agriculture Research Council (ARC) and Council for South African Industrial Research play pivotal in delivering climate services in South Africa.

The SAWS and the ARC established meteorological stations in several parts of the country. These stations provide vital data for weather and climate. The data underpins climate forecasts for early warning systems, emergency response and decision-making for climate change response. Noteworthy, the SAWS oftentimes provides targeted climate services on commercial terms, that is, the agency sells climate information and services to customers that require them.

South African universities have also been involved in producing climate information (Mason et al., 1996). The Universities of KwaZulu-Natal, the Witwatersrand, Pretoria and Cape Town produce, analyse and exchange climate information with many stakeholders. These universities variously collaborate in modelling, downscaling and promoting the application of climate information in decision-making. An example is the Climate Information Platform of Climate System Analysis Group, which provides a holistic package of climate services to various users.

The impetus for climate services is the country's vulnerability to extreme weather events, mainly droughts and floods (Archer, 2003). Therefore, the evolving climate services have focused on climate-sensitive sectors such as water, agriculture and food security, human health, human settlements, energy, marine fisheries, disaster management and reduction and biodiversity. These can be considered climate services demand sectors.

Reviewed literature on climate and health in South Africa is diverse. It specifically highlights the direct and indirect effects of climate change on health (Myers et al., 2011; Myers 2012). For brevity, a recent systematic review on climate change adaptation in South Africa’s health sector encompassing 21 studies with diverse health outcomes aptly provides evidence on climate change and health (Chersich and Wright, 2019). The only caveat is that the review was not focused on climate services for health. Hence, some studies included in this review do not explicitly deal with this subject.

Other studies that implicitly discuss climate information for health in the country are worth mentioning. A study by Wright et al. (2019) considered climate change planning in relation to the National Health Insurance (NHI). This study importantly provides evidence on how climate change may affect health delivery through the NHI, a scheme that focuses on inclusivity in healthcare delivery. A few studies analysed the role of environmental health workers and health practitioners in climate-health interventions as well as climate change and occupational health (Kjellstrom et al., 2014; Wright et al., 2014; Shezi et al., 2019).

The National Climate Change and Health Adaptation Plan 2014-2019 was also reviewed. It was found that the policy document clearly outlines the health-environment and climate-health issues without specifically stressing climate services. Most aspects relating to interagency co-ordination highlighted in the policy were aspirational and futuristic. Our review of the first draft of the revised National Climate Change and Health Adaptation Plan 2020-2024 suggests that climate services for health have not been amplified. Despite this, South Africa is amongst the few African countries that voluntarily respond to the WHO Health and Climate Change Survey. The responses highlight the country’s progress on national adaptation plans for health. In addition, some South African cities have carried out city-level climate change risk assessments.

Literature on climate information for agriculture and food security was found, while literature that explicitly focused on climate services for human settlements, biodiversity and marine fisheries in South Africa was not found (Ziervogel et al., 2006; Mandleni and Anim, 2011). Literature that implicitly focused on human settlement and climate change provides limited insights on climate services (Williams et al., 2019; Melore and Nel, 2020). Similarly, literature on climate change effects on marine fisheries, biodiversity and energy does not explicitly focus on climate services, albeit it highlights in passing the importance of climate services (Duncan, et al., 2019; Pfaff, *2*019; Hoveka et al., 2020; Monnier et al., 2020).

Notwithstanding all the efforts outlined above, reviewed literature, however, did not foreground the critical mechanisms needed for co-ordinating climate services within the sectors and across the sectors. Thus, there is a paucity of literature focusing on the "governance" of climate services in South Africa. Furthermore, existing literature places less emphasis on the inclusion of marginalised population groups in the delivery of climate services and enabling the marginal and communities to make inputs to various planning agendas (Lugen, 2016; Samuel and Jacob, 2021).

7.6 Climate Services for Health in the Agincourt Sub-District

Having provided an assessment of the state of climate services in South Africa, attention now turns to the focus of the paper presented for publication that now forms part of this chapter. The key findings on climate services and climate services for health in the Agincourt sub-district are presented in this section. These findings mainly derive from interview data. It is important to point out that the details of the Agincourt sub-district have been provided in chapter 2 and section 7.42 and, therefore, will not be repeated here. The next section will present the demographic characteristics of the study participants.

7.6.1 The Demographics of Study Participants

The demographic characteristics of study participants were previously explained in chapter 3. A total of 93 persons were interviewed for this study. The socioeconomic and demographic characteristics of study participants were shown in Table 3-1 in chapter 3. The study participants mainly live in the Agincourt sub-district (85%), while about 15% lived within 150 kilometres of the area. In terms of highest education level completed, 59% of the study participants had completed matric (Grade 12), and 24% had completed tertiary level education. Most respondents (66%) lived in the area for five years or longer. About 40% of the study participants had formal employment in health institutions, airports, a meteorological station, national park, district and provincial offices, a research institution and educational institutions.

7.6.2 Accessibility to, Types, and Coverage of Weather and Climate Information

Climate and climate change are increasingly being mainstreamed into public discourse. Notwithstanding this spread of terms such as climate and climate change, many citizens, when asked, are often not clear about the important differences between weather, climate variability and change. To probe where people were "at" (ensuring a form of sense and meaning-making), the interviews began with ensuring a shared understanding of weather, climate and climate change.

Participants were asked to distinguish between weather and climate. Most respondents confounded weather and climate to mean the same thing. One respondent stated:

> *'Weather is something that changes daily and people can feel. Climate is the situation of the weather as remembered after two days or one week or a month.'*

The above statement was clarified by a teacher as follows:

> *'Community members here think and talk about the weather. They assess and deal with the weather changes daily because weather affects what they can or cannot do. Weather affects their livelihoods there and then. Issues of climate arise when community members discuss changes in seasons. But people don't talk about change of season regularly. In fact, community members tend to remember bad seasons and forget the good seasons that are considered the normal seasons. Climate is something we read in books without really reflecting on it daily.'*

Noteworthy, key informants understood the concept of climate information. They stated that access and coverage to scientific climate information, including seasonal forecasts, is limited to professionals, thereby excluding community members. Key informants from the meteorological station, national park and airport, however, noted that they have the climate data at hand. A key informant from the national park noted:

> *'I don't think most community members require scientific weather and climate data, unlike us in the tourism and hospitality sector who must know the daily weather forecast and the climate information because our business depends on this. This does not mean that people here do not talk about the weather. We talk about it without reference to any data. Our discussions are about how we feel when we go out there and what we think about the weather and the season.'*

In terms of accessibility, all study participants stated that weather information is readily accessible to many community members compared to climate information. They also averred that there was better coverage of weather information. Community members can get weather information whenever they need it. Community members get weather information from the radio, television and their mobile phones as well as neighbours, friends or colleagues during discussions. All participants, however, noted that the weather information is not specific to the Agincourt sub-district. The weather forecast is usually for the next 24 hours.

In terms of the sources of weather information, respondents stated that meteorological stations managed by the SAWS are located about 80 to 100 kilometres away from the area. The ARC weather stations located in Hoedspruit and Skukuza areas close to the Agincourt sub-district are unknown to study respondents. Respondents stated that South African National Parks (SANParks) has some weather stations in and around the Kruger National Park. A road divides the Skukuza weather station from one village that falls under the Agincourt HDSS study site.

Most respondents confirmed that community members did not have access to scientific climate data and rarely reference climate data in their discussions. A few respondents stated that the processes to access the climate data are cumbersome because an application must be lodged and approved by the authorising agency before the data is availed. One key informant noted:

> *'Getting specific climate information from the SAWS and other agencies is not easy. An application requesting for the information must be submitted to these agencies. They take time to respond. They may give you access to the data with conditions attached to use, reporting and publication. Given this, people interested in climate information go on the internet to search for it. What they get is incomplete data which is not quality assured.'*

Despite this, respondents were clear that community members shared seasonal rather than short- or long-term climate information. They exchange seasonal climate information about whether they will have a good or bad season. One community member stated:

> *'We generally want to know whether the season will bring good rains or not. Good rains mean a good harvest and more jobs. We also want to know whether it will be too cold or not during winter. In rare circumstances, we also check whether it will be hot or not and whether we will be affected by floods.'*

Formally employed participants and students get weather information from the radio, television and internet, while most community members verbally exchange the information. Community members discuss seasonal forecasts without reference to scientific data. The elderly and traditional healers help them in seasonal forecasting by interpreting the position and shape of the moon, animal, birds and insect behaviour, as well as the conditions of certain fruits, plants and flowers. One traditional healer stated that:

> *'Forecasting how the season will look is a specialised area. A few spirit mediums can forecast whether the rain season will be normal or there will be drought or floods. The spirits mediums can inform people what to do in cases of drought or floods. Apart from these mediums, there are also some people who learned how to forecast the season from their parents and grandparents. For example, we know that when certain fruits are in abundance, there is a bad season. We also know that when birds circulate in a certain way, it will rain. This knowledge has been passed on from generation to generation.'*

One issue raised was that inaccurate predictions by spirit mediums have resulted in less trust in traditional climate forecasting. One key informant averred:

> *'Although community members share traditional weather and climate forecast among themselves. Nowadays, they tend to compare this information with scientific forecasts. However, it is not clear whether they use the information, whether traditional or scientific.'*

Some community members verify the traditional forecasts with scientific forecasts because while traditional forecasting provides generalised ideas of what to anticipate, scientific forecasts sometimes provide the date and times of the events. One responded noted:

> '*Traditional forecasts are quite general. They give us an idea of what to expect without providing the actual dates. This information is vital because it makes us prepare in advance. We then listen to weather forecasts to be certain of the dates when the predicted event will happen. If one uses the two, one will never be surprised when an adverse weather event happens.'*

7.6.3 Institutions for and Community Involvement in Climate Services

Most respondents stated that scientific climate data are produced by weather services. Key informants from the weather services stated that they generated the weather information and provided it to the national SAWS, SANParks and ARC to disseminate. These institutions have no mandate and capacity to disseminate scientific climate information to local communities. Respondents could not explain the flow of ARC and SANParks data. However, some key informants pointed out that these institutions use the data in their operations and share weather data with the SAWS.

All participants stated that community members are not involved in producing climate information or indigenous knowledge-based seasonal forecasts. In the Agincourt area, a few institutions such as weather services, the elderly, traditional healers and spirit mediums are involved in producing climate information. Despite this, they acknowledged that community members are informally involved in disseminating climate information. One key informant noted:

> *'The weather stations work in silos. Station employees are the only ones who generate the climate information. Likewise, the elders do not call people to ask whether the season will be good or bad. They analyse the conditions and predict how the season will look. They tell their close associates, and the information is spread into the communities. People learn about the seasonal forecasts as they share the information.'*

Participants averred that there is no clear leadership and co-ordination institutions for climate services in the area. Most participants suggested that the leadership should come from professionals working in local institutions. Most participants could not state the policies that facilitate the production and delivery of climate information to the community. Participants suggested that climate information should be delivered in their local language using existing channels, including radio, mobile phones, televisions, health and educational institutions.

7.6.4 Demand for and Investments in Climate Services

The demand for climate services was also explored. Participants stated that every person in the community requires climate information in one way or another. They also noted that there is greater demand for climate services amongst staff working in national parks, airport, health facilities, schools, churches, farmers, miners, research institutions, as well as persons working in formal and informal settings. All participants noted that although vulnerable persons need climate information, there is no existing climate information structure to cater for them. One respondent stated:

> *'Most chronically ill persons will be happy to know well in advance weather changes. This will enable them to go to health centres to get their medication rather than planning to go on a day when the weather will be bad. Similarly, we have elderly persons who attempt to get social grants on certain days and find themselves under terrible weather. This can be avoided if they get weather information prior to their trip. In the area of agriculture, predicting how the season will be can help farmers in this area plan the dates to plant and the types of crops to grow.'*

Participants suggested that targeted climate information delivery would be more effective to cater for vulnerable members of the community. One key informant stated:

'What we tend to get is general information and one has to think how it applies to their circumstances. My suggestion is climate information must target specific population groups. It will be good to get information that informs elders which weeks they can go to get their social grants, or which days children can write their exams without being affected by extreme weather conditions. Similarly, if clinics get information they plan their admissions of pregnant mothers, amongst other decisions.'

Most respondents stated that communities demand seasonal climate information that indicates the actual days when the community will be affected by adverse climate events such as floods, extremely hot and extremely cold days and droughts. Most key informants suggested that communities would like information on when to expect malaria, diarrhoea and other diseases to increase. Farmers want information on what types of crops to grow before the onset of the rain season and what pests and diseases to expect. Other employers require forecast information on days they will be unable to work for them to arrange other activities or their staff leave days. One key informant said:

'My work is outdoor(s), and I am self-employed. If I know in advance how the season will look, I plan my days properly so that I go back to my rural home when it is impossible to work. Unfortunately, we do not have that information, and we continue coming to work, only to go back home without doing anything.'

Given these responses, it can be said that there is a demand for climate services in the area.

The investments necessary for climate services and whether community members would be willing to pay for the services were also explored. All participants stated that community members were too poor to pay for climate services. They suggested that government must partner with mining firms and other private companies to pay for the poor communities. Participants recommended that private firms pay for specific climate information they require.

7.6.5 Status of Climate Services for Health

The status of climate services for health in the area was also investigated. All key informants and respondents stated that climate information services for health are not fully developed. One key informant from a health facility stated:

'The state of climate information for health is that of fragmentation. Individuals get their own information. There is no institutionalised process to deliver the climate information for health here. Yet, the information is important. It can help improve treatment outcomes.'

Most respondents stated that there is no interaction between healthcare workers and meteorological officers, which makes it impossible to share climate data. In addition, since weather services charge some fees for people to access data, this hinders sharing of climate data. They suggested that the climate information must be produced at a local level.

7.6.6 The Types of Climate-Health Information Required

Having established if climate services would be of value in local decision-making, the nature and type of climate services were also probed. All participants stated that communities primarily need seasonal forecasts on rainfall and drought as well as context-specific weather and climate information that shows the probability of an extremely hot day, rain, thunderstorm, floods, humidity and windy days, among other conditions. One key informant aptly stated:

> *'The key climate-health information we need is on the rain season, that is, whether we will have sufficient rainfall or we will experience a drought. This information will help us [to] plan which crops to plant. It helps us decide on the right time to buy and store foodstuff in case of drought. It also shows us whether the community will be affected by malnutrition or not. It will demonstrate to us whether our water sources will be affected or not. That information will indicate whether we will have fruits and vegetables. The information will indirectly show the pests and insects that may affect us, and we fear malaria.'*

Participants noted that wind carries with it dust particles associated with respiratory infections. Dusty winds generally affect people with respiratory diseases such as asthma and limits visibility. Participants pointed out that mining operations in the area are a source of dust. Therefore, information on wind speed and direction is important as part of the climate-health information package. Key informants specifically emphasised the importance of information on humidity. They noted that humid conditions make people feel hot. Information on hot days importantly informs them on what activities to engage in and whether children can go to school or not. In addition, heat information is essential because it enables communities to create interventions to prevent dehydration and diarrhoea, especially among children.

A few participants stated that climate-health information on extreme weather events is generally useful, especially floods, thunderstorms and hailstorms forecast crucial for people caring for people living with disabilities, vulnerable community members, people who work outdoors as well as those who travel long distances to and from work.

7.6.7 Indigenous Climate-Health Services vis-a-vis Scientific Climate Information

Under this theme, the role of indigenous knowledge on climate and health in relation to scientific climate information was explored. Most study participants noted that a few community members are aware of the indigenous knowledge that influence the health-seeking behaviours of community members. Most participants stated that few elderly people, as well as some traditional healers, can identify diseases that can be associated with climate change and variability. A traditional healer in the area stated:

> *'We know that most of these illnesses result from drinking unclean water, eating poor quality foods, eating infected and even poisonous fruits during periods of drought, as well as dehydration during extremely hot days. These sicknesses mainly affect children, the elderly and those with underlying medical conditions. Most traditional healers and herbalists are aware of traditional remedies for these health complications that may be associated with climate change.'*

Respondents noted that most community members go either to church leaders, some elders or traditional healers and to herbalists for consultations and treatment. One respondent stated:

> *'Most people go to herbalists who will give them some traditional herbs to deal with minor ailments arising from heat and other sicknesses of weather. The problem is that the herbalist always keep their practices a secrete and would not want to share the information with anyone. Some community members go to churches where they get oil or water as well as prayers. The interventions of churches and herbalists are helpful to those who believe in their value.'*

Some respondents also stated that when the traditional and religious solutions fail, community members then visit the healthcare centres. Other respondents stated that community members concurrently use traditional remedies together with medications from health facilities. One respondent stated:

> *'Community members tend to try all forms of available ways to be healed or cured. While most start first at herbalists, others start at the churches. What is clear is that if the solutions from the herbalists and faith leaders do not work, the members end up going to the healthcare centres. Sometimes they are referred to the clinics by the herbalists and the faith leaders.'*

The health solutions provided by faith leaders were explored. One faith leader noted:

> *'Although our interventions are usually spiritual, at times we provide practical solutions to problems. We sometimes provide oil, water and other protection items to children of God so that they experience the healing power of God. We believe God is the ultimate healer for any condition, even weather and climate-related sickness. And we know most of our believers use these, and they find them effective.'*

All participants suggested that health climate services should integrate scientific and indigenous knowledge. The main issue is how to communicate these.

7.6.8 Communicating Climate Services for Health

Having understood the role of scientific and indigenous climate information service, efforts were then extended to find out what would be some of the most accessible forms of communicating the climate services. Participants stated that posters and pamphlets written in local languages and pasted at health facilities, community centres, churches, schools, shopping areas and other public places are an acceptable means to communicate climate information for health. The same posters and pamphlets can be distributed by selected community leaders. Participants stated different views on the role of agriculture extension services in disseminating climate-health information. While some participants thought agricultural extension workers would be effective, others thought this was not their area of focus.

Most participants noted that disseminating climate-health information through WhatsApp, radio, short-text messages on mobile phones, and verbal announcements will enable the information to reach many people. The importance of television was debatable because it is unable to distribute Agincourt sub-district-specific information. Most participants concluded that the television is an inappropriate channel to communicate climate-health information for the area. Respondents suggested using social media platforms such as Facebook and Instagram.

Key informants noted the importance of verbally communicating the information to community leaders. The community leaders and influencers share the information verbally during their interactions with individual community members, and they will announce the information during community events.

7.6.9 Investing in Climate Services for Health

People's opinion were collected to assess the investment necessary for climate services was also done. Most key informants stated that money should be invested in creating physical and virtual platforms for sharing climate information. Some respondents suggested more investments in building new weather stations. They stated that each health facility and school must have a weather station, and investments must be directed towards training targeted personnel in schools, health facilities as well as community representatives. Further investments in capacity building must target professionals working with the data so that they can interact with stakeholders and produce consensus-based climate services.

All respondents stated that the government must pay for these services because they are for the greater good of everyone in the community. In fact, community members would be unwilling to pay for health climate services. Respondents argued that government must pay because climate services for health are a preventative rather than curative approach to healthcare delivery, and they create savings for the government by reducing costs associated with treating sick patients.

7.6.10 An Example—Heat-Health Services in the Agincourt Sub-District

Since existing literature and meteorological data show that the Agincourt sub-district is experiencing heat and heatwaves and communities will be affected by heat and heatwaves in future, the evolving heat-health services in the area were explored (Kruger et al., 2002; Kruger and Sekele, 2013; Kruger and Shongwe, 2004; Byass et al., 2017; Macfadyen et al., 2018; dos Santos et al., 2019; South African Weather Service, 2019; Mbokodo et al., 2020; van der Walt and Fitchett 2020). In addition, study participants suggested that since the Agincourt area was already experiencing extreme heat, heat-health services were supposed to be prioritised. Overall, all participants stated that scientifically informed heat-health services were non-existent in the Agincourt sub-district. However, heat-health information informed by indigenous knowledge may be in existence, albeit the extent of their coverage is unknown.

The types of heat-health information communities that residents in the Agincourt would require was also investigated. The heat-health information necessary include the days when it will be too hot and humid, days with less wind and days when extreme heat will be followed by rain and cold. Participants noted that information on hot days should be forecasted and reported at least two weeks in advance to give community members time to prepare a response. They also suggested that a seasonal forecast of hot days would be very important if it were possible to have this. However, further probing showed that this suggestion was a request for information when the rain season would be interrupted by a short period of drought or extreme dry days.

Most participants stated that heat forecasting is important because it would make them prepare in advance to reduce the health effects of heat. Participants noted that communities would store large quantities of clean water, food and buy or collect medications in advance. A few participants stated that heat-health forecast information would enable them to disseminate the information in the community. They noted that providing heat information in advance allows every member of the community to be ready for the heat or extreme heat events.

Respondents stated that community members that would benefit most from heat-health information include the elderly, children, people living with disability and people on chronic medications. Participants stated that heat-health information is complex to explain and must be disseminated to a limited number of key persons, including community leaders, traditional healers/herbalists, teachers and healthcare workers. These people must cascade the information to other community members. However, some key informants disputed this. They argued that some community leaders and influencers might politicise or fail to articulate the information and even misinform others. They suggested that heat-health information be disseminated widely through diverse channels and every community member be involved in the production and delivery of the services. Thus, key informants emphasised that heat-health services are essential for everyone in the area.

7.6.11 Community and Medical Staff Awareness of Heat-Health Impacts

An investigation of community and medical staff awareness of heat-health effects was done. Study participants and medical staff showed an excellent understanding of the health effects of extreme heat. They reported that many community members would be able to articulate the direct and indirect impacts of extreme heat anomalies and relate these to general health. Participants ascribed their understanding of the heat-health effects to the fact that they live in a generally hot area. Key informants stated that although heat-health campaigns are lacking in the Agincourt area, they are necessary and should be integrated into existing campaigns that are carried out by healthcare providers in the area.

7.6.12 The Necessity of a Heat Response System

Key informants noted that the area required early warning systems for extreme events, including extreme heat. One key informant from a meteorological station stated:

> *'We have weather and climate data. We do not have capacity to translate this to be useful for health interventions in this area. It will be good to do so, but right now, it is practically impossible. Which agency must lead this? The area needs early warning systems for a variety of natural disasters.'*

All participants stated that a heat-health early warning system was supposed to be informed by community knowledge of the area as well as scientific information. The participants highlighted that two-way communication and participation of the community in the production of a heat-health response system is necessary.

7.6.13 Investments and Heat-Health Co-Ordination System

The investments necessary, as well as the co-ordination of a heat-health response system, were investigated. All participants stated that investments in heat-health services should be made by government because these services are aimed at saving lives. However, some participants pointed out that some firms, especially mining firms, farms and national parks must invest in heat-health services because their employees are vulnerable to heat exposure. By investing in these services, the firms would be directly and indirectly protecting their employees and their families. The suggested investment areas included training, capacity building and community relations.

In terms of co-ordination of the heat-health system, participants held different views. While most participants thought that the leads should be staff at meteorological stations and the SAWS, a few participants suggested health department staff. However, key informants noted that the system must involve co-chairing or co-leadership by employees from the weather stations and the health department.

7.7 The Implications of Findings for Climate Services for Health

In this chapter and in this thesis, an assessment of the existence of and need for climate services was probed in the Agincourt sub-district of South Africa. This study is the most comprehensive effort to assess the status of climate services for health and heat-health services in Agincourt sub-district. To guide the analysis of the findings, the components of the novel inclusive systems of climate services for health framework are firstly employed as follows.

Climate services for health must be people-centred and co-delivered in a manner that recognises the importance of the involvement of users. People-centredness can be viewed as analogous to patient-centred care (Ekman, 2021; van Diepen and Wolf, 2021). Patient-centred care demands considering the patient's information needs, shared decision-making and implementing appropriate responses informed by the process and substance of dialogue (Stewart, 2001). A similar view emphasises that the users of climate services are the reason for the existence of the service.

The study results show that scientifically informed climate services are not well-developed in the Agincourt sub-district. In addition, heat-health services are non-existent in the area. The limited scientific climate information accessible to the populations is disseminated from the national level. This information, while good in coverage, is too general to impact local-level decision-making processes. Therefore, the current scientific climate information the populations can access lacks people-centredness. This situation may not be limited to the Agincourt sub-district. It seems a general challenge found across many countries where scientific climate information is disseminated from a centralised system. It is difficult to establish a balance between centralised delivery of climate services and people-centredness. Hence, decentralised systems of climate services for health may be necessary to implement.

The study findings also point out the existence of climate services for health that are based on indigenous knowledge. This study may indeed be the first to comprehensively elaborate on this result. While the coverage of the services could not be established, the mechanisms by which they function, including community involvement in information dissemination, were clearly articulated. The indigenous knowledge-based climate services for health are produced within the communities and delivered by community members. Hence, they are community-specific and people-centred to a certain extent. However, they are exclusive to populations that do not interact with the producers of these services or their associates. To enhance people-centredness in the delivery of climate services for health, efforts to integrate scientific and traditional systems of services delivery must be made. Principles of co-production and co-delivery must undergird the integration process.

The study results also critically highlight the multilevel institutions that explicitly and implicitly influence climate services, including climate services for health in South Africa. Our findings importantly show that the governance of climate services, health climate services and heat-health services is fragmented and lack clear leadership. Current production and delivery of climate services, including climate services for health, happens in silos. The SAWS generates and distributes climate information with little to no involvement of other stakeholders, including those from the health sector. Co-ordination across the various government agencies is weak. Moreover, efforts to co-ordinate scientific and traditional services systems are non-existent. The involvement of communities within the multilevel structure of governance is not robust and meaningful. Without community involvement, it is difficult for climate services to impact local-level decision-making. Therefore, the current multilevel systems governing the delivery of climate services for health are not synergised.

Climate services for health and heat-health services require transdisciplinary approaches in their implementation. Intrinsically, climatologists/meteorologists and climate communication specialists must collaborate with healthcare and allied workers to deliver relevant and impactful climate information for health, particularly heat-health information. The study results demonstrate that transdisciplinarity must include other indigenous healthcare providers such as traditional healers, herbalists and even faith group leaders. These oftentimes forgotten stakeholders provide forecasts and healthcare advice that influence some members of the community. These actors, their message and practices have been resilient, and it is necessary to include them as part of the transdisciplinary teams. The current situation of climate services for health and heat-health services in the Agincourt area does not demonstrate institutionalised, systemic and inclusive transdisciplinary principles. Applying an inclusive system of climate services requires broadening the transdisciplinary lenses to include other non-professional community leaders and community members.

The use of locally available technologies is imperative for inclusive systems of climate services, including climate services for health and heat-health services. The results show that climate services are accessed using locally available technologies and informal information dissemination channels that have existed over time. This finding is very important because it calls into question the efficacy of current climate information products. Hence, a review of current climate information products is encouraged.

The findings generally demonstrate that countries should not adopt a one-size-fits-all approach to the co-delivery of climate services for health and heat-health services. Some of the current communication products must be upheld. For example, the finding that posters and pamphlets targeted at specific public venues must be used to deliver climate services for health and heat-health information demonstrates the belief in their efficacy as a public health communication tool. The reported centrality of verbal exchange of climate information in rural settings calls for innovative ways to co-deliver climate services for health and heat-health information.

Interactive learning is important in facilitating the co-delivery of climate services. Interactive learning provides insights on the co-delivery of climate services to vulnerable populations such as children, the elderly, people living with disability and people on chronic medications. In the Agincourt sub-district, traditional forecasting systems demonstrated inherent elements of interactive learning, while there is little interactive learning in scientific climate information.

The exploration of the necessary investments for climate servicers, including climate services for health and heat-health services, provided invaluable and new information not exposed in existing literature. The key findings on investment show that resources for climate services must be provided by government, while the private sector can complement government efforts, and firms must pay for climate products specific to their needs. However, the results suggest the existence of a very strong view that governments must invest in climate services for health and heat-health because the populations are poor to accept the user-pays principle, and climate services for health and heat-health services are lifesaving investments. These findings are very important as they provide unequivocal empirical evidence to African governments to invest in climate services for health and heat-health services.

The study results demonstrated that investments for climate services for health and heat-health services must be directed towards training, capacity building, stakeholder relations and infrastructure, especially weather stations. Existing literature highlights the importance of investing in infrastructure and capacity building without alluding much to investments in training and stakeholder relations (Dinku, 2011; Dinku et al., 2011; 2014b). Therefore, the study findings are very important for the African continent, where the density of weather stations is unacceptably low. The suggested investments in training are important in the African context, where many countries are affected by skilled labour shortages. While investments in stakeholder relations were alluded to, this may be considered as part of the capacity building exercise.

The general implications of some findings are worth elaborating outside of the inclusive systems of climate services framework. One such finding is that climate services for health and heat-health services are necessary for the Agincourt sub-district. This finding shows that communities are aware of the importance of climate services, and they understand the services they require. This is useful for researchers, practitioners and policymakers because they must consult communities to facilitate organic or endogenous growth of the services.

The finding that healthcare workers and communities are fully aware of the health effects of extreme heat is also worth elaborating. The results showing increased awareness of the effects of extreme events on health among medical staff confirm what is reported in existing literature (Watts et al., 2020). However, the practical application of such knowledge to save lives and assist those affected is lacking. Heat-health campaigns are recommended. A detailed analysis of existing interventions that have enabled the communities to be resilient to past temperature anomalies encompassing traditional healers and faith leaders is encouraged.

The results showing the importance of a heat-health early warning system are insightful. Existing literature clearly shows that heat is going to affect many African communities, including communities in and around the Agincourt sub-district (Byass et al., 2010b; Byass et al., 2017; dos Santos et al., 2019). Therefore, it is important for the South African and other African governments to create heat policies. While this study did not establish the costs of inaction, several studies carried out in other settings show excess deaths and increased morbidities from extreme heat events (Smith et al., 2016; Campbell et al., 2018).

The finding that government must invest in climate services for health and heat-health services must be examined further, especially in relation to sustainability of the services. The key question is, what investments must be made towards integrating the scientific and indigenous systems climate services for health? In addition, should indigenous producers and disseminators of climate services, including climate services for health, be incentivised?

The study is scientifically robust based on the degree to which findings are reproducible, replicable and generalizable. The research design, sampling method and sample size, as well as the use of appropriate methods for data collection and analysis were thoroughly explained. In addition, most participants (83%) completed education levels that would allow them to give insightful responses to the subject under research. Furthermore, gender parity was achieved as males and females equitably participated in the study. The involvement of people living outside of the Agincourt sub-district helped give a somewhat outsider perspective to the study necessary in corroborating or refuting evidence and minimising bias. Triangulating multiple data sources increased the reliability and validity of the findings.

There are, however, some study limitations worth mentioning. The data collected in this study mainly focused on South Africa, specifically the Agincourt sub-district. Therefore, the generalisability of the study findings is limited. As such, any generalisations that were made from this study were qualified. While attempts were made at reaching data saturation on each theme, there is no gold standard to refer to ascertain with certainty that data saturation was reached on all themes. The study number of participants may be considered low. However, it can be argued that the 93 participants included in the study was an acceptably huge number. While some participants interviewed were referred by key informants, which creates bias, some participants were selected outside of the referral chains to minimise bias associated with snowballing.

7.8 Conclusion

In this chapter of the thesis, a detailed case study of the local perceptions of status of climate services, emphasising climate services for health and heat-health services in South Africa's Agincourt sub-district, has been presented. A qualitative case study methodology encompassing multiple data collection methods as well as triangulation of data sources was used. The study presented several novel findings on climate services, climate services for health and heat-health services in South Africa and the Agincourt sub-district. The findings show that the provision of climate services is still fragmented in South Africa, albeit existing policy frameworks and supporting institutions to deliver these. Although research on climate services for health has been evolving for nearly a decade now, the actualisation and delivery of the services are limited. Hence, climate services for health are largely underdeveloped. While climate data shows that the population has been and will continue to be affected by heat and heat events, the results show that heat-health services are non-existent. This is of great concern. Planning for heat and heatwaves is essential to minimise the health effects of these climate-related conditions. While this study provides detailed information for adaptation research, policy and practice, we recommend further research that examines the cost of acting or not taking any action against the changing climatic conditions and extreme events in the sub-district. Further research on heat and health, as well as responses to heat stress and heatwaves, is encouraged.

7.9 Chapter Postscript

In this chapter, evidence on the state of climate services in South Africa and climate services for health in the Agincourt sub-district has been presented. Empirical evidence on the evolution and delivery of heat-health services in the Agincourt sub-district has also been probed and results explicated. The next chapter presents the conclusion to this thesis.

7.10 References

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8 CONCLUSIONS

8.1 Introduction

In this final chapter, the aims, objectives and results of the research presented in this thesis are drawn together. The aim of this research was to explore the human health effects of EWEs, particularly heat. The research further examines the climate services, especially climate services for health and heat-health services in Africa. The overarching research question was: In what ways do EWEs, especially heat, affect human health in Africa, and what implications does this have on the delivery of climate services for health moving forward?

Five sub-ordinate questions were posed. First, what are the human health effects of EWEs, particularly heat in Africa and in particular, in the Agincourt sub-district of South Africa? Second, what are the socioeconomic and demographic characteristics of persons susceptible to health complications from heat in the Agincourt sub-district of South Africa? Third, what is an Africa-relevant conceptual framework that can be used to explore climate services for health in Africa? Fourth, what is the status/conditions of climate services in Africa and climate services for health in the Agincourt sub-district of South Africa? And finally, what Africa-specific responses can be applied by African countries to respond to the human health effects of heat?

In concluding this study, the key findings and arguments from the previous chapters are summarised, the initial research aims and questions reflected upon and synthesised based on literature and actual findings. Finally, some policy implications are suggested, some recommendations for practice made, and the challenges experienced in carrying out this study reviewed. Some recommendations for future research end this thesis.

8.2 Overview of the Research

This study centred on examining the occurrence, impacts and actions related to heat and heatwaves in Africa but in particular in the Agincourt area. A health and demographic surveillance study carried out in the Agincourt area from 1992 to date demonstrates that the area has a long history of health research in South Africa. While there is a limited set of rigorous heat-health research at very local levels (for a variety of reasons as shown in **Chapters 2, 3 and 7**), the focus in this thesis was more on finding out from participants and decision-makers some of the ‘lived experiences’ of heat effects on health currently and then probing future scenarios and how better adaptations could be made to enhance adaptation to heat-health stresses.

The focus on the “so what question” included an assessment of current climate services (**Chapters 4, 5, 6 and 7**) and aimed to assess the delivery of climate services as a solution for adaptation and resiliency to heat. As such, the overarching essence of the work was to understand the direct and indirect impacts of heat on human health in Africa and to assess the state of climate services for health on the continent. In addition, the study aimed to understand the situation of the delivery of climate services targeting the health of the African population. Even though previous studies and existing literature have alluded to the effects of heat on human health, evidence grounded in African realities and context is scarce.

With this background, the next section provides the key message from each chapter, including research findings and key learning points.

8.3 Chapter Overviews

Chapter 1: Introduction

In this chapter, the research background and context, research aim, research questions, rationale for the study, the results of preliminary research, research conceptual frameworks, methodology and the thesis outline were provided.

The aims of this research were:

1) To demonstrate the current and projected health effects of heat and heatwaves on the African populations;
2) To understand how increased health effects of heat relate to the development of climate services, especially climate services for health;
3) To create conceptual frameworks to guide analysis of climate services, particularly climate services for health in Africa and promote transdisciplinary research;
4) To provide empirical evidence on the evolution of climate services and climate services for health in Africa;

In the chapter, the study methodology was explained, especially the use of qualitative, multiple embedded case study methodology to explore the subject under research. To enable the qualitative research, primary and secondary data sources were triangulated:

- The research participants comprised 93 people who were interviewed for this research.
- Structured observations were made at some venues, and primary and secondary data were also collected.
- HDSS data were provided by the SAMRC/Wits Rural Public Health and Health Transitions Research Unit-Agincourt for analysis and used to verify/corroborate the findings.
- Meteorological data were collected from the SAWS.
- A systematic review of literature on EWEs was conducted, particularly heat and heatwaves; climate services in Africa; climate services for health and heat-health services in Africa.

In explaining the methodology further, the data collection, data analysis and reporting processes and the study limitations, especially the inadvertent response biases, limited generalisability of the study and the handicaps of snowballing when recruiting study participants, were explained.

The logistical and technical justification for choosing the Agincourt sub-district case study include:

- First, there is ongoing work by the SAMRC/Wits Rural Public Health and Health Transitions Research Unit-Agincourt that the research could piggyback on, especially the existing friendly community relations that could facilitate this research.
- Second, the SAMRC/Wits Agincourt Unit provided longitudinal health and demographic surveillance data from 1992 to date that the researcher used to verify some findings.
- Third, there are many meteorological stations in the sub-district that could provide temperature and other meteorological data essential for the research.
- Fourth, the researcher manages health projects in the area and therefore could get access to health and educational facilities without facing many challenges.
- Fifth, the researcher could be accommodated at the Wits Rural Facility, which is close to the sub-district.

The main potential contributions of the study are:

- a new conceptual framework for analysing climate services and climate services for health in the context of Africa;
- an expansion of transdisciplinary research to inform international climate change and health adaptation negotiations;
- evidence provided that brings to the fore the urgency of planning heat-health responses in Africa;
- filling several gaps in existing literature; and
- essential opportunities given for marginalised voices from local communities affected by climate change in Africa to be heard.

Chapter 2: Extreme heat events, high ambient temperatures and human morbidity and mortality in Africa: A systematic review of the literature

Noting that there are no scientifically robust Africa-specific reviews on EWEs such as heat and their effects on human health in Africa, a systematic review that explicitly presents an overview of the literature on heat-health effects in Africa was carried out and the results presented in this chapter. The chapter included a systematic review of literature that highlights the status of heat-health research in the context of Africa and the key themes from the research. The following key points on heat and health in Africa emerged:

- There are gaps in existing literature on the effects of heat on human health in Africa. For example, a clear articulation of the populations most vulnerable to exposure to heat and heatwaves is lacking. The research presented in appendixes 2.3 and 2.4 demonstrate attempts made to plug the gaps in existing literature through focused studies that demonstrate populations most vulnerable to temperature changes. The study in appendix 2.3 shows that pregnant women, including pregnant African women, are likely to be affected by increasing temperatures, while appendix 2.4 shows that increased diarrhoeal cases are associated with temperature changes in South Africa. Unlike most of the existing studies, these studies provide empirical evidence that can inform African climate-health practitioners and policymakers.
- The main methodological deficiency in existing studies is that the research tends to infer findings from continents other than Africa, ignoring the fact that Africa is made of a variety of contexts that all have specific relevance when designing and implementing adaptations for climate change, including heat health. The systematic review demonstrates that most

global studies on heat effects on health oftentimes completely excludes Africa-specific studies but generalise their findings to encompass Africa.

- African countries are and will be affected by EWEs in general, particularly heat. Africans are, however, ill-prepared to respond to morbidity or mortality associated with heat and heat events.
- The existing literature is not very detailed in suggesting clear Africa-specific heat-health interventions. The mechanisms for African populations' health adaptation and resiliency to heat and heatwaves are also not clear.
- Reviewed literature, moreover, is weak on policy suggestions. The few suggestions on heat-health policies for African policymakers from the literature provide minimum insights on policies for preventing and treating diseases arising from heat and heat events.

Despite these limitations, some preliminary themes found in existing literature, including vulnerability to heat exposure, prevention of health effects of heat, treatment of diseases associated with heat and heat-related morbidity and mortality, were identified. These themes are central to the research presented in this thesis.

Chapter 3: The self-reported human health effects associated with heat exposure in The Agincourt sub-district of South Africa

The heat-health discussion begun in **Chapter 2** was unpacked in more detail with a context-relevant interrogation of a case study in the Agincourt sub-district of South Africa. Innovative use of internationally known heat-health indicators, for example, indicators from the *Lancet* Countdown Reports, are expanded on to explore the effects of heat on human health in an African context. By doing this, international indicators were applied to a local African setting. The following key points have arisen:

- Africa-specific studies guided by heat-health indicators are few. This means that there is limited empirical evidence from Africa to inform internationally existing heat-health indicators. The lack of indicator-guided studies makes it difficult to compare findings from Africa to other continents. Given this, qualitative studies that provided preliminary data for heat-health indicators (such as this research) are essential.
- Several concepts around heat and health, including "vulnerability to heat", "heatwaves" and "heat spells" are ill-defined. For example, the definition of "heatwave" was not easily

comprehended by communities in the Agincourt district, which demands climate scientists and policymakers to reflect on the words they use in relation to local communities.

- African communities can easily discuss heat effects on morbidity instead of mortality. There is reluctance to acknowledge; however, people can die of high ambient temperatures. Reasons articulated include because people living in rural areas have strong social networks that will help to intervene to stop deaths. In future, it may be useful to explore whether such networks exist in all African areas, including more remote rural areas and urban areas.

Most of the key themes advanced in this chapter are similar to those presented in Chapter 2, including vulnerability to heat and heatwaves, heat-related morbidity and mortality, and heat responses. The heat-health indicators theme was introduced in this chapter to guide analysis of heat effects in Africa and provide more insights on how African studies relate to global studies. The main findings highlighted in this chapter are that the Agincourt area has been experiencing heat and heatwaves and that projected temperatures are rising, resulting in more frequent and intense EWEs. Heat is already affecting the population health in the area.

Chapter 4: Climate services in Africa: Re-imagining an inclusive, robust and sustainable service

Responses to EWEs and an examination of the "state of climate services" were addressed in Chapter 4. The connection of the scientific aspects of heat health and responses or decisions around these was found to be missing in existing literature. Two major concerns related to the "framing" of climate services were examined: assessing the evolution and delivery of climate services on the continent and envisioning the processes and potential content of appropriate and relevant climate services for the continent.

Overall, the argument advanced in this chapter is that it is important to have Africa-relevant and Africa-specific climate services. Indeed, African countries require context-relevant assessment and investigation, and as elaborated in **Chapters 2 and 3**, heat-health effects on the continent have peculiar characteristics. A cogent argument presented in the chapter is that Africa-relevant climate services must be re-imagined to be inclusive, robust and sustainable.

Chapter 5: Systems approach to climate services for health

Having interrogated the "status of heat health" in Africa and in Agincourt, attention then turned to examine and offer a conceptual framework for climate services for health. The theme of inclusiveness in such work and by adopting a transdisciplinary approach anchored the outcomes:

- Presenting a new conceptual framework for climate services for health applicable globally;
- Highlighting that decision-makers in all contexts (policy and practice) need to adopt a non-linear approach to the complex issue of how communities can adapt and be resilient to the health effects of heat.

These principles are derived from a systems approach to climate services for health, which enables a generic and holistic framework for understanding and assessing the services. The examples presented in the chapter focus on responses to the health effects of heat. Of importance is the Ethiopian case study, which demonstrates the evolution of climate services for health in Africa.

Overall, the systems approach with feedback loops eschews linear approaches to climate services for health and aptly reflect the messy world that decision-makers confront in developing solutions for health adaptation and resilience. The systems approach thus enables decision-makers to re-imagine more inclusive, robust and sustainable climate services for health.

Chapter 6: Climate change and health: The case for more inclusive climate services for human health and their characteristics

The conceptualisation of climate services began in **Chapter 5** and was expanded on in **Chapter 6** as climate services for health. A rationale and characteristics for inclusive climate services for health are presented in **Chapter 6**. Overall, inclusiveness is shown to be key to ensuring that marginalised populations are involved in the co-generation and co-delivery of climate services for health. Facilitating the evolution of inclusive climate services for health can influence the content of the services while solving the persistent problem of inequalities prevalent in the populations disproportionately vulnerable to EWEs, particularly heat, as well as inequalities in capacities to respond to the health effects of heat. Inclusive climate services for health are imperative for Africa, a continent affected by widespread poverty and inequalities, as well as a lack of capacity to effectively respond, without international assistance, to the health effects of EWEs, including heat.

The characteristics of inclusive climate services include that the services must be 1) people-centered, 2) include multilevel/co-operative governance, 3) involve interactive learning, 4) encompass transdisciplinarity and 5) be delivered as public good. These characteristics are derived from transdisciplinary literature and have not been elaborated in a unified and coherent form as done in this thesis.

Chapter 7: The fragmented and indispensable nature of climate services for health in the Agincourt sub-district in South Africa

The findings of Chapter 6 were interrogated and attempts were made to validate them in **Chapter 7**. The main aim of this chapter was to present empirical evidence on climate services and climate services for health in South Africa and the Agincourt sub-district. **Chapter 7** is a multiple embedded case study that focuses on climate services, climate services for health and heat-health services in South Africa and the Agincourt sub-district. The key findings presented are:

- Notwithstanding the paucity of existing studies that have explored climate services in the context of South Africa, climate services are evolving in the country, targeting various climate-sensitive sectors.
- While heat is adversely affecting population health in the Agincourt sub-district, the delivery of climate services is fragmented, and heat-health services are non-existent.
- Whereas the lack of a systematic response to heat generally affects all persons living in the sub-district, the populations most vulnerable to heat exposure and heatwaves include the elderly, infants, persons living with disabilities and outdoor workers, as well as people with underlying medical conditions.
- There is a notable lack of interagency co-ordination between the Departments of Health and Education and SAWS, among others, that pose a serious challenge to the delivery of effective climate services for health.
- Paucity of data, especially data gaps in meteorological data, affects the delivery of actionable climate services for health, especially heat-health information in the area.

The findings on paucity of data on climate information on the continent accord with findings in existing literature (e.g., Thomson et al., 2011). However, the results on heat-health responses and governance of climate services for health have not been explicitly expressed in existing Africa-focused literature.

8.4 Summative Research Findings

This research has brought greater clarity on the necessity of understanding the understudied climatic events, especially EWEs and climate services for heat and health. The findings linked to the research questions are presented below.

Complex EWEs-health relationship with inferences made from non-African contexts

The frequency and magnitude of EWEs in Africa are rising more rapidly than available resources and capacities can respond to disasters (Codjoe and Atiglo, 2020). In the African context, EWEs such as droughts and floods have been studied over long periods of time (Kew et al., 2019; Tramblay et al., 2020; Adaawen, 2021; Engelbrecht and Monteiro, 2021; Ramiaramanana and Teller, 2021; Shukla et al., 2021). Conversely, other EWEs, such as heat events, have been understudied (Ceccherini et al., 2017; Marcotullio et al., 2021). Thus, knowledge and understanding of salient EWEs, including drought, floods, desert locusts, cyclones, mosquitos and their effects on human health, is largely available. In addition, multiple responses to these salient EWEs have been tried and tested over time.

Like the highlighted salient EWEs that receive much research focus, the understudied events such as heat and heat events also adversely affect human lives in general and human health in particular. Therefore, understanding non-salient EWEs is essential for saving lives as well as maintaining healthy individuals and communities. Despite this, the responses to the question of the human health effects of EWEs, particularly heat in Africa and the Agincourt sub-district of South Africa, are limited hence prompting this research. Reasons for gaps in knowledge and implementation include:

- While the relationship between EWEs and human health in Africa is complex, EWEs, for example, heat, are and will negatively affect the population health of people in Africa through amplifying mortality and morbidity.
- African populations perceive their social capital and networks may prevent some deaths associated with EWEs, especially heat and heatwaves.
- Some scientific concepts related to EWEs, including the definition of “heatwaves”, are not easily comprehensible to communities showing a disjuncture between scientists, policymakers and local communities.

- Existing literature on EWEs, such as heat and heat events, mainly focus on other contexts and infers findings from these to the African continent. Such non-context grounded attributions are less informative to policy and interventions.

Given these responses, the effects of EWEs, specifically heat in Africa and South Africa's Agincourt sub-district were clearly identified in the research.

People who are socio-economically vulnerable are also most vulnerable to EWEs.

Having explained the key findings on EWEs' impacts on African populations above, the focus of this section is on the second research question. With regards to population groups disproportionately affected by heat exposure, existing evidence shows that the rate of temperature increase averaged across the African continent is higher than the global average with near-surface air temperature averaged across Africa in 2020 at 0.45°C and 0.86°C above the 1981-2010 average making 2020 between the third and eighth warmest year on record (WMO, 2021). The continent is experiencing increased heat as well as increased frequency of heatwaves that variously and severally affect African population health (Ncongwane et al., 2021). Heat stress will cause unprecedented discomfort for humans in Africa (Sylla et al., 2018).

As stated before, the second research question focused on the socioeconomic and demographic characteristics of persons more vulnerable to heat exposure. In terms of socioeconomic conditions that make persons more predisposed to heat exposure, the most vulnerable population groups were found to be those living in African urban areas where the heat island effect is experienced as well as those whose dwellings lack air conditioning. For example, community members in the Agincourt area reported that the lack of air-conditioned homes makes them more vulnerable to heat and heatwaves.

Concerning the socio-demographics of persons most vulnerable to heat exposure, the study results show that children, pregnant women and the elderly are the most vulnerable to heat exposure on the African continent. The Agincourt sub-district specific findings highlighted that the elderly, infants, persons living with disabilities and outdoor workers, as well as people with underlying medical conditions, may be more susceptible to heat and heat events. Noteworthy, these Africa-specific findings provide preliminary empirical evidence on this subject.

Systems and inclusive conceptualisation of climate services is critical for effective heat-health climate adaptation

The previous section dealt with the scientific aspects of EWEs. Existing literature normally presents these scientific aspects of EWEs separately from the responses. This thesis bridges this gap by presenting the scientific evidence on health impacts of climate change together with climate services essential for adaptation and resilience to the EWEs and climate change in general. Notably, existing literature on climate services in Africa mainly lacks conceptual frameworks to guide the analysis of issues. Universal approaches are largely applied in the existing literature (Dinku et al., 2014). No Africa-specific conceptual frameworks on climate services were found in existing literature. The institutionalist and value chain conceptual frameworks to climate services, among a few others that are inferred and applied to African settings, are too limited in scope to be appropriate to the heterogenous African context (Vaughan and Dessai, 2014; Harvey and Singh, 2017).

Given this, the question of an Africa-relevant conceptual framework, that can be used to explore climate services and climate services for health in Africa, has been central to this research. Two key findings are worth explaining in response to this question:

- It is essential to conceptualise African climate services holistically and to eschew linear framing of the services to enhance their robustness, inclusiveness and sustainability (Vogel et al., 2019). Therefore, a systems approach to climate services for health effectively provides the framework for analysis of the services (Manyuchi et al., 2021).
- Considering the glaring socioeconomic and health services delivery inequalities that bedevil African countries, it is also essential to emphasise inclusiveness when conceptualising Africa-relevant climate services. The inclusive climate services for health can solve glaring inequalities in the delivery of the service. Climate services for health in the African context thus must be conceptualised through the inclusive systems of climate services for health framework. The definitions, characteristics and the rationale for inclusive climate services for health were provided in this research.

This thesis, therefore, provides a body of literature that deepens the conceptualisation of climate services, especially climate services for health. Furthermore, the conceptual frameworks were tested in the real-world context of the Agincourt sub-district, and the results demonstrated the efficacy of the conceptual frameworks.

Effective climate services should leverage and improve on current and past heat-health efforts

Following the presentation of the key findings on the third research question, the focus now turns to the fourth research question. A key finding that is threaded through this research is that one should not craft new climate service efforts without understanding better what already exists even if this existing effort is weak and incomplete. The findings below addressing the question of status/conditions of climate services in Africa and climate services for health in the Agincourt sub-district of South Africa revealed that:

- The evolution and delivery of climate services in Africa is negatively affected by the predominant linear approach to knowledge dissemination that limits co-production and co-delivery of the services. Therefore, substantial efforts need to be undertaken to break the linear approaches to the services and promote co-delivery of actionable climate information for decision-makers on the continent. Taking stock of past climate services delivery efforts is essential. This will help in charting a clear direction for the delivery of climate services and climate services for health.
- Climate services for health in South Africa and the Agincourt sub-district are underdeveloped and fragmented. As stated before, paucity in quality meteorological and health data, as well as coordinating mechanisms, negatively affect the development of climate service nationally and in the sub-district. Past and current efforts to deliver the services must be examined so that actionable and context-relevant services can evolve.

The last research question is about Africa-specific responses that can be applied by African countries to respond to the human health effects of heat. It is important to point out that Africa-focused research aimed to create heat-health interventions and policies at various levels, including the very local, has commenced (Nana et al., 2019). This emerging research will provide evidence that will inform practitioners, researchers and policymakers. In this research, three key findings emerge on the Africa-specific responses that can be applied by African countries to respond to the human health effects of heat as follows.

Context matters when designing effective heat-health climate services

The results throughout the thesis point to the fact that "context" matters when designing effective heat-health services. Underlying this finding are the following points highlighted in the thesis:

- Existing literature mainly provides generalised information on heat-health interventions. Some suggested interventions have no relevance to the African context, albeit useful in other contexts.
- Africa-relevant interventions for prevention, care and treatment are essential in responding to the health effects of heat.
- Policies for climate-health adaptation and resiliency in Africa must encompass heat-health issues.

Barriers and challenges to effective heat-health services

There are a number of reasons that prevent and challenge effective heat-health services. There is a scarcity of evidence that should inform policymakers and practitioners. This study clearly demonstrated that while there is scientific evidence that shows that some parts of Africa are warming and are projected to be regularly affected by intense heat and heat events, this information is not aggregated or consolidated to be easily accessible. The research also revealed that most of the studies carried out on heat are not Africa-specific and therefore do not explore in-depth Africa-specific and Africa-relevant aspects. Findings from other continents are usually inferred to Africa, which poses problems for African policymakers and practitioners alike. The need for empirical evidence grounded in the unique and peculiar African climate and socioeconomic realities cannot be overemphasised.

Institutional weaknesses were also found to be prevalent, particularly in climate heat-health services. Existing institutions may not have the needed capabilities to coordinate holistic responses. This research revealed several institutional weaknesses that hinder the translation of meteorological and health data to climate information for health in the Agincourt sub-district and South Africa as well. These inherent institutional weaknesses handicap the execution of appropriate responses. As such, this study demonstrates that while EWEs are affecting African countries, the response to EWEs is not yet measuring up to the magnitude of the problem.

Using a broader transdisciplinarity is central to holistic heat-health responses

One key finding was that many African countries currently lack explicit heat prevention, care and treatment interventions and policies. Despite this, it was suggested that early warning systems are developed, heat-health plans are created, housing conditions are changed, and education awareness campaigns are implemented. In fact, an emphasis on health in all climate policies approach was recommended. Considering that multiple heat-health responses have been suggested, crafting and implementing or enforcing these becomes a complex endeavour.

The heat-health responses must be created with the inclusion of the people who will benefit from them. Given this, policymakers and practitioners have to rethink current project design and policymaking processes. A broader transdisciplinary approach that involves professionals working with non-professionals is central to creating Africa-relevant heat-health interventions and policies

8.5 Some Policy Recommendations

Complex issues of human health effects of EWEs, especially heat and the delivery of climate services, especially climate services for health in Africa, have been explored in this thesis. The empirical evidence generated can be used to develop various policies, regulations, guidelines, and other measures pertaining to heat-health response. A wide range of recommendations for different groups has been generated in this study. The key policy recommendations that can be made based on the empirical evidence, especially from the case studies, are:

- African governments must shun a parochial, narrow and reductionist approach to responding to EWEs where they only focus on the most recurring events or those that they have traditionally responded to. As such, they must continue to analyse and understand EWEs more broadly and forecast and anticipate some of the EWEs before they happen. To achieve this, African governments must encourage scientific research on EWEs on the continent and collaborate with other continents already responding to some silent and less violent EWEs. They must also effectively use scientific reports with projections from international institutions such as the IPCC. Prevention of adverse effects of the EWEs *before they occur* is important and will save African lives. As demonstrated in this study, the understudied EWEs, such as heat, are already affecting and projected to affect African populations. Hence, widening the scope of EWEs that government focus on is greatly recommended.

- The governance of institutions (at various levels) for responding to EWEs in Africa must be strengthened. As demonstrated in the Agincourt case study, institutional weaknesses and lack of co-ordination capabilities hinder evolution and delivery of climate services and climate services for health. The Agincourt case study further demonstrated that institutions of governance must include the community or local levels that will decide and respond to the EWEs. Overall, capabilities of institutions to respond to EWEs at various levels, including heat-health responses, must be enhanced. Importantly, the study articulated the importance of policy co-ordination among government agencies. A mechanism that may bring commitment to the heat-health response includes locating the response mechanism in the office of the head of government, namely a Prime Minister or President, as happened with COVID-19 responses in Africa. Placing the response with the head of government may bring to fore the urgent nature of heat-health responses and ensure that the responses are sufficiently resourced. It is, therefore, recommended that the co-ordination of responses to EWEs such as heat should be a mandatory responsibility for the head of government.
- A review of policies related to EWEs must be carried out across African countries. Such a review provides evidence and learnings on which policies have been applied in response to which EWEs as well as the efficacy of the policies. The review of the policies is to facilitate the integration of One Health and health in all climate policies approaches. Furthermore, a review of current national adaptation plans against available scientific evidence is important. Following the policy review, and where necessary, new policies for responding to EWEs, including heat, must be drafted and promulgated.
- As demonstrated in this study, endogenous development of climate services is imperative for the continent. The current situation where African countries are following the research and application agenda set elsewhere must be rejected based on empirical evidence and conceptual frameworks that demonstrate Africa's uniqueness. Given this, it is recommended that African countries make serious commitments towards advancing Africa-relevant climate services that are inclusive, robust and sustainable.
- The evidence presented showed that some population groups, such as infants, the elderly, people living with disabilities, outdoor workers, persons with underlying medical conditions and persons on chronic medications, may be adversely affected by EWEs, including heat. Therefore, it is imperative for stakeholders to prioritise policies that promote inclusiveness in their responses to the effects of EWEs. Prioritising policies for

inclusiveness will guarantee that the marginalised population groups actively participate in policies and interventions that serve them.

- The study highlighted the importance of climate services, their focus and design. So far, efforts have focused on climate-sensitive sectors. Notably, health is amongst the sectors. Considering that there are several international negotiations that happen yearly on health that are independent of environmental and climate negotiations, it is recommended that African policymakers drive the agenda for integration of health and climate change issue-areas at international level for the benefit of the marginalised and vulnerable African populations. To be able to drive this, it is recommended that the heat-health agenda be articulated as an area of national and foreign policy.
- Although mentioned in passing, there is evidence that urban areas will experience more heat than rural areas. The increased heat in urban areas is caused by the heat island effect, high rates of urbanisation and population growth in urban areas. It is an established fact that African countries are urbanising at a rapid rate as people move from rural areas for various reasons. With the continent's growing youthful population, it can be forecasted accurately that most Africans will be living in urban areas in the coming three decades or so. Given this, it is recommended that urban planning policies consider EWEs, especially heat and how it will affect the urbanised African populations.
- There is need for African governments to consider who to better integrate climate services and other relevant service delivery by government (in addition to health services), such as water, school buildings, low-cost housing, access to electricity.
- The empirical evidence from Agincourt sub-district shows the importance of intersectoral interactions and coordination for effective and robust climate services for health. Given this, it is recommended that African government consider creating transformative policy mixes for cross-sectoral interactions and social acceptance of climate-health services.

8.6 Some Suggestions for Interventions

The suggestions for interventions for EWEs such as heat are not easy to discern. The key barrier to creating one-size-fits-all suggestions for interventions is the fact that some of the heat-health effects are limited to specific geographic areas. There are also some inherent variations in resource endowment among countries in Africa. Thus, suggestions for interventions may easily be dismissed if they are not grounded in the realities and experiences of certain populations residing in certain localities. It is a mammoth task to come up with regional interventions in respect of EWEs such as heat. The vulnerability of persons to heat exposure varies just as the capabilities to adapt and be resilient to these. However, there have been localised efforts to come up with some evidence and associated responses. Despite this, some suggested interventions deriving from the empirical evidence presented include the following:

- It is important to create education awareness campaigns on the effects of EWEs on human health, especially heat effects on human health. These campaigns must focus on the prevention of health effects of EWEs, treatment and care of persons already suffering the effects, as well as post-effect care. It is recommended that the campaigns target the most vulnerable members of the community, their caregivers and community leaders.
- Training must be emphasised as an intervention. Training must deal with what diseases and deaths can be attributed to heat and heat events as well as their classification. The training must focus on professionals and non-professionals. For instance, it may be imperative for medical practitioners to diagnose diseases and deaths associated with heat and record these accordingly or teachers to respond to children affected by heat in classes. Similarly, some community members would be able to give informed advice and respond effectively to the needs of persons affected by EWEs, such as heat, if trained.
- Attempts at integrating various data is recommended. As demonstrated in the Agincourt sub-district data, data for climate services are scientific, that is, based on meteorological observations and also critically indigenous knowledge-based, that is, based on the knowledge embodied in community members. To ignore the fact that indigenous forecasts are used by community members, albeit less accurate, is to take an unnecessary partisan, non-scientific, exclusionary approach. It is, therefore, essential that efforts are made to share integrated climate information from the scientific and non-scientific communities. Lessons learned from regional climate forums can be used to create forums for integrating the data. Integration of the data may enhance the usability of climate information.
- Programmes and interventions to deal with less studied EWEs have been taking place independent of each other and on a small scale. It is recommended that lessons from these emerging programmes and interventions be captured and shared. In this regard, one of the outcomes of this research, once examined, will be to return to Agincourt and share the results with various interested parties and to also publish a popular policy brief for wider dissemination. Nodes or networks based on these interventions should also be formed and supported so that the data and findings can be aggregated. Through the recommended networks programmes with subregional and regional coverage can be implemented.

- Investments into heat-health response programmes must be made. It is recommended that the investments target the local, national and regional levels. Transparency, accountability and openness must be prioritised. Active public participation is encouraged.
- For adaptation and resiliency, it is suggested that interventions must not be created to solve EWEs in an isolated manner but holistically to tackle a number of interrelated events concomitantly. This recommended approach varies from what takes place in Africa. For example, African countries have since time immemorial responded to the health effects of drought or floods without taking a holistic approach. A holistic approach to drought, for example, must create sustainable interventions that enhance food security and end malnutrition. Similarly, a holistic approach to heat must deal with the direct and indirect health effects associated with it.
- Support of community-led interventions must be prioritised. The Agincourt sub-district case study demonstrated that communities have responded to heat and other EWEs without much external support. This shows that there are ingrained community-based response systems that can handle some low-scale EWEs. It is recommended that such initiatives and solutions be supported and strengthened rather than be replaced. Similarly, effective traditional/alternative medical interventions must be assessed and, if effective, promoted.

8.7 Challenges Experienced During the Course of the Research

Several challenges were faced in conducting this study. First, the researcher was affected by COVID-19 during the writing phases of the thesis. COVID-19 caused untold anxiety to the researcher who worked in the health sector in South Africa. The researcher was actively involved in the country's COVID-19 response. The infections and involvement in the response delayed the writing and submission of articles for peer review in selected journals. Furthermore, journals shifted focus to articles on COVID-19, and some journals faced challenges finding reviewers who could timely give feedback on submitted articles. Despite this, the quality of the articles submitted was never compromised, and it is anticipated that all articles will be published.

Second, available literature did not establish a clear connection to the complex research problem posed by this study. Realising this, systematic reviews had to be done to try to build an evidence base as well as fathom some connections from the different literature strands. The systematic reviews proved demanding as a protocol had to be written and published before the research commenced. Despite this, going through the process was enlightening and enhanced some research skills.

Apart from systematic reviews, a conceptual framework had to be developed to tie together the various strands of information so that the subject under research could be examined. Creating a conceptual framework specific to the heterogeneous African continent is not an easy task. Through reviewing existing literature and consultations, the systems and inclusive climate services for health emerged and guided analysis of climate services for health in the study. It took time and effort to develop these frameworks.

Third, although the researcher initially wanted to use meteorological data from weather stations located close to Agincourt in some of the articles, extensive data gaps in the meteorological data proved to be an insurmountable challenge, which watered down the use of the data in this study. Even though this happened, the use of other forms of data did not compromise the final research outputs.

And finally, COVID-19 transformed the education system and stopped the traditional face-to-face contact sessions that the researcher regularly had with the supervisors. All sessions became virtual. While this was acceptable considering the threat posed by the COVID-19 pandemic, the reality is that the extra human touch that came with face-to-face contact was lost. Meeting in person with supervisors during the height of the pandemic was always professionally and personally rewarding. As the infection waves weakened, face-to-face meetings resumed. Virtual and face-to-face meetings all increased the mental stamina necessary to pull through complex research, such as this study. The patience and understanding, as well as support from all my supervisors, made me continue to carry out the research, even at times when it was a lonely environment.

8.8 Recommendations for Future Research

There are vast opportunities for further research on issues of EWEs, especially heat and human health, as well as climate services, including climate services for health. This study has only dealt with a few specific aspects pertaining to EWEs, especially heat and its effect on human health, as well as focused on climate services and heat-health services. Further research needs to be done on:

- This study is, most probably, among the first to bring together heat-health and climate services in a single document. The conceptual frameworks proposed in this research requires further refinement. Thus, the design of a strong conceptual framework for dealing with EWEs and human health as well as climate services in Africa should be viewed as still in its infancy. Further research that strengthens the conceptual frameworks is, therefore, essential.
- This study mainly draws conclusions from the Agincourt sub-district of South Africa. Agincourt is located in a rural part of the country and may be representative of some rural settings on the African continent. Urban areas may be disproportionately affected by heat due to the urban heat island effect. It is, therefore, recommended that further research be done in urban areas, and future research take a comparative approach where multiple-location case studies are used.
- As indicated in this study, there are many understudied EWEs and their effects on health in the context of Africa. This is despite the IPCC reports providing some empirical evidence and projections on EWEs. Given this, it is recommended that mapping of EWEs affecting or projected to affect Africa be done. Furthermore, future research must be done on understudied EWEs.
- There is growing interest in climate services as well as climate services for health, even on the African continent. However, there is limited understanding of the investments necessary to stimulate viable services. It is, therefore, recommended that future research on investments in climate services on the continent be undertaken.
- Related to the above, it was also observed that climate services and climate services for health are gaining currency in international negotiations. The posture of African policymakers in such negotiations is unknown but mostly uninformed by empirical evidence. Future studies on the diplomacy of climate services and climate services for health are encouraged.
- The issue of community responses to EWEs, especially heat, was briefly highlighted. For adaptation and resiliency, further research on community-based responses to EWEs such as heat must be done.

8.9 Final Conclusions

In this study, the effects of EWEs, particularly heat on human health as well the evolution and delivery of climate services, especially climate services for health in the context of Africa in general, and South Africa’s Agincourt sub-district, in particular, were examined. A transdisciplinary conceptual approach and multiple embedded case studies were used to examine the health effects of heat and heat-health responses.

The key themes covered in the various chapters of this thesis include vulnerability to heat exposure, prevention of health effects of heat, treatment of diseases associated with heat and heat-related morbidity and mortality, heat-health indictors, and climate services and climate services for health. Several of these findings are now published in academic journals.

On the one hand, the systematic review demonstrated the Africa-specific studies on heat-health as well as the suggestion for interventions and policies in existing literature. The conclusion drawn from this systematic review is that, albeit there is a lack of tangible Africa-relevant suggested policies and interventions in existing literature, African populations are being and will be adversely affected by heat as well as other EWEs. On the other hand, the Agincourt heat-health case study demonstrated that African populations are aware of the changing heat as they are already experiencing it. One conclusion from the Agincourt heat-health case study is that heat effects on health adversely affect vulnerable population groups in Africa, including infants, the elderly, people living with disabilities, among others.

Effective climate services in African countries, however, must **re-imagine an inclusive, robust and sustainable service using an Africa-relevant conceptual framework**. The Agincourt climate services case study demonstrated that climate services are underdeveloped. In addition, climate services for health and heat-health services are non-existent in the area. One conclusion to draw from these findings is that it is imperative to invest in developing climate services, especially climate services for health, which are imperative to respond to the effects of heat on human health.

There are three key recommendations from this study worth re-iterating. First, African policymakers must holistically understand EWEs and their effects on human health. Second, a mixed and integrated, systemic policy approach that promotes climate services and climate services for health must urgently be drafted and promulgated. And finally, further research that generates empirical evidence for policymakers, practitioners and researchers must be encouraged. Since it is unequivocal that climate change affects human health through increased morbidity and mortality, effective climate services for health are central to robust climate change adaptation and resilience.

8.10 References

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9 APPENDIXES

9.1 Appendix 2.1: Description of Articles Included in the Systematic Review

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
Azongo et al., (2012)	Ghana	Kasene-Nankana District, 1995-2010	Assess association of daily temperature and precipitation with daily mortality by age and sex	31,144 deaths	Ambient temperature	All-cause mortality	Time series	Included both seasonality and lag effects	A statistically significant association of mean daily temperature with mortality at lag days 0-1 was observed below and above the 25th (27.488°C) and 75th (30.688°C) percentiles (0.19%; 95% confidence interval CI: 0.05%, 0.21%) and (1.14%; 95% CI: 0.12%, 1.54%), respectively for all populations. In addition, a statistically significant association of mean daily temperature above 75th percentile at lag days 2-6 and lag days 7-13 (0.32%; 95% CI: 0.16%, 0.25%) and (0.31% 95% CI: 0.14%, 0.26%), respectively was observed.	The elderly and young children were more susceptible to short-term temperature-related mortality.
Kynast-Wolf (2010)	Burkina Faso	Kossi Province, 1999-2003	Evaluate seasonal patterns of cardiovascular disease mortality of adults	11,174 adults aged 40 and above	Ambient temperature	Cardiovascular disease mortality	Modelling	Seasonality, no lag effects	Cardiovascular deaths were higher during the hot dry season (March to May). Cardiovascular mortality was stronger among people older than 65 years (P = 0.05) and it peaked at the beginning of May.	Mean monthly temperature was significantly associated with mortality amongst the elderly (65 years plus)
Wichmann (2017)	South Africa	Cape Town, Durban and Johannesbu	Investigate the association between daily apparent	Over 460,000 deaths across the 3 cities	Ambient temperature	All-cause mortality	Case-crossover	Lag effects, no seasonality reported	The strongest association between all-cause mortality and apparent temperature (TAPP) for all ages combined was found in Cape Town-- 3.3% increase in mortality	A stronger association was observed in the ≥65-year group in Cape Town, namely

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
		rg, 2006-2010	temperature and daily all-cause mortality						per IQR increase in Tapp (lag0-1) (3 °C) above the city-specific threshold (18.6 °C). An increase in Tapp (lag0-1) above the city-specific thresholds was insignificantly associated with 2.6% and 2.8% increase in all-cause non-accidental mortality in Durban and Johannesburg. The meta-analysis indicated an overall significant increase of 0.9% in all-cause mortality per 1 °C increase in Tapp (lag0-1) for all age groups combined in the three cities. This translates to 2.7% (95% CI: 1.2–4.2) per IQR increase in Tapp (lag0–1) (3 °C). In the meta-analysis for the ≥65-year group, a significant increase of 2.1% in mortality was observed, which translates to 6.5% (95% CI: 0.5–12.8) per IQR increase in Tapp (lag0-1) (3 °C).	6.5% increase in mortality. Women in the ≥65-year group in Cape Town were significantly more vulnerable compared to men in this age group. No vulnerable groups were identified in Durban. A stronger association was observed in the ≥65-year group in Johannesburg, namely 10.1% increase in mortality per IQR increase in Tapp (lag0-1) (2 °C) above the city-specific threshold (18.7 °C). Women in the ≥65-year group in Johannesburg appeared to be more vulnerable compared to men in this age group.
Mrema et al., (2012)	Tanzania	Rufiji District, 1999-2010	Assess association between monthly weather on all-cause mortality by age and determine differential susceptibility by age groups	10,1116 deaths	Ambient temperature	All-cause mortality	Time-series	Included both lag effects and seasonality	There is a linear temperature-mortality relationship across lags. Negative temperature-mortality association was observed below the threshold temperature of 26^{o}C and 27^{o} C across all ages. Monthly average temperature was associated with all-cause mortality in all	Younger age groups and the elderly population are more susceptible to the Influence of monthly weather.

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									age groups. A decrease in temperature to 24 °C from the threshold is associated with an increased in mortality by 80.7%, 65.7% and 74% in age groups 0-4, 5-59, and over 60, respectively. The effects of monthly mean temperature on all-cause mortality are significant at lag 2 in age group 5-59. There are no strong lag effects on the association between mean temperature and mortality in age group 60 years and above	
Thompson et al., (2012)	South Africa	Musina, Makhado, Polokwane, Tzaneen Bela Bela municipaliti es, 1999-2010	Examine the impact of climate change on children's health in five municipalities in Limpopo Province	Children aged 0 to 13 years, 7,869 cases	Ambient temperature	Morbidity and Mortality	Correlational	Unreported	No temperature data available for Makhado Municipality. The R coefficient of variations for each of the cities are 0.50, 0.56, 0.48, and 0.02 respectively for Bela-Bela, Tzaneen, Mussina and Polokwane. The corresponding R coefficients for minimum temperature are 0.004, −0.383, −0.004 and 0.135. Therefore, while maximum temperature tends to increase during the 21 years period, minimum temperature shows a decrease over the same period, thereby indicating tendency towards local warming which is a possible consequence of climate change in the province. The most prevalent diseases in the study area are diarrhoea (42.4%), respiratory infection (31.3%), asthma	More than half of the children who suffered from climate change related disease were males (54.7%). Also, male children had higher proportion, notably 52.8%, 54.6%, 55.9%, 54.9% and 62%, respectively, for diarrhoea, respiratory infection and malaria. The observed sex variation in incidence of disease is statistically significant, with a p-value of 0.00. This implies that male children are more

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									(6.6%), malaria (6.5%) and meningitis (4.5%). There is also a significant presence of measles (2.4%).	susceptible to climate change related diseases than their female counterparts. Young children between ages of 1 and 2 are also more susceptible to indoor related diseases.
Diboulo et al., (2012)	Burkina Faso	Nouna, 1999-2009	Study the association between weather patterns and daily mortality in Nouna Health and Demographic Surveillance System (HDSS) area	7,402 deaths	Ambient temperature	All-cause mortality	Time-series	Seasonality, no lag effects reported	An approximate linear significant increase with increasing temperature in lag 0-1, and a slightly decreasing mortality (but not significantly) in lag 2-6, and lag 7-13 was estimated for all age mortality. The increase in mortality in lag 0-1 corresponds to an approximate 50% increase in mortality over the range of temperature. The analysis using smooth curves show approximate linear relationships overall. As linear estimates the group of all-ages appear to experience significant elevated risks to temperature increases in lag 0-1 only. This association is particularly apparent in the age group of 0-4.	The short-term direct heat effects lag 0-1 was particularly strong among the younger population, but also apparent in all ages. Childhood mortality seems to be most affected by high temperature and children suffer the most from extreme heat conditions resulting from climate change.
Egondi et al., (2012)	Kenya	Korogocho and Viwandani,	Describe the relationship between and mortality and evaluate the	60,146 individuals; 2,512 deaths	Ambient temperature	All-cause mortality	Time-series	Included both seasonality and lag effects	A non-linear temperature-mortality relationship was found. Threshold temperature for all-age mortality lies between 18^{o}C and 20^{o}C. The pattern of	A significant positive relationship for high temperatures is observed in

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
		Nairobi, 2003-2008	relationship by cause of death, age and sex						temperature and mortality association exhibited J-shape for all-ages mortality and U-shape for under-five mortality. At Lag 0-1, a 1 °C increase in temperature above the 75th percentile (threshold = 20 °C) was significantly associated with U5 and non-communicable disease mortality (% change = 1 [95% CI: 0, 2] and 1 [95% CI: 0, 3] respectively). At lag 0-1, a 1 °C decrease in temperature below the 25th percentile (threshold = 17.9 °C) was associated with 3%, 9% and 13% increase in all-cause, 50+ years and acute infections deaths respectively, albeit statistically insignificant.	deaths in the 0-4 age group and among people with NCD.
Scovronick et al., (2018)	South Africa	Nationwide -52 districts 1997-2013	To analyse the association of temperature and mortality using a national dataset.	8,814,625recoded deaths; 8,509,130 records from 52 districts included	Ambient temperature	All-cause mortality	Time-series	Included both seasonality and lag effects	The study found an association between daily maximum temperature and mortality. The relative risk for all age all-cause mortality on very cold and hot days (1st and 99th percentile of the temperature distribution) was 1.14 (1.10,1.17) and 1.06 (1.03,1.09), respectively, when compared to the minimum mortality temperature. This "U" shaped relationship was evident for every age and all-cause group investigated, except among 25–44-year olds. The strongest associations were in	There was evidence of elevated risks from cardiovascular and respiratory diseases and in the oldest and youngest age groups. There was definitive evidence for heat effect on mortality among infants <5 years.

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									the youngest (< 5) and oldest (> 64) age groups and for cardiorespiratory causes. Heat effects occurred immediately after exposure but diminished quickly.	
Alexander et al (2013)	Botswana	Nationwide , 1974 to 2003	Evaluate monthly reports of diarrheal disease among patients presenting at public health facilities and compared this to climatic variables	Diarrheal patients at public facilities, number of cases unreported	Ambient temperature	Diarrheal incidence	Time series	Included both seasonality and lag effects	Minimum temperature has a bidirectional influence on diarrheal case incidence by season. Elevated minimum temperature was positively associated with increased diarrhoea incidence in the dry season (proportion deviation from yearly seasonal mean [Pmy] = 0.074) but negatively associated with diarrhoea in the wet season (Pmy = −0.0071). Increases in maximum temperature are not related to increased diarrhoea prevalence.	
Heunis et al., (1995)	South Africa	Cape Town, 1978-1985	Examine the possible effect of short-term temperature changes during winter on cardiovascular disease mortality	Elderly whites and coloureds of 60 years and above	Heat events (extreme cold and hot temperature)	Cardiovascular disease mortality	Cross-sectional	Lag effects, no seasonality reported	There is an association between cold and cardiovascular mortality. Average deaths per day following extreme heat were 8.27 (2.66), 8.97 (2.54), 10.3 (3.13), 8.7 (2.72) and 8.67 (3.10) for lag days 0, 1, 2, 3 and 4, respectively. 2-day lag between occurrence of extremely hot temperatures and CVD mortality was statistically significant (p b 0.1 and 0.005 respectively). The highest mean daily CVD mortality was recorded on days with the largest July temperature range.	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
Kovats et al., (2005)	South Africa	Cape Town, 1996-1999	Investigate and quantify the effect of daily temperature variability on mortality in order to identify the most vulnerable groups	About 76,000 deaths	Ambient temperature	All-cause and cause-specific, namely cardiovascular, infectious, external and other mortality	Time series	Unreported	Low temperature influenced all-cause mortality. The greatest effects of low temperature were seen for infectious and cardiovascular diseases which increased by 4.42% (95% CI: 3.13, 5.73) and 2.53% (95% CI: 1.25, 3.83) respectively per 1 °C decrease	At a threshold of 15 °C, a 1 °C decrease in temperature resulted in a 3.14% (95% CI: 1.86, 4.43) and 1.77% (95% CI: 0.5, 3.3) increase in deaths among the elderly and children respectively. A small heat effect was apparent in the elderly at daily mean temperatures above 18°C.
Tchidjou et al., (2010)	Cameroon	Yaunde, 2007-2007	Investigate the association between climatic factors and Acute Respiratory infections (ARI) in children using data from Chantal Biya Foundation paediatric hospital	1,306 children of 18 years and below	Ambient temperature	Acute Respiratory infections	Time series	Seasonality, no lag effects reported	Significant associations were seen for maximum (1.94: 1.34, 2.81) and minimum temperatures (0.72: 0.59, 0.87). When malaria cases were excluded the results were Tmax IRR = 1.43 (95% CI: 1.12, 1.84), Tmin IRR = 0.84 (95% CI: 0.74, 0.95)	Weather associated ARI affects children under 18 years of age.
Reyburn et al., (2011)	Tanzania	Unguja, Zanzibar, 2002-2008	Examine the association between climate variability and cholera outbreaks and develop a climate-based forecasting model for cholera in Zanzibar	3,245 cholera cases	Ambient temperature	Cholera outbreaks	Time series	Included both seasonality and lag effects	The results of the cross correlations using seasonal differencing of the data showed that cholera outbreaks were significantly positively associated ($P < 0.05$) with minimum temperature at lags of 2 and 4 months negatively associated with maximum temperature at a lag of 2 months. An increase of 1°C in minimum	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									temperature at a 4-month lag resulted in a 2-fold increase of cholera cases.	
Fernández et al., (2009)	Zambia	Lusaka, 2003-2006	Describe the evolution of cholera epidemics in Lusaka between 2003-2006 and explain the association with daily maximum temperature and rainfall	13,069 quarantined cholera patients	Ambient temperature	Cholera Outbreaks	Time series	Included both seasonality and lag effects	The results showed a statistically significant association between the increase in the number of cases and the increase in temperature 6 weeks earlier. A 1 °C rise in temperature 6 weeks before the onset of the outbreak explained 5.2% [relative risk (RR) 1.05, 95% CI 1.04—1.06] of the increase in the number of cholera cases (2003—2006). The attributable risks for temperature were 4.9%.	
Ng et al., (2014)	Multi-country	Guinea, Gabon, South Sudan, Uganda, DRC, 1976-2014	Investigate association between Ebola virus disease outbreak and climatic conditions in Africa	28 reported Ebola virus outbreaks	Ambient temperature	Ebola Virus Disease outbreaks	Time series with DLNM-Modelling	Lag effects, no seasonality reported	Lower temperatures were found to log-linearly associate with increased risk of human EVD outbreak onset during each month in the lag periods. Cumulative ORs of EVD outbreaks associated with deviations (−1, −2 and −3 °C) from the mean monthly temperature were all statistically significant with a consistent dose-response relation across the entire lag period ranging from 1.20 to 1.71, 1.43 to 2.93, and 1.71 to 5.00 for the same, first and second month, respectively.	
Bunker et al., 2017	Ghana	Nouna, Kossi Province 2000-2010	Investigate the association of heat exposure on years of life	18 367 NCD-YLL corresponding to 790 NCD	Ambient temperature	Non-communicable diseases-years of life lost	Time series	Included both seasonality and lag effects	Moderate 4-day cumulative rise in maximum temperature from 36.4°C (50th percentile) to 41.4°C (90th percentile)	The effects of heat on NCD-YLL were greater in men in comparison to women. At lag 0, daily excess mean NCD-YLL

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
			lost from non-communicable diseases	deaths					resulted in 4.44 (95% CI 0.24 to 12.28) excess daily NCDYLL for all ages, rising to 7.39 (95% CI 0.32 to 24.62) at extreme temperature (42.8°C; 99th percentile). The strongest health effects manifested on the day of heat exposure (lag 0), where 0.81 (95% CI 0.13 to 1.59) excess mean NCD-YLL occurred daily at 41.7°C compared with 36.4°C, diminishing in statistical significance after 4 days.	were higher for men, 0.58 (95% CI 0.11 to 1.15) compared with women, 0.15 (95% CI −0.25 to 9.63) at 41.7°C vs 36.4°C.
Egondi et al., (2015)	Kenya	Korogocho and Viwandani, Nairobi, 2003-2012	Analysed the effect of temperature on years of life lost due to all-cause mortality	66,000 individuals, 4, 671 deaths	Heat Events (Heat waves and cold spells)	Years of life lost, all-cause mortality	DLNM-Modelling	Lag effects, no seasonality reported	There were no heat effects on all-cause YLL in Nairobi, Kenya. The exposure-response curve between temperature and YLL was J-shaped, with the minimum mortality temperature (MMT) of 26 °C. An average temperature of 21 °C compared to the MMT was associated with an increase of 27.4 YLL per day (95% CI, 2.7–52.0 years). However, there was no additional effect for extended periods of cold spells, nor did we find significant associations between YLL to heat or heat waves.	
Musengimana et al., 2016	South Africa	Cape Town Metropolitan area November 2012 to	To explore the possible association between temperature variability and	58, 617 diarrhoea cases in children under five	Ambient Temperature	Diarrhoea incidence	Time series with mathematical modelling	Included both seasonality and lag effects	The mixed effect over dispersed Poisson model showed that a cluster adjusted effect of an increase of 5 ℃ in minimum and maximum temperature results in a 40% (Incidence risk ratio IRR: 1.39, 95% CI	Children under five years are affected by diarrhoea

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
		May 2013 and November 2013 to May 2014	the high incidence of acute diarrhoea in Cape Town						1.31–1.48) and 32% (IRR: 1.32, 95% CI: 1.22–1.41) increase in incident cases of diarrhoea, respectively, for the two periods studied. Autocorrelation of one-week lag (Autocorrelation AC 1) indicated that a 5 ℃ increase in minimum and maximum temperature led to 15% (IRR: 1.46, 95% CI: 1.09–1.20) and 6% (IRR: 1.06, 95% CI: 1.01–1.12) increase in diarrhoea cases, respectively.	
Horn et al., 2018	Mozambique	National 1997-2014	To investigate the associations between temperature and diarrhoeal disease	7,315,738 total diarrhoea cases from 141 districts over 18 years	Ambient temperature	Diarrhoea incidence	Time-series	Included both seasonality and lag effects	The national estimate was that a 3.64% (95% CI: 3.35, 3.93) increase in diarrheal disease for each 1 °C increase in the hottest day of the concurrent week. Regionally, each 1℃ increase in maximum temperature was associated with a 1.45% (95% CI: 0.77, 2.13), 1.87% (95% CI: 1.44, 2.30), 5.74% (95% CI: 5.18–6.29), and 2.15% (95% CI: 1.51, 2.80) increase in diarrheal disease in the northern, central, coastal, and southern regions, respectively	
Thiam et al., 2017	Senegal	Mbour Health District January 2011 to December 2014	To statistically assess the relationship between diarrhoea incidence and daily land surface temperature (LSTDay) and night land surface	23,385 diarrhoea child visits in 24 health facilities over 4 years	Ambient Temperature	Diarrhoea incidence	Time-series	Included both seasonality and lag effects	The unadjusted analysis revealed significant positive associations between diarrhoeal cases and LSTDay, average LST, LST variability. A very high LST Day ≥ 36 ℃, average LST ≥ 28 ℃ and high LST variability ≥12 ℃ were significantly associated with higher number of monthly	Children under five years are affected by diarrhoea

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
			temperature (LSTNight), average temperature (LST), temperature variability (defined as the difference between temperature LSTDay and LSTNight),						diarrhoeal cases (+25–95%). The unadjusted analysis revealed that moderate LST Night at lag 0 showed a significant positive association with diarrhoeal incidence. The results from the lagged models showed a significant negative association between diarrhoeal incidence and high average LST ≥ 26 ℃ (IRR: 0.70, 95% CI: 0.58–0.86) and LST Night ≥ 18 ℃ at one-month lag. In the multivariable analysis, association of diarrhoeal incidence with higher levels of LSTDay, LST Night and average LST of the same month (Table 6 and Table S2, respectively) were positive, while we did not find any evidence of an association. High LSTDay ≥32 ℃ and high LST ≥ 26 ℃ showed a significant negative association with diarrhoeal incidence of the following month (IRR: 0.78, 95% CI: 0.66–0.91; IRR: 0.76, 95% CI: 0.66–0.87, respectively). The corresponding results for LST Night were even stronger. Compared to the lowest level, all other levels of LST Night were associated with significantly lower diarrhoeal incidence in the following month.	

9.2 Appendix 2.2: Description of Articles Included in the Secondary Analysis

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
Asamoah et al., (2018)	Ghana	Ghana 2004-2007	To use an existing maternal health database to test the hypothesis that maternal heat exposure during pregnancy in hot regions is associated with increased prevalence of spontaneous abortions or stillbirths, and to develop an analytical strategy to use existing data from maternal health surveys and existing data on historical heat levels at a global grid cell level.	1136 women with pregnancy experiences between 2004 and 2007, out of which 141 cases had a pregnancy that terminated in miscarriage or stillbirth.	Wet-bulb globe temperature (WBGT).	Miscarriage and stillbirths	Cross-sectional	Not applicable	Using the yearly WBGT averages, the crude odds ratio indicated a 15% increase (OR 1.15, 95% CI 0.92–1.42) in the odds of having an adverse pregnancy outcome (stillbirth or miscarriage) with each additional degree increase in atmospheric heat exposure level, although this was not statistically significant.	Women resident in rural areas have reduced likelihood of adverse pregnancy outcomes related to miscarriage or still birth
Amegah et al., 2016	Sub-Saharan Africa	Relevant literature on PubMed, Scopus and Ovid Medline till December 2014	To systematically review all studies investigating temperature variability and non-vector borne morbidity and mortality in SSA to establish the state and quality of available evidence, identify gaps in knowledge, and propose future research priorities.	Not applicable	Ambient temperature	Morbidity and mortality	Systematic Review	Not applicable	Moderate evidence exists to associate temperature variability with cholera outbreaks, cardiovascular disease hospitalization and deaths, and all-cause deaths in the region.	The quality of evidence on child undernutrition is low, and for diarrhoea occurrence, meningitis, Ebola, asthma and respiratory diseases, and skin diseases, very low.

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
Paz (2009	Multi-country	Uganda, Kenya, Rwanda, Burundi, Tanzania, Malawi, Zambia, and Mozambique, 1971-2006	Analyse the possible association between the cholera rates in south-eastern Africa and the annual variability of air temperature and sea surface temperature (SST)	8 country cholera cases (actual number unreported)	Ambient (air) temperature	Cholera cases	Time series	Lag effects, no seasonality reported	Associations have been found between the annual increase of the air temperature and cholera incidence increase. Linkages have been detected having exp(b1) = 1.87 (P = 0.18) for the current year and exp(b1) = 2.78 (P = 0.03)—the impact of the previous year. This means that when, in a specific year, the annual mean air temperature increases by 0.1°C, the expected annual number of cholera cases will be multiplied by 1.87 for that year and by 2.78 for the previous year.	
Dukić et al., (2012)	Ghana	Navrongo, 1998-2008	Assess the association between number of reported meningitis cases and relative humidity, rain sunshine, wind, maximum and minimum temperature adjusted for air quality	Unreported	Ambient temperature	Laboratory confirmed meningitis cases	Modelling	Included both seasonality and lag effects	For every °C increase in monthly average maximum temperature, the log of the mean number of meningitis cases increases by 0.181—or equivalently, the mean number of cases increases approximately by	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									20 %. Consequently, a 10 °C increase in the monthly average maximum temperature is associated with the 6-fold increase in the mean monthly number of meningitis cases.	
Trærup et al., 2011	Tanzania	Nationwide, 1998-2004	To estimate the relationship between climate variables and cholera in Tanzania and use the results for projections of future burden cholera attributable to climate change by 2030	Unreported	Ambient temperature	Cholera cases	Time-series	Lag effects, no seasonality reported	Cholera cases are positively correlated with minimum temperature, maximum temperature and their one-month lags. For a 1-°C temperature increase the initial relative risk of cholera increases by 15 to 29 %.	
Oloukoi et el., 2014	Nigeria	Oke-Ogun, 2008-2009	To investigate the perceived and observed trends of associated health risks with seasonal climate variability and identify types of and preference for adaptation available at household and community levels.	397 households	Ambient temperature	Skin diseases, malaria and fever	Correlational study encompassing a household survey	Seasonality, no lag effect reported	From the survey and the FGDs analysis, severe heat during the dry season was linked to prevalence of skin diseases, malaria and fever	
McMichael et al., 2008	South Africa	Cape Town, 1996-1999	To characterise systematically the patterns of temperature related	Unreported	Ambient temperature	All-cause mortality	Time series	Included both seasonality and lag effects	Temperature threshold for heat related mortality was 17 °C (95% CI: 15, 22).	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
			mortality in populations from 12 cities in low-and middle-income countries in order to describe current vulnerability to heat and cold effects.						Percentage increase in mortality for each 1 °C increase in temperature above the temperature threshold was 0.47 (95% CI: −0.31 to 1.24).	
Chang et al., 2004	Multi-country	Kenya, Zambia and Zimbabwe 1989-1995	To examine the relationship between variation in three climatic variables and risk of hospitalization for venous thromboembolism (VTE), arterial stroke, and acute myocardial infarction (AMI)	Women aged 15–49 years experiencing cardiovascular events 153, 199 and 4 cases of VTE, AS and AMI	Ambient temperature	Venous Thrombo-embolism (VTE), arterial stroke (AS) and acute myocardial infarction (AMI) cases	Time series	Included both seasonality and lag effects	IRRs for 5 °C change in mean temp. Kenya: VTE, 0.43 (95% CI: 0.14, 1.27); stroke, 0.65 (95% CI: 0.11, 3.89) Zambia: VTE, 1.16 (95% CI: 0.21, 6.47); stroke, 0.89 (95% CI: 0.45, 1.75) Zimbabwe: VTE, 0.70 (95% CI: 0.49, 1.01); stroke, 0.91 (95% CI: 0.62, 1.34). Estimates: VTE, 0.69 (95% CI: 0.49, 0.96); stroke, 0.89 (95% CI: 0.64, 1.24); AMI, 0.96 (95% CI: 0.04, 21.2)	
Jankowska et al., 2012	Mali	Nationwide, 1960-2009	To examine potential relationships between climate change and malnutrition and climate change in Mali and speculate where future climate change could impact malnutrition.	407 DHS clusters with 14,238 children	Ambient temperature	Child under nutrition, stunting, anaemia and underweight	Cluster Analysis-modelling	Seasonality, no lag effect reported	Temperature increases of >1.0 °C for the Sudan-Niger-Mali arc during the period and is equal to or greater than the inter-annual standard deviation of 0.65 °C. Combined temperature and	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									precipitation (PPET) index b−100 zone was associated with stunting (β = −0.165, p b 0.001), underweight (β = −0.159, p b 0.001) and anaemia (β = −0.149, p b 0.01) for all clusters.	
Grace et al., 2012	Nationwide	Kenya 2008 DHS data	To determine if climate variables are related to rates of childhood stunting in Kenya	320 clusters consisting of 2255 children aged 1–5 years	Ambient temperature	Child stunting-	Cluster analysis	Seasonality, no lag effect reported	Temperature has no impact on child stunting variation (β = −0.0385, p N 0.1 for average temperature, and β = 0.0878, p N 0.1 for temperature variability)	
Bandyopadhyay et al. 2012	Multi-country	Benin, Cameroon, Ghana, Kenya, Madagascar, Malawi, Mali, Rwanda, Niger, Tanzania, Togo, Uganda, Zambia and Zimbabwe	To explore how rainfall and temperature variation, in their seasonal context, affect the prevalence of diarrhoea in particular sub-national regions in Africa	Children under the age of 3 years, Number unreported	Ambient Temperature	Diarrhoea	Time series	Included both seasonality and lag effects	Temperature was statistically associated with diarrhoea prevalence. A 1°C Celsius increase in average max temp leads to 1% increase in diarrhoea prevalence (β = 1.039, p b 0.01), while a 1°C increase in average mean monthly temp reduces diarrhoea prevalence by 0.7%. (β = −0.460, p b 0.05).	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
		Varied-1991-2000								
Ahmadalipour and Moradkhani 2018	Multi-country	North African countries in the MENA region	To investigates the impacts of global warming on the mortality risk of people over 65years of age caused by extreme high temperatures.	Elderly above the age of 65 years	Ambient temperature	Mortality	Modelling	Unreported	The highest mortality risk is found in the areas of western Africa below the Sahara. Even if the future global temperature increase is limited to 2°C (RCP4.5), heat related mortality risk in western Africa will be about 10 times higher than that of the historical period. However, following a business-as-usual scenario (RCP8.5), the mortality risk ratio for the same region will be about 30 times higher than the historical risk.	
Wells and Cole (2002)	Multi-country	Included 40 African countries	To consider the hypothesis that environmental heat load and birth weight are associated using data from a wide range of populations	Populations in report selected if >200 individuals and temperature data provided	Ambient Temperature	Birth weight	Time series		Annual heat index (0-4), drawn from monthly discomfort ratings using temperature and humidity data. Simple linear regression weight (gm) and heat index r=-0.59 (P<0.001). Analysis with	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
									108 populations with full data: 1 unit rise in heat index birth weight decreases 2.7% (P=0.002). Linear relationship	
Green et al., 2019	Multi-country	Included 10 Countries in Sub Saharan Africa and 8 in MENA region	To gather the existing evidence within the literature related to the impact of temperature on human health, specifically in low- and middle-income countries	Not applicable	Heat waves and ambient temperature	Morbidity and mortality	Systematic Review	Not applicable	Most studies found a positive association between heat and morbidity/mortality, and only nine (6.2%) either found no association or a negative association between the heat exposure and the health outcome of interest.	It was also generally found that the elderly, women, and those with low socioeconomic status were more vulnerable to heat effects.
Burkat et al., 2014	Multi-country	Burkina Faso, Senegal, Tanzania, Kenya, Gambia, Ghana, Nigeria	To identify relevant research studies on seasonal and meteorological effects in the tropics, extracting and synthesizing respective information thus elucidating cause and effect chains.	Not applicable	Ambient temperature	Mortality	Systematic Review	Not applicable	Studies conducted in sub-Saharan Africa demonstrated a dominance of heat effects. Heat-related mortality was observed in Burkina Faso, Ghana and Kenya while cold-related mortality was not significant.	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
MacVicar et al., (2017)	Uganda	Bwindi Community Hospital, Kanungu District 2012-2015	To examine associations between meteorological factors and birth weight, identify the highest-risk period for exposures during pregnancy and compare effects of exposures on birth weight in Indigenous and non-Indigenous mothers.	3 619women and 3197 hospital birth records	Ambient temperature	Birth weight	Population registry	Seasonality, no lag effects reported	A 1°C increase in mean temperature, BW increased 41.8g in 3rd trimester (95%CI=0.64, 82.92). Other trimesters NS, low point estimates. Entire pregnancy changes a 1°C temperature=26.03 (-95%CI=35.33, 87.40). Driest season (June-Aug), 1°C increase in mean temperature in 3rd trimester =123.06g rise (95%CI=18.95, 227.18; P<0.05). Rainy season (Sept.-Nov) 98.37gm rise per 1°C (95% CI =23.04, 173.7; P<0.05). Other seasons NS.	Higher effects of heat in vulnerable indigenous population. No interaction between sex and temperature
Gace (2015)	Multi-country	Burkina Faso, Central African Republic, Ethiopia, Guinea, Kenya, Lesotho, Liberia,	To examine relationships between birth weight, precipitation, and temperature in African countries			Birth Weight	Time-Series		Change in weight (gm) per day >100°F. 3 months pre-conception -0.45 (P<0.1), 1st trimester -0.71 (P<0.01), 2nd trimester -0.85 (P<0.001), 3rd trimester -0.24 (NS). Larger estimates with temperature threshold	

Reference	Country of Research	Location and Period	Study Aim/ Objective	Study population and sample	Temperature Variable	Outcome Measure	Methodology	Seasonality and Lag Effects	Study Outcomes	Subgroup analysis
		Madagascar, Malawi, Mali, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Uganda, Zambia, Zimbabwe (19 countries)							>105°F. LBW rise with temperature. Regression coefficient for LBW with n days >100°F 3 months preconception -0.17 (NS), 1st trimester -0.20 (P<0.1), 2nd trimester -0.33 (P<0.01), 3rd trimester -0.17 (NS). Also, significant findings with days above 105°F	

9.3 Appendix 2.3 Association Between High Temperatures in Pregnancy And Risk of Preterm Birth, Low Birth Weight and Stillbirths: A Systematic Review and Meta-Analysis

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A2.3.1 CHAPTER OVERVIEW

This co-authored systematic review appendix chapter elaborates on the effects of heat on morbidity and mortality encompassing some African countries. The chapter presents further evidence of the effects of heat on human health, including on the African country. It espouses similar themes as Chapter 2. Its importance is in advancing the argument that African populations are not spared from the effects of heat. As such some interventions and policies to respond to heat effects must be urgently created.

A. 2.3.2 CHAPTER ABSTRACT

Objective To assess whether exposure to high temperatures in pregnancy is associated with increased risk for preterm birth, low birth weight, and stillbirth.

Design Systematic review and random effects meta-analysis.

Data sources Medline and Web of Science searched up to September 2018, updated in August 2019.

Eligibility criteria for selecting studies Clinical studies on associations between high environmental temperatures, and preterm birth, birth weight, and stillbirths.

Results 14 880 records and 175 full text articles were screened using Joanna Briggs Institute appraisal tools. 70 studies were included, set in 27 countries, seven of which were countries with low or middle income. In 40 of 47 studies, preterm births were more common at higher than lower temperatures. Exposures were classified as heatwaves, 1°C increments, and temperature threshold cut-off points. In random effects meta-analysis, odds of a preterm birth rose 1.05-fold (95% confidence interval 1.03 to 1.07) per 1°C increase in temperature and 1.16-fold (1.10 to 1.23) during heatwaves. Higher temperature was associated with reduced birth weight in 18 of 28 studies, with considerable statistical heterogeneity. Eight studies on stillbirths all showed associations between temperature and stillbirth, with stillbirths increasing 1.05-fold (1.01 to 1.08) per 1°C rise in temperature. Associations between temperature and outcomes were largest among women in lower socioeconomic groups and at age extremes. The multiple temperature metrics and lag analyses limited comparison between studies and settings.

Conclusions Although summary effect sizes are relatively small, heat exposures are common and the outcomes are important determinants of population health. Linkages between socioeconomic status and study outcomes suggest that risks might be largest in low and middle

income countries. Temperature rises with global warming could have major implications for child health.

Systematic review registration PROSPERO CRD 42019140136 and CRD 42018118113.

A.2.3.3 CHAPTER INTRODUCTION

The frequency and intensity of heatwaves and other extreme weather events is increasing rapidly owing to climate change and is set to escalate in the coming decades.[1] Heatwaves and rising mean temperatures both present major health threats, especially for populations with limited physiological ability or socioeconomic means to respond or adapt to high temperatures.[2]

Pregnant women have only recently been included among the groups most vulnerable to heat stress,[3 4] and it will take time for that recognition to translate into action. Studies in 2011 and 2015, for example, showed that the large majority of heatwave response plans in European Union countries had not identified pregnant women as a high risk group.[5 6] The public also appears largely unaware of the risks of heat exposure during pregnancy.[7]

Several factors could account for the relative neglect of maternal and newborn health in research and policies on the impacts of, and adaptation to, climate change. Perhaps most notably, the cause and measurement of adverse outcomes in maternal and newborn health make it difficult to attribute a single cause, such as heat exposure. This complexity is heightened by the lag times between heat exposure in pregnancy and adverse outcomes, which can be several months with congenital anomalies, for example, as these anomalies might become apparent only at birth. Additionally, lag times can even be decades, with outcomes that manifest in adulthood.[8-10] Much of the research on climate change and health in low and middle income countries has centred on infectious diseases such as malaria, and in high income countries, the focus has been on heat related mortality among groups such as elderly people or those with chronic conditions.

Pregnancy raises the vulnerability of women to environmental hazards, including exogenous heat. The physiological and anatomical changes that occur during pregnancy pose particular challenges to thermoregulation.[11] Internal heat production rises with fetal and placental metabolism, and with increased body mass and the resulting physical strain.[12] Equally, pregnancy could bring social vulnerabilities to the fore, especially in low and middle income countries, where women often continue to perform household chores during pregnancy (eg, fetching wood and water, and subsistence farming). Exposure to high temperatures in agricultural and other outdoor work, could occur before the pregnancy is recognised,[13 14] and, even late in pregnancy, poorer women might work beyond their heat tolerance limits to avoid losing pay.[15]

Systematically documenting the association of heat exposure with maternal and newborn health is important for quantifying the overall burden of climate related conditions, especially as adverse birth outcomes, such as prematurity, contribute many person years lost to these estimates.[16] Measuring disease burden, in turn, is key to increasing the resources allocated to adaptation services for pregnant women, for tracking progress over time, and for supporting arguments for mitigation of climate change. Moreover, in order to design interventions to avoid the effect of heat on health, we need a clearer understanding of the different pathways from exposure to outcomes, and how these vary across settings and between population groups. Previous systematic reviews have summed the evidence for associations between exposure to high temperatures and maternal and newborn health outcomes,[17-22] but we have focused on temperature connections with preterm birth, birth weight, and stillbirth. In particular, we examine the extent to which varying heat exposures (including heatwaves, increments per 1°C, and temperature threshold effects) affect these outcomes.

A.2.3.4 METHODS

The review forms part of a larger systematic mapping survey of the impacts of high temperatures and adaptation interventions on health.[23] In the mapping review, we identified heat exposure studies, defined as articles that assessed the effect on health of exposure to high temperatures, but did not include an intervention. We also identified heat adaptation studies, which assessed the outcomes of interventions aiming to counter the impacts of heat exposure.

In brief, in September 2018 we searched Medline (PubMed), Science Citation Index Expanded, Social Sciences Citation Index, and Arts and Humanities Citation Index (supplementary file 1.[23] The search identified studies on exposure to high temperatures and not those that examined the impacts of low temperatures. Screening of titles and abstracts was done independently in duplicate, with any differences reconciled by a third reviewer or the principal investigator (MFC).

All studies that were classified as heat exposure studies or heat adaptation studies were then screened to identify papers that reported the association between heat in pregnancy and the review outcomes (preterm birth, birth weight, and stillbirth). An additional search using simplified search terms was done on Medline (PubMed) in September 2019 to locate articles published since the date of the initial search (supplementary file 2) **[**.[24] Reference lists of included articles were also screened.

We included studies only on humans, published in Chinese, English, German, or Italian, and studies on heat related to weather and not heat sources such as saunas and hot baths. No date restrictions were applied. All study designs were eligible except systematic reviews and studies that modelled the potential or hypothetical associations between heat exposure and the review outcomes. EPPI-Reviewer version 4 software[25] provided a platform for management of articles, screening of titles, abstracts, and full text articles, and for data extraction. No contact was made with authors to obtain additional information.

Preterm birth was defined as a live birth before 37 completed weeks of gestation,[26] but we also included studies reporting on the duration of gestation as a continuous variable. We incorporated studies that reported either birth weight in live births as a binary variable, low birth weight (weight <2500 g),[26] or as a continuous variable. Studies that assessed temperature associations with death of a fetus after more than 20 weeks' gestation were included in the stillbirth analyses.[26]

Data extraction

Eligible articles were extracted independently in duplicate and all reconciled by the principal investigator. Data were extracted on the following study characteristics: study location, dates when outcomes were measured, study design, and the way in which the temperature metrics had been used (supplementary tables 1a-c). Data extracted on outcomes included assessments of different lag periods and results in population subgroups (supplementary tables 2a-c). We did not extract data on the impacts of humidity, air pollution, or low temperatures (except in assessments of the shape of associations). Finally, single reviewers completed the critical appraisal checklist for analytical cross sectional studies developed by the Joanna Briggs Institute to assess the risk of bias (supplementary table 1d).[27] Studies that were scored "yes" on six or fewer of the eight itemswere considered at high risk of bias.[28]

Data synthesis

We describe patterns in study characteristics over time and between study settings. We paid specific attention to analysing studies in low and middle income countries, and outcomes in population subgroups. We attempted to identify particular critical gestational periods or windows when exposure to heat might have had the largest impacts.

We classified temperature metrics into four groups. Firstly, heatwaves defined as two or more days with temperatures above a predefined threshold. Where multiple significant outcomes were reported, we used the effect size of a two day heatwave, with temperatures at or above the 90th centile. Secondly, changes in frequency of the outcome per 1°C rise in temperature, used effect estimates of lags on individual days (or date of birth) or of periods up to four weeks. The last two groups consisted of temperatures dichotomised as above and below a threshold level to assess the impacts of temperature on the whole of pregnancy or a full trimester (the third group); or in shorter periods, such as individual days or up to four weeks (fourth group).

In the third and fourth groups of temperature metrics, owing to considerable diversity in the way in which time and lag variables were used, we report the average combined effect (odds ratio) of the occurrence of the outcome at high versus low temperatures and are unable to provide specific temperature cutoff points for these. The high threshold level signals temperatures above the 75th, 90th, and 99th centile, for example, depending on individual studies. Fourteen studies did not report outcomes in any of these four categories and were not included in forest plots or summary measures.[29-43]

In studies that reported several significant outcomes, we selected the measure with the highest effect size. Given that the lag or temperature threshold at which impacts are largest is unknown and will probably vary between populations, the highest estimate might be the true highest level, rather than the result of multiple testing. As studies had assessed outcomes in a range of ways, we used the available statistics to convert effect measures to a common measure, allowing us to calculate an average combined effect, where possible. We attempted to explain statistical heterogeneity, including using meta-regression, to identify effect modification. We used random effects meta-analysis to describe the average exposure effect of temperature, with the summary statistic presented as an odds ratio.[44] The decision on whether meta-analysis was appropriate was based on statistical heterogeneity as measured by the I^2 statistic, and the direction and magnitude of the effect sizes. In instances where there were major outlier studies, we present the meta-analysis measures with and without the outlier studies and propose possible explanations for variations between studies. If meta-analysis was deemed inappropriate, we summarise the effect estimates, providing information on the magnitude and range of effects (median and interquartile range).[28] Data syntheses do not assume that associations between absolute temperature levels and the outcomes are the same for different areas, but rather that the setting specific relative changes in temperature are sufficiently similar to combine into a synthesis measure (eg, comparing the preterm birth rate when the temperature is above and below the 90th centile in different settings). Low quality studies were included in the summary measures as their exclusion had little or no impact on the findings.

For analyses of differential impacts by socioeconomic status, we classified women with low education levels as having a low socioeconomic status if income data were missing. We aimed to assess changes in heat sensitivity over time, by comparing outcomes of studies conducted in the same area over time, or in studies that had stratified their findings by time period. The climate in each study site was classified into Köppen-Geiger climate zones, and studies ordered by latitude in the forest plot figures.[45]

Patient and public involvement

Patients were not involved in the development of the research question or its outcome measures, conduct of the research, or preparation of the manuscript.

A.2.3.5 RESULTS

The search in the mapping review identified 14 880 non-duplicate articles (PRISMA flowchart, fig 1). None of the 919 studies coded as heat intervention studies included data on pregnant women and were all excluded. Overall, 2273 articles were classified as heat exposure studies, and 175 of these selected for full text screening (7.7%). In total, 70 studies were eligible for this review (13 presented data on more than one review outcome). Most studies covered impacts of heat exposure on preterm birth (n=47), 28 presented data on birth weight, and eight on stillbirth (supplementary table 1a-c). Most studies were time series analyses using population registries or birth records from facilities (n=58), 10 used case crossover methods, and two employed a case-control design.

The number of studies per year increased markedly over time, from only two studies before the year 2000, to 22 from 2000 to 2015, and to 46 thereafter (66% of the 70 eligible studies).

The studies covered 24 countries, seven of which were low and middle income countries, consisting of none in lower income countries, one in lower middle income countries, and six in upper middle income countries). Most studies were set in North America (20), the European Union (17), or Australia and New Zealand (n=7). Two studies were done in sub-Saharan Africa. Six articles reported studies in China, all published since 2016. Articles were published a median of six years after the birth of the infants, and only three studies reported data on births that had occurred since 2015 (5%).Studies included a median of 111 834 births (interquartile range 11 886-556 990)

Temperature and lag windows were classified in a number of ways. In total, 34 (72%) of 47 papers on preterm birth were classified as high quality, as were 14 (50%) of 28 studies on birth weight, and six (87.5%)of eight on stillbirths (supplementary table 1d). Weaknesses in research quality pertained mostly to the lack of a detailed description of the study population and setting (23 (33%) of 70 studies) and use of inappropriate analytical methods (18 (26%) of 70 studies). In most cases the study inclusion criteria and outcomes were well defined (65 (93%) and 66 (94%) of 70 studies, respectively).

Preterm births analysis

The median preterm birth rate of the included studies was 5.6% (interquartile range 5.0-7.9; range 2.6-15.5; supplementary table 2a). Of the 47 studies on preterm births, 40 documented an association between high temperatures and preterm birth. In meta-analysis of six studies, the odds of a preterm birth during a heatwave were 1.16-fold higher than on non-heatwave days (95% confidence interval 1.10 to 1.23; I^2=44.7%; table 1, fig 2). Although there was considerable heterogeneity in estimates of the odds of preterm birth for each 1°C increase in temperature (I^2=87.7%), all estimates showed significant effects in the same direction. Meta-analysis of this outcome showed an average odds of a preterm birth increased by 1.05 for each 1°C increase in temperature (95% confidence interval 1.03 to 1.07; fig 3). The summary measure of associations between exposure to high temperatures over a trimester or all of pregnancy was odds ratio 1.14 (95% confidence interval 1.11 to 1.16; I^2=88.2%; supplementary fig 1). An analysis that excluded a study in Shenzhen, China that reported a protective effect of high temperatures,[46] reduced the heterogeneity, but the overall estimate was similar. The authors of that study ascribed their findings to the high use of air conditioning in the study area, which had reduced exposure to high temperatures. The median odds ratio for preterm birth after exposure to high temperatures over short periods (<4 weeks) was 1.07 (interquartile range 1.05-1.16; supplementary fig 2). This value was slightly larger than the estimate in a meta-analysis involving 19 studies that excluded the Shenzhen study, and another in London where women had been exposed only to mild temperatures (odds ratio 1.0; 95% confidence interval 0.99 to 1.0; fig 4).[46 47] The odds ratio in the meta-analysis involving all 21 studies was 1.01, but the finding here was dominated by the London study, which accounted for 59.9% of the weighting of the overall estimate.

Most studies reported dose-response associations, where rates of preterm birth rose progressively with increasing levels of temperature or with longer durations of heat exposure (supplementary table 2a). Positive associations were detected in all lag windows, including five with heat exposure in the month of conception,[48-52] or preconception[50] (supplementary fig 7a). In low and middle income countries, five studies documented heat associations with preterm birth in the first and second trimester, while only three detected these effects in the last week of pregnancy. Conversely, in the European Union and Central Asia region only one study documented heat vulnerability in the first trimester, and eight did so in the last week of pregnancy, mostly at lag zero to three days before childbirth. Similarly, in North America only two studies noted associations in the first or second trimester, whereas six did so in the final week of pregnancy.

Six studies reported null findings, three of which were of low quality.[35 42 53] One study set in Brisbane, Australia found no association between heat exposure and gestation length,[54] but, in a separate analysis, did detect an association when the outcome was dichotomised as preterm birth.[52] Another study in Canada did not detect an association between temperature and preterm birth, but reported that during heatwaves, early term births at 37-39 weeks were considerably more common than births above 40 weeks.[55] A study in London, United Kingdom, where maximum daily temperatures were below 25°C on almost all days, had null findings.[47] One study in Shenzhen, China reported an apparent protective effect of heat exposure, which could be due to high air conditioning use in the study area, as noted above.[46] Similarly, a study in northern California noted the effect sizes were lowest in the areas that had the highest use of air conditioning.[56]

Few studies reported the shape of association, though, of note, five studies, all in humid subtropical areas, detected U shaped associations, with the base covering a range from 18 to 25°C[57-61] (supplementary table 2a). Three studies found that the size of diurnal fluctuations in temperature or the level of temperature during the night were more predictive of preterm births than levels during the day,[37 62 63] and another study found stronger associations in areas that had high night time temperatures.[64]

A study in Israel disaggregated findings by induced and spontaneous preterm births, and noted associations only with spontaneous births (induced births incidence rate ratio 0.99, 95% confidence interval 0.97 to 1.0).[65] In the 11 studies on preterm birth that stratified findings by age group, the highest risks were noted in women under 25 (seven studies)[61 66-71] or over 35 (two studies; fig 5).[72 73] In two studies that did not fit this pattern, age had been dichotomised, making it difficult to determine specific risk bands.[62 63] Associations between exposure to heat and preterm birth were strongest in low socioeconomic groups in all six studies that reported this composite variable (supplementary fig 8a).[35 53 67-69 71] In one example, a study in South Korea, women with both low education levels and low socioeconomic status had a 1.1-fold increased hazard ratio of preterm birth for each quartile increase in temperature, considerably higher than that in other women in the study.[70] In four studies in the USA, black or Hispanic women had two or more fold higher effect sizes than white women (fig 6).[35 66 67 74] In one study where risks of preterm birth associated with heat were higher in whites than in other races, the differences in effect sizes were negligible.[71] Associations between heat and preterm birth were highest in indigenous women in a study in the coastal region of Australia,[72] but in non-indigenous women in the hot central region.[75] Greater impacts of heat on female than male fetuses were noted in six of nine studies (supplementary fig 8b). Three studies found that associations between temperature and preterm birth were higher in women with chronic conditions such as diabetes or depression.[61 66 69]

Overall, there was little evidence available on whether relationship between temperature and preterm birth had changed over time. A study in Brisbane, Australia, the only one that stratified findings by time period, found that the hazard ratio of preterm birth was lower in 2013 than in 1994 for the same temperature exposure.[58]

Birth weight

The median rate of low birth weights in the included studies was 3.0% (interquartile range 1.8-6.4; supplementary table 2b). Of the 16 studies that provided data on the association of temperature with low birth weight, 10 reported that risk increased at higher temperatures, and only one reported the converse (five had null findings). The median of the observed effects of high temperatures on odds of low birth weight was 1.09 (interquartile range 1.04-1.47; table 1; supplementary figs 2 and 3). No meta-analysis was done on any of the outcomes for birth weight given the marked variation in magnitude and direction of effect. We also did not present a summary measure of changes in birth weight for each degree increase in temperature given the high levels of methodological diversity between these studies.

Of the 19 studies reporting birth weight as a continuous variable, 12 noted decreases in birth weight at higher temperatures, including two where the direction of effect varied by trimester (supplementary figure 7b),[76 77] three studies had non-significant findings, and four noted that weight increased at higher temperatures. Generally, the impacts of temperature on weight were small, with most studies reporting changes of under 10 g per change in degree, or under 20 g when comparing high and low temperatures (supplementary table 2b, supplementary fig 4). Changes in birth weight were especially small in studies in low and middle income countries.[78 79] Notably, in the lag measures, high temperatures in the last four weeks of pregnancy appeared to have little impact on birth weight, and were even associated with an increase in birth weight in two studies (supplementary fig 7b).[77 78] Among studies that showed an association between reduced weight and high temperatures, the largest impacts were in women aged less than or equal to 22 or above 40[29 68 76]; who were black,[76] indigenous,[78] or Hispanic [68]; and of low socioeconomic status[29 68 76] (fig 5, fig 6, supplementary fig 8a).

Stillbirth

The median stillbirth rate was 6.2 per 1000 births (interquartile range 4.4-6.4; supplementary table 2c). All eight included studies detected an increase in stillbirths at higher temperatures (table 1). In most cases, associations between temperature and stillbirth were most pronounced in the last week or month of pregnancy (supplementary fig 7c). Stillbirths increased 1.46-fold (95% confidence interval 1.09 to 1.96) in the one study in Brisbane, Australia that reported this outcome.[52] In meta-analysis, stillbirths increased by 1.05 (95% confidence interval 1.01 to 1.08) per 1°C rise in temperature, by 1.24-fold (1.12 to 1.36) at lags measured on individual days in the last week of pregnancy,[59 80] and by 3.39-fold (2.33 to 4.96) when temperature effects were examined over a trimester or the whole pregnancy period[58 80] (supplementary figs 5 and 6). In subgroup analyses, point estimates of associations between heat and stillbirth were higher in term than in preterm stillbirths,[80] in black and Hispanic women than white women,[81] in younger women,[82] male fetuses, and had reduced over time[58] (fig 5, fig 6, and supplementary fig 8b). Only one study provided information on multiple pregnancies, reporting associations similar to those with singleton pregnancies.[80] None of the eight studies were done in low and middle income countries.

Table 1 Meta-analysis results by outcome and temperature metric

	No of studies	Synthesis method	No of studies in summary measure	Average effect size (OR (95% CI))	I^2 (%)
Preterm birth:					
Odds of preterm birth during heatwaves	6	Meta-analysis	6	1.16 (1.10 to 1.23)	44.7
Odds of preterm birth per 1°C temperature increase	6	Meta-analysis	6	1.05 (1.03 to 1.07); 5% increase per 1°C rise (3% to 7%)	87.7
Odds of preterm birth during high versus low temperatures (exposure over a trimester or all of pregnancy)	9	Meta-analysis	9	1.14 (1.11 to 1.16)	88.2
			8*	1.15 (1.13 to 1.18)	65.2
Odds of preterm birth during high versus low temperatures with exposure period <4 weeks	21	Meta-analysis	21	1.01 (1.01 to 1.02)	89.8
			19†	1.05 (1.04 to 1.05)	83.6
	21	Summary of effect estimates	21	Median OR=1.07 (IQR 1.05-1.16; range 0.99-1.94)	—
Birth weight:					
Odds of low birth weight during high versus low temperatures (exposure over a trimester or all of pregnancy)	9	Summary of effect estimates	8‡	Median OR 1.09 (IQR 1.04-1.47; range 1.01-2.49)	—
Changes in birth weight at high versus low temperatures	6	Summary of effect estimates	4§	Median difference −25.5 g (range −39.4 to −15.0)	—
Stillbirth:					
Odds of stillbirth during heatwaves	1	—	1	1.46 (1.09 to 1.96)	—
Odds of stillbirth per 1°C temperature increase	3	Meta-analysis	3	1.05 (1.01 to 1.08)	81.3
Odds of stillbirth during high versus low temperatures (exposure over a trimester or all of pregnancy)	2	Meta-analysis	2	3.39 (2.33 to 4.96)	27.8
Odds of stillbirth during high versus low temperatures with exposure period <1 week	4	Meta-analysis	4	1.24 (1.12 to 1.36)	53.1

IQR=interquartile range; OR=odds ratio.
*Excludes Liang (2016). **[A: Please add reference citations where studies are referred to in the table footnotes – we can renumber in-house if needed]**
†Excludes Lee (2008) and Liang (2016).
‡MacVicar (2017) reported a non-significant association, but effect estimates not provided.
§Madsen (2010) and Bruckner (2014) reported non-significant associations, but effect estimates not provided.

A.2.3.6 DISCUSSION

Principal findings

The systematic review findings—in particular, the size and relative consistency of associations and dose-response patterns, appear to support the hypothesis that heat exposure increases the likelihood of adverse pregnancy outcomes. Association with preterm births and stillbirths in some analyses shows these outcomes rising by about 1.05-fold per 1°C increase in temperature, and the odds of a preterm birth to be 1.16-fold higher during heatwaves.

Associations of heat with preterm birth and stillbirth appear to be stronger and more consistent than those with birth weight. For example, only 18 of 28 studies which assessed birth weight found an association, compared with 40 of 47 preterm birth studies. This is even more remarkable as measurement of gestation is subject to a range of errors, which are probably non-differential, biasing findings to the null, whereas one might expect data on birth weight to be of higher quality. In other studies the associations of heat exposure with other measures of newborn anthropometry, such as birth length, also appear small,[29 79 83] and no association was noted between temperature and ultrasound measurements of fetal anthropometry in an Australian study.[84] Taken together, evidence for heat sensitivity on birth weight is limited and most studies reported only minor changes. It is important to note, however, that even apparently minor decrements in birth weight could have a major impact on public health as exposure to high temperatures is common and escalating.

We were unable to discern any clear windows of vulnerability during pregnancy, except that heat exposure in the final weeks of pregnancy appears most important for preterm births and stillbirths. Some evidence suggested that pregnant women in low and middle income countries were vulnerable to heat exposure throughout pregnancy, whereas vulnerability among women in high income countries was largely confined to the last weeks of pregnancy. Any effects on birth weight seem to occur early in pregnancy.

It is also difficult to isolate which dimension(s) of heat mediate the impacts noted. The evidence was strongest and most consistent for heatwaves, although the largest effect sizes were from measures of the cumulative dose of heat over the whole of pregnancy. Three studies reported sizable impacts of diurnal fluctuations in temperature.[37 62 63] Clearly, the complexity of thermoregulation in pregnancy and the interactions between temperature and other meteorological variables, make it difficult to isolate which aspects of heat are responsible for each adverse pregnancy outcome. A better understanding of these complexities and how they vary by climate zone could inform the design of adaption services. For example, several studies pointed to a threshold temperature of 18-25°C, above which rates of preterm births escalate and interventions might be needed. This cutoff point might also explain why the London study had null findings as the temperature was below 25°C on almost all days in that study.[47]

The review was not designed to assess associations between low temperature and birth outcomes, though these were documented in several studies, most of which reported U shaped associations between temperature and outcomes.[46 48 58 59 61 76 85 86] Links between exposures to cold and other outcomes, such as mortality, are well documented. Little attention is paid to these links when climate change is discussed, even though the current climate variability encompasses both increases in temperatures and periods of low temperature extremes.[87]

Several health conditions in newborns, other than those assessed here, have been linked to heat exposure, including small for gestational age and congenital anomalies.[17-22 88] Sensitivity to heat might also vary by sex of the fetus. A study in Japan, which noted higher spontaneous abortions among male than female fetuses after a period of heat exposure,[89] is consistent with the study in our review. We found that higher temperatures were associated with stillbirths in male fetuses.[82] The preponderance of female newborns in studies on preterm birth in the review could be explained by this differential sensitivity. Heat exposure is implicated in many conditions in pregnant women, with evidence pointing to heat effects on pre-eclampsia, prolonged labour, and antepartum or postpartum haemorrhage.[32 90 91] During heatwaves, pregnant women might also have higher rates of admission to hospital emergency departments and increased cardiovascular events, such as stroke and myocardial infarction.[92 93] Some studies have also linked emotional stress and sleep disturbance in pregnancy to hot weather.[94 95] Group B streptococcus colonisation of the vagina and cervix of pregnant women could increase at higher ambient temperatures,[96] raising risks for newborn sepsis. Lastly, it is important to note that in utero exposure to heat has been linked with a range of childhood and adult conditions, and even long term economic prospects.[8-10 97 98] Each of these topics warrants closer study.

Associations between temperature and birth outcomes appear especially pronounced among women in low socioeconomic groups. This suggests that pregnant women in low and middle income countries could be at particular risk from heat exposure. Women in low and middle income countries already have high rates of preterm birth (10.4% of births in Asia are preterm and 12.0% in sub-Saharan Africa),[99] about twice the rates of the studies in this review. Preterm birth and low birth weight are both key risks for neonatal mortality, which accounts for almost half of all child deaths under five.[100] Heat related risks might be especially high among subgroups of pregnant women in low and middle income countries who have reduced physiological ability to respond to high temperatures, including women with multiple pregnancy, obesity, malaria, HIV infection, or mental health and other chronic conditions.[66 67] Many of the protections that are afforded to these groups in high income countries are unavailable in low and middle income countries. As the world's temperature increases, risks for pregnant women in low and middle income countries become even more concerning as their ability to reduce heat exposure through space cooling, for example, could be severely constrained.

Future intervention and methodological implications

The review highlights the need for research to identify and study interventions to reduce problems due to heat among pregnant women (no such studies were located in the mapping review which preceded this review). During pregnancy, a package of home based services could be provided by community health workers whose work already largely centres on pregnant women and children. Many of the WHO recommended interventions for health promotion in pregnant women could be adapted for this purpose.[101] Heat reduction in labour wards in low and middle income countries might include optimising natural ventilation, making fans and cold potable water available, and integrating heat counselling within the services provided by health workers, HIV counsellors, and birth companions. These interventions warrant further investigation. It is important to closely monitor maternal hydration when temperatures are high. In the Paris heatwave of 2003, for example, oligohydramnios, possibly caused by maternal dehydration, was diagnosed in 17.5% of term pregnancies, compared with 4.4% in the same week in the previous year,[102] consistent with a similar study in the USA.[103] Rates of dehydration and heat stress might be high in women who give birth in facilities that have little heat resistance, where temperatures can be as much as 4°C higher than outdoors.[104]

[105] Lastly, interventions that build resilience in pregnant women, such as cash transfers, could have an important protective role.[106]

Several observations on research methodology should be mentioned. Standardising temperature metrics, lag durations, and subpopulation analyses in future studies would enable direct comparison between studies, identification of windows of vulnerability, and more robust estimates of overall size of associations. Standardisation could also reduce selective reporting of significant findings. Few studies examined whether temperature effects varied across subpopulations—critical evidence that would inform the targeting of specific groups of pregnant women. An individual participant data meta-analysis that combined raw data from several studies in a single analysis could deal with many of these limitations.

Strengths and limitations

The review included more studies than previous reviews and covered three outcomes, allowing comparisons among these outcomes and a more comprehensive assessment of heat sensitivity in pregnancy. The review has several limitations, however. Differences in the ways that temperature and lag measures were used meant that we had to develop decision rules for classifying temperature metrics and other variables. Additionally, about a third of studies were of low quality, limiting analysis. Moreover, publication bias, multiple testing, and selective reporting of positive associations (eg, at different lag times) might have been common, as with all observational research.

More generally, considerable challenges exist in interpreting studies that examine impacts of environmental exposures on birth outcomes, especially spontaneous abortion or stillbirth. For example, severely damaged embryos or major birth defects from an environmental exposure could result in spontaneous abortion, often before pregnancy recognition.[107] Heat related early pregnancy loss might be difficult to detect, though studies of assisted reproduction provide one way of doing so. In one such study in Qatar, for example, spontaneous abortions in hotter months were double those in cooler months.[108] Importantly, potential confounding by air pollution could occur, and future reviews need to explicitly examine this problem. Furthermore, adaptation measures such as air conditioning use, and heat action planning might attenuate the strength of associations between heat exposures and adverse outcomes.[6] This possibly explains the inconsistent findings of the study in Shenzhen, China[46] and the very low point estimates in a study in Seoul, South Korea.[70] Null findings might be interpreted as the absence of an association, rather than as the effectiveness of adaptation measures. Given these complexities, we presented some meta-analyses that excluded those studies which could have been influenced by high levels of adaptation. Major challenges exist in interpreting these findings, however, and future reviews might consider stratifying analyses by use of air conditioning, for example.

A.2.3.3.7 COCNLUSIONS

The studies included could be subject to a range of measurement biases, but this review suggests that exposures to high temperature might be associated with birth outcomes, with evidence most consistent and effect sizes largest for preterm birth and stillbirth.

Overall, the review highlights the need to identify interventions targeting heat related conditions in pregnant women, especially in women at the age extremes and in lower socioeconomic groups, and to determine their effectiveness. Pregnant women merit a place alongside the groups typically considered as at high risk for heat related conditions. Estimates of the global burden of disease from heat effects on newborns could be modelled from the evidence collated in this review. These estimates are key for securing funding for reducing heat exposure for pregnant women, for demonstrating the health risks of climate change more generally, and for supporting efforts to curtail greenhouse gas emissions. Given increases in the frequency and intensity of heatwaves, the number of pregnant women exposed to these conditions worldwide, and the significant individual and societal burdens associated with preterm birth and stillbirth, research and policy initiatives to deal with these connections are a high priority.

Box start

What is already known on this topic

Physiological and anatomical changes in pregnancy compromise a woman’s ability to thermoregulate, potentially raising risks of adverse pregnancy outcomes

Increases in global temperatures heighten concerns about heat impacts on health, especially in vulnerable groups with limited physiological or socioeconomic ability to respond

Previous systematic reviews have summed evidence of associations between exposure to high temperatures and pregnancy outcomes, but have included few studies and have not assessed variations across population groups and by type of heat exposure

What this study adds

This systematic review collates evidence that exposure to high temperature is associated with an increase in adverse pregnancy outcomes, especially preterm birth and stillbirth, and among women in lower socioeconomic groups

The study shows the potential effects on health of continued increases in mean global temperatures and of the frequency of heatwaves

Box end

Contributors: MFC conceived and coordinated the study and wrote the first draft. MDP, AA, MH, AM, CPS, BW, MR, RH, and MB screened titles, abstracts, and full text articles, and assisted with data extraction from included papers. SH provided senior inputs to data analysis and conceptualisation of the article. All members of the Climate Change and Heat-Health Study Group provided key inputs to the article, including screening of articles, data extraction, and input on specific specialist topic areas. All authors reviewed the various drafts of the article and cleared it for publication. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. MFC and SMFL serves as guarantors.

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9.4 Appendix 2.4: Climate Change and Control of Diarrhoeal Diseases in South Africa: Priorities for Action

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A.2.4.1 Chapter Overview

This appendix chapter focuses on temperature and diarrhoeal diseases in Africa, particularly South Africa. To provide evidence on this subject, a systematic review of evidence was carried out. The discussion in this chapter is imperative in bolstering the evidence on heat effects on human health in Africa. The chapter demonstrates the recent research taking place focusing on African countries. The important point presented is that temperature variations, especially heat affects human morbidity in Africa, including through diarrhoeal infections.

A. 2.4.2 Connections between temperature and diarrhoeal disease

Weather conditions, especially temperature and precipitation, play a critical role in shaping patterns of diarrhoeal diseases. They determine the frequency of outbreaks, and the spatial and seasonal distribution of cases. Not surprisingly, it is anticipated that the burden of diarrhoeal diseases will escalate with climate change, in tandem with gradual increments in mean temperatures, but also during episodic heatwaves. The degree and nature of this escalation will, however, vary with the mix of pathogens in an area, the quality of sanitation services, food hygiene regulations and their enforcement, and the age structure of the population, among other factors. Understanding these patterns can inform the design of measures to prevent and control heat-related diarrhoea. In this editorial, we sum evidence on the heat sensitivity of enteric infections in South Africa (SA) and other parts of sub-Saharan Africa (19 studies), drawing on articles located in a systematic review (methods detailed in Manyuchi *et al*.[1]), and consider the implications of these findings for control of diarrhoea in SA in the context of climate change.

Several mechanisms underlie the heat sensitivity of microbes. The reproduction, growth and survival rates of most microbes rise with temperature, within certain limits. Higher ambient temperatures accelerate contamination of food across the whole food chain, from preparation, processing and storage to eventual consumption. Importantly, on hot days people spend more time outdoors, and may eat food that is unrefrigerated and is raw or cold, rather than served cooked and hot.[2] Being outdoors also raises exposure to pathogens carried by birds, and farm and wild animals. Rural areas, *per se*, may be especially susceptible to heat-related impacts on diarrhoea.[3] Further, dust storms, especially frequent on hot and dry days, may settle dust particles with microbial contaminants onto vegetables and other fresh produce. Importantly, if power blackouts occur during hot weather – as we are currently seeing in SA and Venezuela – the integrity of food chains can be compromised, increasing risks of contamination.

While 15 of the 19 papers identified in the review reported strong connections between heat exposure and cases of diarrhoea,[3-17] 4 found negligible or even negative associations.[18-21] This inconsistency illustrates the complexity of pathways between temperature and infectious diseases. Indeed, these correlations are seldom linear and more frequently take an inverted U-shape, where diarrhoea rates rise with temperature, plateau and then decline. Relationships may also be J-shaped, where the incidence of diarrhoea remains stable below a certain temperature threshold, beyond which there is a rapid incline. Moreover, many enteric infections have seasonal patterns: rotavirus cases, for instance, classically occur in winter and campylobacteriosis peaks in spring.[18-20]

Seasonal patterns are not solely related to climatic factors, however, and are generally poorly understood. The complexity of transmission dynamics also means that many pathogens are both food- and waterborne, with temperature influencing both modes of transmission. On the plus side, the complexity of these connections means that there are multiple potential points of intervention.

A.2.4.3 Patterns of heat sensitivity of enteric infections in sub-Saharan Africa

During periods that are hot and dry, any additional increments in temperature appear to have especially marked impacts on the incidence of diarrhoea in sub-Saharan Africa.[4,8] This is concerning, as periods of hot and dry weather may lengthen and warm further with climate change, and cover ever-larger geographical areas. A study among children aged under 5 in Cape Town, SA, during the hot, dry months of the year, for example, found that a 5°C rise in temperature increased cases of diarrhoea by 40% 1 week later. [8] Similar effect sizes were noted in a study in Northern Ghana, at a 2-week lag,[12] and in Limpopo Province, SA.[15] In a study in Mozambique, the incidence of diarrhoea rose by 3.6% per 1°C increase in temperature.[6] Another study, however, using data from demographic health surveys across sub-Saharan Africa, found only weak associations between temperature and cases of diarrhoea in children.[21] Additionally, rotavirus occurrence was associated with lower temperatures in several studies, as shown elsewhere.[18-20]

Risks of cholera outbreaks are clearly raised by flooding, and interruptions and breakdowns in water and sanitation services, as is presently unfolding in the neighbouring countries of South Africa following Cyclone Idai, but can also be raised during periods of warm weather.[14,16,18] For example, a study in Zambia found that a 1°C rise in temperature 6 weeks before the onset of a cholera outbreak explained 5.2% of the increase in number of cholera cases. [5] The authors of a Tanzanian study reported that an increase of 1°C would raise cholera cases by 29%, considerably more than estimates in studies elsewhere.[13]

Sea surface temperature appears to predict cholera outbreaks on the subcontinent.[7,9,10,17] The incidence of cholera rose in a linear fashion with sea surface temperature in the KwaZulu-Natal outbreak in 2000. [7] High sea surface temperatures raise risks of heavy precipitation associated with cholera outbreaks,[11] but also enhance phytoplankton growth, leading to higher numbers of copepod zooplankton (small crustaceans commensal to cholera) that feed on these organisms. Cholera infections then occur after people drink untreated water with even a few cholera-containing copepods.

A.2.4.4 Implications for control of diarrhoea in SA in the era of climate change

Broadly speaking, there are two approaches to controlling heat-related diarrhoea. The first entails reducing pathogen concentrations in food chains, water sources and the community in general.[22,23] This approach attenuates the effects of temperature on diarrhoeal infections, potentially counterbalancing the impacts of climate change on case burden. The second approach involves outbreak preparedness, early-warning systems and heat-health action plans, where a specific set of actions are triggered at prespecified temperature thresholds.

Information about the lag time between periods of extreme heat and increases in cases of diarrhoea (1 - 6 weeks in the studies reviewed) can provide warning about outbreaks and facilitate their early detection, a central pillar of diarrhoea control. In the absence of forecasting and early detection, many unplanned admissions may occur, in under-prepared services, and with high morbidity and mortality rates. Lag periods vary considerably, however, contingent on the incubation periods of the pathogen(s) involved, and where and when food contamination occurred. Shorter lags point to heat-related contamination closer to the time of food consumption, while longer lags indicate exposure at the production and processing stages.

Longer lags may also suggest that heat pathways involve an additional step of mechanical vectors, such as flies, which are mostly thermophilic.[4]

The recent floods in southern Africa following Cyclone Idai may suggest gaps in preparedness for extreme weather events, at national, regional and international levels. In Mozambique, a cholera outbreak began 2 weeks after the cyclone and oral cholera vaccination was initiated 1 week thereafter, in a large campaign involving almost 1 million doses.[24] It is worth considering whether global stockpiles of the vaccine could have been mobilised earlier, however, based on the expected lags and given the fact that a cholera outbreak occurred in 2018, suggesting favourable conditions for cholera transmission, even pre-cyclone.[25] Experiences with the listeriosis outbreak in SA in 2017/18 indicate that deficiencies in preparedness and outbreak control are not restricted to the neighbouring countries: it took 14 months to identify the outbreak source, and there were substantial gaps in the case histories of affected patients, for example.[26,27]

Although heat sensitivity and related causal pathways vary considerably between pathogens and settings, heat-health action plans can set out graded actions, where sets of preventive and control measures are implemented at different temperature thresholds. These actions include rapidly sharing information with health professionals and the public on levels of risk; promoting food safety and safe water use; making provision for additional case burdens in health services; shifting from surveillance of all-cause diarrhoea to making specific pathogen diagnoses; and specific measures such as cholera vaccination.[23]

A.2.4.5 Conclusions

Average temperatures in SA are anticipated to escalate by 2 - 4°C in the forthcoming decades.[28] Risks of cholera and other outbreaks clearly increase during disasters, but now also need to be recognised as important phenomena during heatwaves and the increasingly high temperatures that characterise climate change. The overall burden of diarrhoeal diseases may therefore increase considerably, especially among lower socioeconomic groups and children. Understanding these impacts can help delineate high- and low-risk periods, provide insights into the epidemiology of enteric diseases in the country, identify remedial actions, and help prioritise diarrhoeal diseases in heat-health action plans. Developing and adequately resourcing such plans, which encompass disaster preparedness, should form a key part of SA's climate change response in the coming years.

A.2.4.6 Chapter Postscript

This chapter provides additional Africa-specific evidence on the effects of temperature on human health focusing on diarrhoea infections. This chapter bolsters the evidence that African countries are and will be affected by EWEs, including heat. The case of heat-health effects in Agincourt subdistrict presented in chapter 3 presents evidence of similar nature.

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9.5 Appendix 3.1: Interview Guide for Key Informants

1. Demographic characteristics of key informant

Date of interview		Participant study ID	
Interview start time		Interview end time	
Gender		Race	
Age		Nationality	
Highest Educational Level completed		Language (s)	
Employment status		Venue of interview	
Interviewer name			

2. Background Information

2.1 How many years have you worked/ stayed in this area?

2.2 What has been your occupation over these years?

2.3 What is your current occupation?

2.4 Do you work indoors or outdoors?

2.5 Given the following categorization, traditional (mud and grass) and modern (brick and zinc/asbestos/tiles, etc) what type of dwelling do you live in?

3. Temperature Information

3.1 How do you generally find the weather (the state of the atmosphere at any given time and place) in Agincourt area?

3.2 Since you have lived in this area for a long period, how do you general describe the changes in the climate (the average weather over a period of time) in this area? [For some, skip if not applicable]

3.3 What years/seasons/ days that you consider to have been different from the general weather and climate patterns you have outlined?

3.4 Would you describe this area as a generally hot, cold or warm area?

3.5 What years/ seasons/ days do would consider to have been too hot than others?

3.6 What do people in this area do when it is extremely hot?

3.7 Do you the concept of a heatwave and how would you define or explain it?

3.8 Does this area experience heatwaves?

3.9 What is the effect of heatwaves on the health of people in this area?

4. Heat-Health Information

4.1 Are there some people you know living/working in this area who sought health services when it was extremely hot or after a heatwave?

4.2 Considering children, adults and elderly persons in this area, which of these groups is mainly impacted by extremely hot temperatures and heatwaves? [Explore positive impacts as well, if any]

4.3 In this area, what diseases result from extremely hot temperatures and heatwaves?

4.4 Which days/months and year(s) do you consider to have had the greatest number of persons affected by extreme heat and which diseases affected them?

4.5 Do the diseases you mentioned above occur on the day it is too hot or they only manifest after?

4.6 Which heat or heatwaves related diseases affect people in this area? [explore the categories of persons affected]

4.7 Do you know of any persons who died from extreme and heat events?

4.8 Do you know of any persons who were hospitalized because of exposure to extreme heat?

4.9 What changes happen to working and other people due to extreme heat and heat events?

4.10 Does extreme heat and heat events reduce labor outputs or productivity?

4.11 Does extreme heat and heatwaves cause any social problems?

5. **Climate Information Services for Health Needs**

5.1 How do people in this area generally get information on when the temperatures are going to be too hot than other days? [Explore where and who gives information]

5.2 What is the content of this information and does the information indicate the effect of too hot days on people's health?

5.3 How is information on extreme heat passed between community members? What languages and channels do people use to communicate the information?

5.4 Do community members prepare in advance when they know it will be too hot and in what ways? [Divide responses into households and workplaces]

5.5 Are there some traditional ways through which people know the days when it will be too hot in this area? If so, how is this information shared and do people take this information seriously?

5.6 What are the modern ways in which people in this area respond to heat and heat events?

6. **Co-production of Climate Information Services for Health**

6.1 In what ways do weather/climate information producers currently interact with the community members and structures?

6.2 What information will be important for the community to prepare in advance for extremely hot days?

6.3 Which institutions should provide the information on days when it will be too hot?

6.3 When should information about days that will be too hot be disseminated?

6.5 What would make the information provided more acceptable to the community members?

6.6 What would be the barriers that would stop community members from participating in generating information?

6.7 What should be the content of the information provided to persons/ communities that will be affected by too hot temperatures?

6.8 What individual/community/occupational health aspects should be highlighted in the information?
6.9 In what ways will health facilities use the information about when it will be too hot?
6.10 Will community members will change their ways of living and working because of heatwave information?
6.11 What health related changes would happen because of heatwave information in the community?
6.12 Would involving community members/structures in co-producing the information enhance its use/application in decision-making?
6.13 Which institutions/people should disseminate heatwave information in the various settings-homes, schools, health facilities, working environments?
6.14 Is it important to have a heatwave plan for the Agincourt area and what aspects should be covered in the plan?
6.15 Which institutions should drive the development, monitoring and evaluation of the heatwave plan?
6.16 How would a local heat plan relate to the provincial and national plans?

9.6 Appendix 3.2 : Interview Guide for Community Respondents

1. Demographic characteristics of key informant

Date of interview		**Participant study ID**	
Interview start time		**Interview end time**	
Gender		**Race**	
Age		**Nationality**	
Highest Educational Level completed		**Language (s)**	
Employment status		**Venue of interview**	
Interviewer name			

2. Background Information

2.1 How many years have you worked/ stayed in this area?

2.2 What has been your occupation over these years?

2.3 What is your current occupation?

2.4 Do you work indoors or outdoors?

2.5 Given the following categorization, traditional (mud and grass) and modern (brick and zinc/asbestos/tiles, etc) what type of dwelling do you live in?

3. Climate background around Agincourt area

3.1 What does existing literature show about the climate of Agincourt area?

a. What does meteorological data and existing literature show about the rainfall, temperature, humidity and sunshine cover in the area?

b. What are the seasonal pattens in climatic variables established in the meteorological data and existing literature?

c. Is there existing evidence of extreme heat and heatwaves in the area?

d. What does existing evidence show about climate/environmental related diseases in the area, including malaria?

4. Perception of vulnerability to heat-related risks of climate change

a. How do you generally find the weather in Agincourt area?

b. Can you describe the climate of this area?

c. Would you describe this area as a generally hot, cold or warm area?

d. Can you describe the changes in the climate in this area?

e. Which years/seasons/ months/days were different from the general weather and climate patterns you have outlined?

f. Which years/ seasons/months/days do would consider too hot than others?

g. Do you consider the changes in climate to be associated with climate change?

h. What do people in this area do when it is extremely hot?

1. Are people living in Agincourt vulnerable to heat?

5. Perception of exposure and vulnerability to extreme temperature change

a. In what ways are people living in Agincourt vulnerable to heat exposure?

b. Can extreme heat cause deaths in Agincourt area?

c. Can extreme and heat events cause people to be sick in this area?

d. Are there any people hospitalized because of extreme heat and heat events?

e. Which population groups are vulnerable to heat exposure?

f. What conditions make the populations vulnerable to heat exposure?

g. How do people in the area adapt to exposure to extreme heat?

6. Understanding, and perception of exposure and vulnerability to heatwaves

a. What is your understanding of the term “heatwaves”?

b. Does this area experience some heatwaves?

c. How do community members adapt to heatwaves?

d. Can heatwaves cause deaths in Agincourt area?

e. Which population groups are vulnerable to heatwaves?

f. What conditions make the populations vulnerable to heatwaves?

g. How do community members adapt to heatwaves?

7. Changes in labour productivity

a. How do extreme heat and heatwaves affect people’s working pattens in this area?

b. Which categories of workers are mostly affected by heat and heatwaves?

c. How do workers adapt to heat and heatwaves?

d. What major changes are made to work schedules and tasks during periods of extreme heat and heatwaves?

e. How does the types of clothing worn by workers affect workers' exposure to heat and heatwaves?

8. Existing interventions focused on heat and human health

a. What are the current heat-health interventions in Agincourt area?

b. How do people in the area conduct themselves during periods of heat and heatwaves?

c. What are the traditional remedies for heat-related diseases?

d. How do clinicians and health workers respond to heat-related diseases?

9. Climate services in South Africa

9.1 What is the status of climate services in South Africa?

a. How have climate services in South Africa evolved?

b. How are climate services in South Africa linked with the regional and international climate services architecture?

c. What institutions are produce, deliver and use climate information in South Africa?

d. What institutions broker climate information in South Africa?

e. What climate services initiatives has South African institutions been involved in?

f. Which policies were enacted to advance climate services in South Africa?

g. What mechanisms coordinate or govern climate services in South Africa?

h. What themes does existing literature on climate and health explore?

10. Accessibility to, types, and coverage of weather and climate information in Agincourt area

10.1. What is your understanding of the meaning of the terms 'weather' and 'climate'?

10.1.a. Do you think these terms are similar or different?

10.1.b. How do other community members understand the terms weather and climate?

10.2. How accessible are weather and climate information?

10.2.a. What are the sources of weather and climate information?

10.2.b. Does weather and climate information cover all areas in the community?

10.2.c. How do community members get the weather or climate information?

10.2.d. Is the weather or climate information specific to Agincourt area?

10.2.e. What weather or climate information do community members exchange?

10.3. Who has access to scientific climate information, e.g. seasonal forecasts?

10.3.a. Do community members trust scientific climate information, e.g., seasonal forecasts?

10.3.b. How do community members share or exchange the scientific climate information such as seasonal forecasts?

10.3.c Do community members use the scientific climate information, e.g., seasonal forecasts?

10.4. Does the community have indigenous ways to provide climate information, e.g., seasonal forecasts?

10.4.a. Do community members trust indigenous knowledge-based climate information, e.g., seasonal forecasts?

10.4.b. How do community members share or exchange the indigenous knowledge-based climate information such as seasonal forecasts?

10.4.c. Do community members use the indigenous knowledge-based climate information, e.g., seasonal forecasts?

11. Institutions for and community involvement in climate services in Agincourt Area

11.1. Which institutions produce scientific and indigenous weather and climate information?

11.1.a. Do the institutions disseminate the scientific or indigenous weather and climate information directly to community members?

11.1.b. How does the scientific or indigenous weather and climate information flow from where it is generated to where it is used?

11.1.c. In what ways are community members involved in the production of scientific or indigenous weather and climate information?
11.1.d. Are there institutional/community structures to coordinate climate services in Agincourt area?

11.1.e What policies facilitate production and delivery of climate services to communities?

11.1.f. What channels must be used to deliver climate information to communities?

12. Demand for an investment in climate services in Agincourt area

12.1. Is there a demand for climate services in Agincourt area?

12.1.a. Who are the persons who need climate services?

12.1.b. What types of climate services do communities need?

12.1.c. What investments are essential for climate services?

12.1.d. Will community members be willing to pay for the services?

12.1.e. Which institutions can pay for climate services?

13. Status of climate services for health in Agincourt subdistrict

13.1. What is the status of climate services for health in Agincourt area?

13.1.a. Are climate services for health important for communities in Agincourt area?

13.1.b. What are the barriers to the provision of climate services for health?

13.1.c. Do healthcare workers interact with the meteorological officers in this area?

13.1.d. What suggestions can you make to improve production of climate services for health?

14. The types of health-climate information required

14.1. What climate information for health do communities require?

14.1.a. Is information on Extreme Weather Events (EWEs) useful to communities?

14.1.b. Which members of the community would greatly benefit from information on EWEs?

15. Indigenous health-climate services vis-à-vis scientific climate information

15.1. What role does indigenous knowledge play in informing health practices and behaviours in the area?

15.1.a. Which persons possess indigenous knowledge that impacts human health in communities?

15.1.b. How does indigenous knowledge and practices interact with scientific climate information for health?

15.1.c. What are the suggestions that you can make to improve indigenous knowledge and practices interactions with scientific climate information for health?

16. Communicating climate services for health

16.1. What channels and languages must be used to communicate climate information for health?

16.1.a. What are the advantages and disadvantages of using agricultural extension officers to communicate climate information be acceptable to community members?

17. Investing in climate services for health

17.1. What types of investments must be made for climate services for health to be enhanced?

17.2. Who should pay for climate services for health and why?

18. Heat-Health services in Agincourt area

18.1. Are health services to protect community members from heat and heatwaves necessary in Agincourt area?

18.1.a. Are health services for heat informed by scientific climate information?

18.1.b. Are health services for heat informed by indigenous climate information?

18.1.c. What information would communities require to protect them from heat exposure?

18.1.d. What population groups would benefit most from heat-health information?

19. Community and medical staff awareness of heat-health impacts

19.1. What are the direct effects of extreme heat and heat events in the area?

19.2. What are the indirect effects of extreme heat and heat events in the area?

19.3. Do health workers in Agincourt area implement heat-health campaigns?

20.The necessity of a heat response system and its coordination

20.1. Is it necessary to have a heat response system for Agincourt communities?

20.2. By whom and how should heat-health response system be coordinated?