Protocol

# Title:

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# Introduction

High ambient temperatures above long-term averages during summer months and discrete

heat extremes (e.g. heat waves) are associated with excess mortality and considerable

morbidity[1-4]. WHO predicts that by 2030 there will be almost 92,000 deaths per year from heat waves, with sub-Saharan Africa amongst the worst affected regions[5]. Anthropogenic climate change has already resulted in a more than 1°C rise in temperature globally since the Industrial Revolution[6]. This increase is not evenly distributed across the planet, however, or even within local areas[7]. Regional differences and the effect of urban development and land use change means that many part of Africa are experiencing higher than average temperature increases, and more frequent, intensive, and longer-lasting heat waves[8]. Work done by a team at the University of Witwatersrand estimated that temperatures in Africa will rise at about 1.5 times the global rate of increase, escalating by 4-6°C above current temperatures in the sub-tropics by 2100[8].

The ‘Urban Heat Island’ is a phenomenon where concrete, non-reflective surfaces, and low greenery and wind results in temperatures considerably higher than in surrounding areas, and concomitant high levels of morbidity and mortality during heat waves[7]. This is concerning as Africa is the most rapidly urbanizing continent in the world and, by 2050, 59% of its population is expected to live in cities (up from 40% in 2018)[9]. In many African cities, nearly half of the population lives in informal settlements or “slums” that are often located in areas unsuitable or undesirable for other uses[10]. People living in these areas have high exposure to heat, as, for instance, informal settlements are often in low-lying hotter parts of cities, are typically densely settled and crowded, lack vegetation cover, have limited or no shade, and poor natural ventilation[11]. Moreover, typical housing materials in informal housing – iron metal sheeting – accentuate heat exposure, with temperatures inside these dwellings commonly 3-4°C warmer than outdoors[12, 13]. In fact, much of the urban environment in African cities offers little heat insulation, with low-cost government-built housing, school classrooms and prefabricated clinics, for example, also often exceeding outdoor temperatures by 3-4°C, or more[11, 13-15]. People inside these structures commonly report heat-exposure symptoms such as fatigue, difficulty breathing, and headaches[14-17]. Heat exposure in occupational settings such as manual labor in factories, construction sites or other outdoor activities can also reach dangerous levels[18]. Urban poor are most vulnerable to heat exposure for a range of factors related to heightened sensitivity (such as high rates of HIV, malnutrition, and non-communicable diseases) and to lowered adaptive capacity (such as lack of access to cool water, air conditioned spaces, health services, and occupational protections). Taking all these factors together means that, for example, an elderly woman living in a tin shack who has respiratory compromise from previous TB will have very few or no options for protecting herself from heat stress. We need to understand the impact that a heat wave has on her health outcomes, and what more can be done to protect her and other vulnerable groups in our warming world. This is critical information as most heat-related morbidity and mortality is preventable with improved preparedness and avoidance of exposure.

Impacts of heat exposure are clearly contingent not just on temperature, but also on geographical, socioenvironmental, and demographic factors[19]. Robust quantifications of the magnitude and pattern of heat vulnerability, exposure, and impacts, therefore need to include an assessment of the extent to which meteorological parameters (temperature, rainfall, wind direction, and humidity, for example), urban forms, population density, and other factors contribute to risk. Importantly, the unique characteristics of the environmental exposures, built environment, demographics, and spectrum of communicable and noncommunicable diseases in Africa mean that findings elsewhere may have little applicability to African cities. To date, however, none of the assessments of heat-health impacts in African cities have taken adequate account of the complexity of urban spaces and most have relied on relatively small datasets with poor spatial and temporal coverage (see Overall section for full literature review of the 40 studies on direct heat impacts in Africa that we located).

Worldwide, the vast majority of studies of heat hazards in cities quantify environmental vulnerability and develop temperature hazard maps without linking these to actual health outcomes (see for example:[11, 20-22]). Equally, studies that focus primarily on health outcome data such as excess mortality during heat waves seldom integrate data on vulnerabilities other than age and presence of chronic diseases[23, 24]. Many studies use summary health outcome data for a district, or hospital record data[4, 25], and assume that the temperatures that patients experienced in the district and their living conditions are uniform. Coarse location information constrains the ability to map health outcomes and limits the extent to which outcomes may be linked with environmental stressors and population activities such as work and residential location.

Studies of heat impacts in cities in high-income countries have found that risk for heat-related morbidity and mortality are highest among the elderly, those with chronic cardiovascular or respiratory conditions, and people who are homeless or in lower socio-economic groups[19]. Some studies in Africa have documented higher heat health risks among the elderly,[23, 24, 26-29] pregnant women,[30-32] and children under five years,[23, 26, 33-36] but, as with most studies in high-income countries, have not taken into account vulnerability determined by geospatial factors. Moreover, virtually no evidence is available on whether high temperatures pose particular risks for some of the key population groups in sub-Saharan Africa, such as those living with HIV. This is a critical question: there are an estimated 26 million people living with HIV on the subcontinent, up to 30% of adults are infected in some countries, and some 440,000 deaths are due to AIDS annually[37, 38]. Of note, rates of HIV are highest in areas most vulnerable to heat impacts, such as informal settlements[37]. In a Pubmed (MEDLINE) search on 7/11/2020, we located three studies that had documented the impacts of heat exposure (measured through actual temperatures) on disease patterns in HIV-infected people[39], and 13 that had identified increased levels of adverse conditions during the summer or the ‘warm’ seasons[40-52]. Increased rates of adverse health conditions during the warm seasons strongly suggests that more nuanced analyses of temperature exposures will demonstrate sizable temperature-outcome relationships and actionable information.

Reducing risks to health from current and projected high temperatures depends not only on physiological acclimatization, but also on planned adaptation by the health and other sectors. Early Warning Systems (EWSs) play a central role in the health sector response to heat waves, as noted in several seminal papers on the topic by K Ebi (co-PI) and J Hess (OSC) from UW[53-59]. These Systems form the central element in the health system’s response to heat waves as outlined in a key USAID report in 2019, and in WMO/WHO guidelines, both co-edited by Ebi[60, 61]. Once a predefined temperature threshold is exceeded, warnings trigger a set of actions intended to lower exposure to harmful temperatures and to assist people to take protective actions. Common interventions in high-income countries include opening of public cooling shelters, targeted messaging, wellness checks, distribution of cold water, and surveillance systems[61, 62]. EWSs have been shown to reduce morbidity and mortality during heat waves[54, 61], including in low- and middle-income countries[63]. EWSs in Ahmedabad, India for example, led to a dramatic decline in heat wave deaths in 2015 compared to a similar heat wave in 2010, as shown in an evaluation by J Hess (OSC, UW)[63]. Over longer time scales, changes to the built environment such as green roofs, shade structures, reflective surfacing, and painting surfaces white can reduce heat exposures in urban areas[64, 65]. These structural interventions are unlikely to be feasible at scale in most African cities for some time, however. Well-functioning, adequately sensitive EWSs accompanied by preventive measures such as dedicated cool spaces for high-risk groups, community health worker outreach, water supplies, and closing of schools and workplaces will be the mainstay of heat wave responses in the short- to medium-term in African cities[61]. Developing effective interventions such as EWSs requires understanding community members perceptions and lived experiences of heat extremes, and associated lifestyles, behaviors, and social circumstances[56]. Alternative data sources, for example social media, have the potential to answer these questions, but remain largely untapped.

Within Africa there is a pressing need to identify: i) the aspects of socio-economics and demographics such as housing types and density, commuting distances, and working conditions, that contribute to heat vulnerability and exposure; ii) the types of heat exposure that are most dangerous for people living in different conditions in African cities (e.g. night time temperatures or daily maximums, extremes, or long-term accumulated heat burden); iii) geospatially detailed heat-hazard conditions across cities related to altitude, vegetation, water bodies, and risk groups under different large-scale weather conditions; iv) people’s understanding of heat as a health hazard and how these risks are framed; and v) novel solutions for communicating warnings of heat exposure, tailored to the particular cluster of risks in different populations, such as individualized warnings in a digital App. Answers to these questions would constitute a major leap towards developing interventions to reduce vulnerability and build resilience against extreme heat in African cities.

## Public Health relevance

HE2AT Center Overall - Project Narrative The Heat and Health African Transdisciplinary Center (HE2AT Center) will generate new knowledge on the impacts of heat waves and extreme heat on clinical conditions and on people living in vulnerable urban settings, applying data sciences approaches to existing environmental and high-quality health outcomes data. Perhaps more importantly, the Center will develop and test innovative solutions for tracking heat-related conditions at a district level and for providing individualized early warnings of dangerous heat periods relevant to high-risk groups, industry and the general population. In all Center activities we will build capacity of the team and key organizations, engage with communities, government and other stakeholder, and work across the DS-I Africa Program.

# Aims and Objectives

Aim 1 begins with quantifying intra-urban socio-economic and environmental vulnerability in Abidjan, Côte d'Ivoire and Johannesburg, South Africa. This involves deploying a range of machine learning methods to construct an index of intra-urban socio-economic and environmental vulnerability factors (e.g. housing types, formal versus informal areas, green compared to built-up areas, population mobility, commuting conditions, and distance from health services), drawing on satellite image analysis, socio-economic data, and open mapping data. Then, in a separate activity, we will use machine learning models to develop high resolution urban temperature hazard maps, using coarse scale weather and seasonal forecast model features combined with high resolution simulation data, urban elevation, land use, and building types.

Aim 2 then involves developing a spatially and demographically explicit heat-health outcome model. The model will integrate operational weather forecasts with the high-resolution weather hazard data and vulnerability models generated in Aim 1, to forecast the probability of adverse health outcomes days and even weeks in advance. Potentially, a pilot project will use social media data to evaluate public perceptions of urban heat exposure and relate these to actual weather data in order to identify the threshold conditions under which intensive heat emerges in the public discourse. These thresholds represent the temperatures at which the public is likely to heed warnings and adopt protective behaviors. Content and sentiment analyses of these data can provide insights to shape the framing and communication of heat warnings.

In the final set of activities (Aim 3) we will develop an Early Warning System, including a digital App, driven by the heat-health outcome forecast model developed in Aim 2 that has the potential to support the general population, health workers, large employers, and others to plan for adverse health impacts. These warnings constitute the fulcrum of the health sector response during a heat wave as they trigger sets of interventions to lower health risks of extreme heat and help to prepare the health system for an increase in cases of heat related illnesses. Individuals who download the App will be provided with a warning when dangerous weather is forecasted, taking into account their vulnerability based on geolocation and individual health risks. The system will also allow for gathering of information on App usability and feedback information, allowing for data collection, and testing and re-calibration of the underlying heat-health model. Governments will also be supported to modify their Early Warning System to include specific temperature thresholds for different population groups, based on their risks. The Vulnerability-Heat-Health approach used in the Project has particular relevance for industries with outdoor workers. These industries need warnings on extreme heat to be sensitive and specific in order to avoid health and economic losses.

# Methods

## Study setting

## Sampling

# Data Management and Analysis Plan

## Outcome definition

### Risk factors for adverse outcomes due to heat

## Exposure definition

## Other variables of interest

# Ethical Considerations

# Logistics

## Project Timeline

Chart

Description automatically generated with medium confidence

## Funding

# Dissemination and Publication Plan

The HE2AT Center will disseminate study findings and other learnings in a timely manner across our consortium and to policymakers, the scientific community, other stakeholders, and the general public to maximize its impact. Our engagement plan includes:

* Scientific publications and presentations to scientific conferences;
* Community engagement; and
* Policy engagement

Scientific publicationsfrom the Research Projects will be published in open access journals with data sharing.

The final protocol for Research Project 1 will be made available on open access to allow replication of the approach in other settings and will be registered with the appropriate registry. It is anticipated that the project will generate high quality data sufficient for at least four publications in high-impact journals. A publication plan will be developed within the consortium that will define the potential publications, authorship, and timeline for manuscript production, as set out in the Administration Core.

Each year there will be *presentations to scientific conferences*, such as the International Society for Environmental Epidemiology, the NIH biannual meetings, the EDCTP Forum, and others. Presentations also will be made upon request to meetings organized by the African Regional Office of the World Health Organization, the United Nations Environment Programme, the United Nations Development Programme, and others. The emphasis will be on promoting junior researchers to increase their confidence and skill in preparing and delivering scientific presentations. Costs for these presentations are included in the Research Projects.

The HE2AT Center will promote the Projects and its findings among the *communities* in which the research will be conducted, to ensure increased acceptability of the Projects and its objectives. Dissemination tools such as newsletters, brochures, and introductory project posters, may be distributed among the community. We will emphasize the guiding principles of Good Participatory Practice, including respect, mutual understanding, integrity, transparency, accountability, and autonomy. Some of the team members already engage frequently with the media about climate or extreme heat concerns, which opens up further avenues for dissemination of findings.

Project results will be disseminated to the *local, provincial, and national authorities*, to inform their Climate Change Adaptation Planning. Very often these authorities do not receive sufficient technical support for the design and implementation of the types of solution that will be developed in Research Project 1 and Research Project 2 (Overall Hub Aim 4). The Africa CDC will play a major role in dissemination activities of the HE2AT Center: they are fully committed to actively participate in the activities of the Center and to host joint dissemination meetings or consultations. Timely dissemination of results is key for updating guidance and for informing national and international policies. The results may contribute to policies on early warning systems and their implementation; and integrated surveillance strategies for low- and middle-income countries.

# Appendices

# References