LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

HUMAN HEALTH

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

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On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

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LONG-TERM ADAPTATION SCENARIOS FLAGSHIP RESEARCH PROGRAMME (LTAS)

CLIMATE CHANGE IMPLICATIONS FOR HUMAN HEALTH IN SOUTH AFRICA

LTAS Phase 1, Technical Report (no. 4 of 6)

The project is part of the International Climate Initiative (ICI), which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

LTAS	Long-Term Adaptation Scenarios Flagship Research Project
NCCRP	National Climate Change Response White Paper
DoH	Department of Health's
NCD	Non-Communicable Disease
PM	Particulate matter
WHO	World Health Organisation
HIV	Human Inmmuno Deficiency Virus
AIDS	Acquired Immune Deficiency Syndrome
MDGs	Millennium Development Goals
UNDP	United Nations Development Programme
HR	Human Resource
SA–NFCS	South African National Food Consumption Survey
TB	Tuberculosis
UNICEF	United Nations Children's Fund
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies model
SANA	Situation Analysis and Needs Assessment Process

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THE LTAS PHASE 1

The Long-Term Adaptation Scenarios (LTAS) Flagship Research Programme (2012–2014) is a multi-sectoral research programme, mandated by the South African National Climate Change Response White Paper (NCCRP, para 8.8). The LTAS aims to develop national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways. During its first Phase (completed in June 2013), fundamental climate modelling and related sector-based impacts and adaptation scoping were conducted and synthesised. This included an analysis of climate change trends and projections for South Africa that was compared with model projections for the same time period, and the development of a consensus view of scenarios for three time periods (short-, medium- and long-term). Scoping of impacts, adaptation options and future research needs, identified in the White Paper and guided by stakeholder engagement, was conducted for primary sectors namely water, agriculture and forestry, **human health**, marine fisheries, and biodiversity. This modelling and scoping will provide a basis for cross-sectoral and economic assessment work needed to develop plausible adaptation scenarios during Phase 2 (scheduled for completion in April 2014).

Six individual technical reports have been developed to summarise the findings from Phase 1, including one technical report on *climate trends and scenarios for South Africa* and five summarising the *climate change implications for primary sectors*: water, agriculture and forestry, **human health**, marine fisheries, and biodiversity. A description of the key messages emerging from LTAS Phase 1 has been developed into a *summary for policy-makers*; as well as into seven factsheets constituting the LTAS *Climate and Impacts Factsheet Series.*

REPORT OVERVIEW

This technical report presents the LTAS Phase I findings for the **human health** sector in South Africa. It references existing South African research combined with insights from international research and global projections to present a preliminary picture of potential impacts of future climate change on human health in the country. Specifically, it summarises the climate change impacts as well as adaptation response options and future research needs for the human health sector, based on the results of relevant past and current research, including the Department of Health's (DoH) National Climate Change and Health Adaptation Plan (DoH, 2012–2016).

LTAS Phase I adopted a narrative, theoretical approach to analysing the likely impacts of climate change on human health in South Africa. This is because during the Phase I process it became evident that the relationship between climate change impacts and human health is not yet well understood quantitatively. In particular, research is not at a stage where the health impacts stemming from climate change can be accurately projected spatially and temporally. Furthermore, research gaps within South Africa prevent a full understanding of the vulnerability of the health sector to climate change. The focus is on nine selected health risks and/or conditions that are likely to be impacted by future climate change, identified by the DoH in the National Climate Change and Health Adaptation Plan (DoH, 2012–2016). These include heat stress; vector-borne diseases; food insecurity, hunger and malnutrition; natural disasters; air pollution; communicable diseases; non-communicable diseases (NCD); mental health; and occupational health.

Chapter 1 (Introduction) describes the existing health challenges and priorities in South Africa.

Chapter 2 (Climate change vulnerability) describes the underlying social and environmental factors in South Africa that contribute to public health vulnerability to climate change; and provides an overview of selected health and environmental risks identified by the DoH as climate change adaptation priorities.

Chapter 3 (Climate change impacts on human health) describes the climate change impacts on heat stress, vector-borne diseases (malaria as a case study), natural disasters, air pollution, communicable diseases (cholera as a case study), and non-communicable diseases (e.g. cardio-vascular and respiratory diseases) as well as the negative effects of climate change on mental and occupational health, and food insecurity (hunger and malnutrition).

Chapter 4 (Climate change adaptation response options) provides an overview of adaptation response options for South Africa.

Chapter 5 (Research requirements) identifies research areas where modelling and projections are advanced or limited and cross-sectoral linkages that need to be integrated into research and adaptation planning moving forward.

Chapter 6 (Conclusion) concludes the report highlighting cross-sectoral linkages in particular with the water and agriculture sectors and the importance of multi-sectoral collaboration in conducting research and in developing and implementing adaptation plans.

Annex 1 summarises the available projections, research needs, metrics and cross-sectoral linkages to consider for key health risks.

EXECUTIVE SUMMARY

South Africa faces complex and pressing public health challenges. These challenges are exacerbated by adverse socio-economic conditions that include dense informal settlements, which constrain effective service delivery. Climate change will exacerbate human health challenges by aggravating a number of existing health and environmental risks. Adaptation to the potential effects of climate change on human health is usefully viewed in this context. However, significant knowledge and information gaps prevent well supported quantitative projections of human health impacts in South Africa.

Existing health risks in South Africa that direct and indirect climate change exposures over the next few decades would aggravate include heat stress, vector-borne diseases (e.g. malaria, dengue fever and yellow fever), natural disasters, air pollution, communicable diseases (e.g. HIV/AIDS, TB and cholera), and non-communicable diseases (e.g. cardio-vascular and respiratory diseases). Climate change could also have deleterious effects on mental and occupational health, and its adverse impacts would be worsened by food insecurity, hunger and malnutrition.

- Increases in average temperatures and episodic extreme events (e.g. heat waves) resulting from a changing climate may have increasingly significant direct impacts on human health. For example, high temperatures are known to induce **heat stress** and increase morbidity and mortality rates, as well as result in non-communicable diseases such as respiratory and cardiovascular diseases.
- Over time, a changing climate would lead to changes in the distribution of **vectors of disease** such as mosquitoes and ticks. This may change the distribution of diseases like malaria and Lyme disease (tick bite fever). However, malaria has been shown to be strongly impacted by non-climatic factors such as land use, control measures, and socio-economic, demographic and vulnerability information.
- A critical indirect constraint to the health sector as a result of climate change may emerge through adverse impacts on the agricultural sector leading to **food shortages and malnutrition**. An increase in the frequency/intensity of dry spells and flood events under a changing climate will result in compromised food availability, food access, and food utilisation, leading to food insecurity. Ecosystem changes could also lead to loss of ecosystem goods and services that currently support healthy environmental conditions that underpin agriculture activities and local community livelihoods.
- The frequency and intensity of **natural disasters** (e.g. flood, storms, drought and fire) is likely to increase in certain areas of South Africa as a result of climate change. Health impacts from natural disasters can be immediate (e.g. death), long-term (e.g. food insecurity/unavailability linked to impacts on agricultural production such as crop yields), direct (e.g. injuries as a result of a landslide) or indirect (e.g. changing vector abundance through habitat destruction or creation), and are difficult to project with the current knowledge base. Social support mechanisms as well as the availability of basic social services greatly influence the effect of extreme weather events on communities.
- Climate change may impact **air quality** in South Africa by affecting weather and thereby negatively influencing pollutants such as particulate matter (PM), sulphur dioxide, ozone, carbon monoxide, benzene, lead and nitrogen dioxide. Health impacts in South Africa resulting from exposure to these pollutants include eye irritation, acute respiratory infection, chronic respiratory diseases and TB sometimes resulting in death.
- **Non-communicable diseases**, such as cardiovascular and respiratory diseases (asthma

and bronchitis), are the leading cause of death in South Africa. Climate change will impact non-communicable diseases directly (e.g. by increasing temperatures and air pollution concentrations) and indirectly (e.g. by adversely impacting agricultural yields and resulting in food insecurity).

- The transmission of **communicable diseases** in South Africa is related to rainfall, temperature and wind. Non-climatic factors such as water insecurity, lack of proper sanitation and population density also influence cholera transmissions. Cholera is a well-known example of a communicable, diarrhoeal and water-borne disease in South Africa. The transmission of cholera is linked to rainfall and temperature (air and sea surface) and, as such, it is likely that it will be affected by climate change-induced changes in rainfall and temperature regimes.
- Climate change will disrupt social and biophysical life support systems (e.g. displace communities, destroy homes, and result in loss of life). This will have serious implications on **mental and occupational health** (e.g. agricultural labourer's productivity) and human well-being.

A quantitative vulnerability and risk assessment for the health sector is an important next step to identify which climate change impacts are most critical and which populations/communities in South Africa are most vulnerable. Health vulnerability assessments would benefit from area-specific analysis, and from a quantitative understanding of cross-sectoral impacts such as those affecting water and food security. The Department of Health, in collaboration with the World Health Organisation (WHO), is in the early stages of developing the first vulnerability assessment of the health sector in South Africa. This, however, will need to be expanded to include vulnerability and risk assessments of specific diseases to climate change, and impact modelling (including consideration of non-climatic factors) to determine risk factors and health impacts which need to be addressed through adaptation. Improved data and enhanced access to data would allow for high-quality surveillance of diseases and risk factors to ensure successful adaptation planning.

At present, research capacity in South Africa does not permit full quantification of climate change impacts on human health. There are existing models and research available for developing certain types of projections, in particular for heat stress, cholera and malaria, with the modelling of the latter being the most robust. However, even for malaria, models do not yet take account of non-climatic factors that need to be considered in projections, as they play a significant role in the transmission/spread of the disease. Furthermore, there is a need to understand other existing disease vectors and how they may be affected by climate change. Projections of malnutrition (either considering or not considering climate change) are not available for South Africa. There are also no air quality projections and therefore the effects of climate change on criteria pollutants cannot be projected. Research is ongoing to project natural disasters; however, these have not as yet been linked to effects on the health sector. Population and environmental models need to be combined to form dynamic models for predicting climate change effects on health risks in South Africa.

Malnutrition and natural disasters are key risks for the human health sector in South Africa. This is because of the cross-sectoral implications and linkages with the water and agriculture sectors. Multi-sectoral collaboration is therefore needed in conducting research and in developing and implementing adaptation plans. Including adaptation measures that support the health sector into other sector policies would facilitate ensuring that health-climate considerations are included in future development and adaptation planning, and in building the climate resilience of vulnerable communities in South Africa.

1. INTRODUCTION

The impacts of climate change on human health are complex and typified by multiple cause and effect pathways, interactions and linkages (Figure 1). Potential health impacts as a result of climate change range from direct exposure (e.g. anomalous temperature and rainfall, and an increase in the frequency and intensity of natural disasters) and/or indirect exposure (e.g. through impacts on agriculture and by optimising the environment for disease vectors) as well as social and economic disruption (Confalonieri et al., 2007).

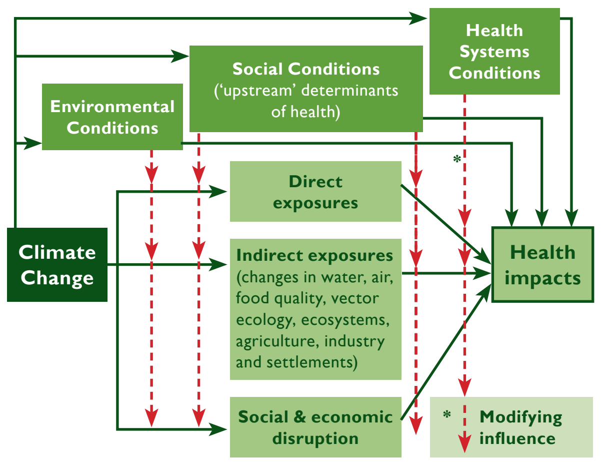


Figure 1: Drawing outlining how health might be impacted by climate change. The dotted lines highlight the potential for modifying influences (Confalonieri et al., 2007).

Modifying or non-climatic factors (as highlighted in Figure 1) act either to alleviate or exacerbate the negative health outcomes. For example, if climate change results in increases in temperatures (direct exposure), there is a risk to public health (i.e. heat stress). If the health system is prepared to react quickly to high temperature events then it can be a modifying influence that alleviates the potential negative health impacts. The impact of these modifying factors is highlighted and discussed in this report.

The effect that climate change will have on human health in South Africa is currently not well quantified. There are, however, indications that the southern African region will be the most impacted in the world. A study by the WHO quantified the impact that climate change had on human health by modelling the health impact that four climate-sensitive health risks (diarrhoea, malaria, inland and coastal flooding, and malnutrition) had in 2000 compared with their impact in 1990 (McMichael et al., 2004). Southern Africa was found to be the region with the largest mortality rates due to climate change. While this study looked at only a partial list of health impacts and the results are a conservative indication of health impacts from climate change, the high impact of climate change on southern Africa indicates a potentially large public health problem. It is critical for South Africa to understand the potential magnitude of the health impacts from climate change, including what areas and communities may be most vulnerable to these impacts and the adaptation measures needed to mitigate an increase in negative health impacts.

1.1 Key health challenges in South Africa

Mortality in South Africa has worsened between 1990 and 2005, primarily owing to the high HIV and AIDS prevalence rate (10.6%; StatsSA, 2012). South Africa has a quadruple burden of disease based on the country's mortality profile (ECONEX, 2009), meaning that there are four main categories that strongly influence the country's burden of disease. These are: i) HIV/AIDS and TB; ii) maternal and child mortality; iii) non-communicable diseases (NCDs); and iv) violence, injuries and trauma (DOH, 2011a). NCD accounts for 41% of the estimated deaths in South Africa (Figure 2)[1].

1 A country's burden of disease pertains to the overall review and evaluation of the following parameters: mortality, morbidity, injuries, disabilities and other risk factors specific to that country (ECONEX, 2009). The Global Burden of Disease assessment (undertaken by the WHO) looks at mortality and loss of health due to diseases, injuries and risk factors for all regions of the world (WHO, 2013a). The overall burden of disease is computed by using the disability-adjusted life years (DALYs), which combines the years of life lost due to premature mortality and years of life lost due to time lived in states of less than full health (WHO, 2013a).

The quadruple burden of disease is a unique situation that highlights that South Africa is dealing with both “development issues” (e.g. malnutrition, maternal and child mortality) that generally have a large impact in developing countries and “lifestyle issues” (e.g. non-communicable diseases) that generally have a large impact in developed countries. This also highlights the challenges facing the health system in the country.

Progress towards achieving the Millennium Development Goals (MDGs) is another metric used to measure the state of a country’s health. The MDGs, established following the Millennium Summit in 2000 (UNDP, 2010), that all 189 UN member states have agreed to meet by 2015 include:

1. To eradicate extreme poverty and hunger;
2. To achieve universal primary education;
3. To promote gender equality and empower women;
4. To reduce child mortality;
5. To improve maternal health;
6. To combat HIV/AIDS, malaria and other diseases;
7. To ensure environmental sustainability, and
8. To develop a global partnership for development.

There has been limited progress within South Africa towards meeting the health-related MDGs (Figure 3). There appears to have been no progress towards the eradication of extreme poverty and hunger (MDG 1) since 2009 (Figure 3). In 2008, 9% of children younger than 5 years were underweight for their age and the average annual rate of reduction of poverty and hunger from 1990 to 2006 was 5.5%. There has also been little or no progress towards achieving MDG 4, pertaining to the reduction of childhood mortality, since 2009 (Mayosi et al., 2012). Similarly, no improvement towards attaining MDG 5 in South Africa has been realised (Mayosi et al., 2012) and there has been insufficient to minimal progress towards meeting MDG 6, related to combating HIV/AIDs, malaria and other diseases (Mayosi et al., 2012).

It is anticipated that climate change will further hinder progress in South Africa towards achieving the MDGs (see Table 1). Some of the negating and detrimental impacts of climate change that are important are morbidity and mortality outcomes, and an increased vulnerability to infection.

Table 1: Potential impacts of climate change on the MDGs in South Africa (redrawn from Blaauw & Penn-Kekana, 2010.)

MDG	Potential impacts of climate change
Goal 1 Eradicate extreme poverty	Further damage to progress likely due to climate change impacts on livelihoods, food security and environmental resources available to the urban and rural poor.
Goal 2 Achieve universal primary education	Frequent natural disasters may disrupt regular education. More children (especially girls) may be taken out of school to earn an income or care for ill family members. Food insecurity and hunger may reduce school attendance and the ability of children to learn and complete primary education. Displacement and migration may disrupt education.
Goal 3 Promote gender equality and empower women	Progress may be reversed if women and girls are compelled by natural disasters to help generate income and support their families. Deaths and illnesses due to extreme weather events have been shown to disproportionately affect women rather than men.
Goal 4 Reduce child mortality	Morbidity and mortality are likely to increase due to climate change-related population migration or displacement, food insecurity and increased risks of water-borne and vector-borne diseases.
Goal 5 Improve maternal health	Morbidity and mortality are likely to increase due to climate change related population migration or displacement, food insecurity and increased risks of water-borne and vector-borne diseases.
Goal 6 Combat HIV and AIDS, malaria and other diseases	Increased vulnerability to infection due to increased water contamination, air pollution, increased malnutrition and changing patterns of vector-borne disease.

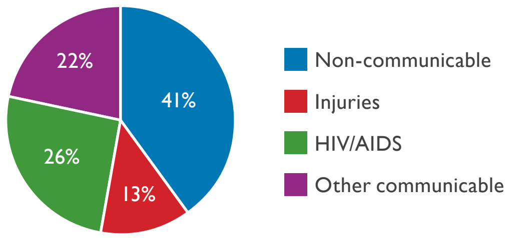


Figure 2: Estimated deaths by broad categories for South Africa, 2000 (redrawn from ECONEX, 2009).

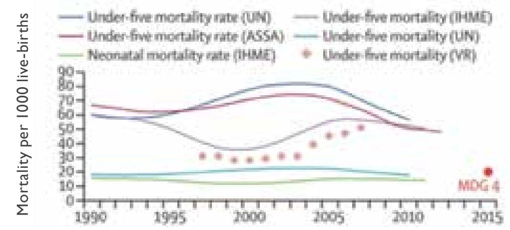
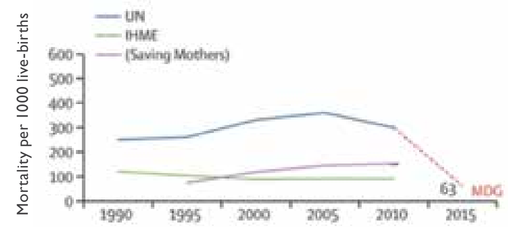
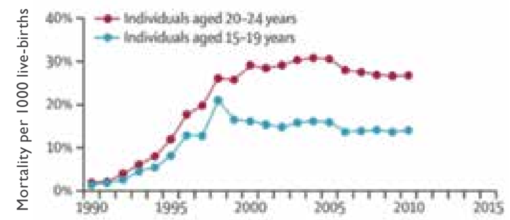
	Status in South Africa?	On track?
MDG 1: Eradicated extreme poverty and hunger	9% of children younger than underweight for age in 2008 Average annual rate of reduction 1990-2006: 5.5% (Target average annual rate of reduction of 2-6% or prevalence of 5% or less)	Reversal of Progress
MDG 2: Achieve universal primary education	94% of children enrolled in primary schools in 2010 (Target 90%)	Insufficient Progress
MDG 3: Promote gender equality and empower woman	1:1 ratio of female-to-male children enrolled in primary school in 2010	Yes
MDG 4: Reduce child mortality by two-thirds (from 1990)		Reversal of Progress
MDG 5: Improve maternal health (reduce 1990 maternal morality ratio by three-quarters)		No Progress
MDG 6: Combat HIV, AIDS malaria, and other diseases		Insufficient Progress

Figure 3: South Africa’s progress since 1990 towards achieving the MDGs by 2015 (reproduced from the review done by Mayosi et al., 2012).

1.2 Health priorities in South Africa

The DOH concentrates on the following central themes to improve the health status of South Africans (DOH, 2013):

- Increasing life expectancy;
- Decreasing maternal and child mortality;
- Combating HIV/AIDS and decreasing the burden of disease from TB; and
- Strengthening health systems effectiveness.

The current health systems and services that are implemented in South Africa have had numerous accomplishments as well as shortcomings (Table 2; Harrison, 2009).

In order to improve the health status of the South African population, the DOH developed the following 10 point plan aligned with the vision of a healthy life for all South Africans (reproduced from SAGI, 2012):

- Providing strategic leadership and creating a social contract for better health outcomes;
- Implementing the National Health Insurance system;
- Improving quality of health services;
- Overhauling the healthcare system and improving its management;
- Improving human resource (HR) management, planning and development;
- Revitalising infrastructure;
- Accelerating implementation of the HIV and AIDS and Sexually Transmitted Infections Strategic Plan 2007–2011 and increasing focus on TB and other communicable diseases;
- Reviewing the drug policy;
- Improving the effectiveness of the health system; and
- Strengthening research and development.

Table 2: Principal accomplishments and deficiencies in the past 15 years with regard to legislation and gazetted policy and better health systems management (redrawn from Harrison, 2009).

Accomplishments
Legislations and gazetted policy
1. Free primary health care
2. Essential drugs programme
3. Choice on termination of pregnancy
4. Anti-tobacco legislation
5. Community service for graduating health professionals
Better health syçstems management
6. Greater parity in district expenditure
7. Clinic expansion and improvement
8. Hospital revitalisation programme
9. Improved immunisation programme
10. Improved malaria control
Shortcomings/deficiencies
Insufficient prevention and control of epidemics
1. Limited effort to curtail HIV/AIDS
2. Emergence of MDR-TB and XDR-TB
3. Lack of attention to the epidemic of alcohol abuse
4. Persistently skewed allocation of resources between public and private sectors
5. Inequitable spending patterns compared to health needs
6. Insufficient health professionals in public sector
Weaknesses in health systems management
7. Poor quality of care in key programmes
8. Operational inefficiencies
9. Insufficient delegation of authority
10. Persistently low health worker morale
11. Insufficient leadership and innovation

1 A country's burden of disease pertains to the overall review and evaluation of the following parameters: mortality, morbidity, injuries, disabilities and other risk factors specific to that country (ECONEX, 2009). The Global Burden of Disease assessment (undertaken by the WHO) looks at mortality and loss of health due to diseases, injuries and risk factors for all regions of the world (WHO, 2013a). The overall burden of disease is computed by using the disability-adjusted life years (DALYs), which combines the years of life lost due to premature mortality and years of life lost due to time lived in states of less than full health (WHO, 2013a).

2. CLIMATE CHANGE VULNERABILITY

2.1 Exposure, sensitivity and adaptive capacity

To contextualise public health within the broader vulnerability framework, it is important to define vulnerability. Vulnerability denotes the extent to which a system, be it the environment, economy or social system, is prone to damage or degradation by hazards (Kaly et al., 2002). Vulnerability is a function of the impact of a hazard on a system mediated or modified by the system response to such hazards. The degree of impact caused by the exposure to the system is dependent on the integrity of the system, which can either enhance or lessen the level of impact experienced by the system. The integrity of the system, which is influenced by both system inherent characteristics as well as external forces, therefore determines how sensitive or susceptible it is to hazards. The interactions among all the factors defining vulnerability are defined in terms of the three characteristics of vulnerability, namely, exposure, sensitivity/susceptibility and adaptive capacity (WHO, 2003):

- **Exposure:** refers to "contact" between agent (e.g. extreme temperature) and target (e.g. individual/community/population).
- **Sensitivity**: refers to the degree of susceptibility to the exposure.
- **Adaptive capacity**: refers to those characteristics that enable the system to respond to exposure to the hazard.

Sensitivity describes the characteristics of the population and the extent to which health, or the social and the biophysical systems on which health outcomes depend, are sensitive to changes in weather and climate (WHO, 2003). At an individual or household level, social vulnerability (sensitivity) is a construct of social status, income sources and their diversity, access to resources, social networks and socio-cultural issues and perceptions (Adger, 1999; Johnsson, 2006). At collective levels, whether at community, national or regional level, social vulnerability is a construct of institutional and market structures, access to social security and insurance, infrastructure, technologies, level of economic development, sociocultural aspects of a population and political environment (Adger 1999; Johnsson, 2006).

Environmental vulnerability is concerned with the risk of damage to the biophysical environment (Kaly et al., 2002). It is a function of both natural and anthropogenic hazards. It may stem from, among others, extreme climate and weather events – including heavy or extreme precipitation, extreme temperatures, pollution, natural disasters, and infrastructure poverty (lack of appropriate infrastructure) (Abson et al., 2012). These factors may lead to the biophysical environmental limits being exceeded resulting in the loss of life support ecosystem goods and services (Kaly et al., 2002). It is important to understand the interaction between exposure and sensitivity in order to gain a better understanding of what adaptive capacity measures may be necessary to respond effectively to climate change and adverse weather events.

Vulnerability of population/public health (target) to climate change (agent) can be defined as the degree to which the public health system is susceptible to the effects of climate change. Exposure in this context refers to the contact between the public health system and climate change and adverse weather events. Sensitivity of the public health system deals with those characteristics that inform the response of the system to the effects of climate change and adverse weather events. Public health adaptive capacity refers to the ability of the system to effectively respond to climate change and adverse weather events. Overall, the relationship between climate change exposure and outcome can be altered or modified by the social and biophysical vulnerability of a population. Poverty, health status and urbanisation are used below to highlight some of the vulnerability factors (both social and environmental) that contribute to public health vulnerability to climate change.

To implement public health strategies effectively in order to prevent diseases, promote health and prolong life, it is important to consider social determinants of health, which are influenced by the social fabric of society (Marmot, 2005). The social and biophysical environments (built and natural environments) provide the building blocks of the social fabric of society in the form of material, psychosocial, behavioural, genetic and socio-cultural factors (Marmot and Wilkinson, 2005), and of the distribution of resources, money and power across global, national and local levels (WHO, 2013b). The interplay of these factors drives inequalities and vulnerability to health threats within populations. Vulnerability to health threats is thus a function of these social and biophysical characteristics. A public health approach that is participatory and inter-sectoral in nature is required for reducing inequalities and the vulnerability of populations to health threats.

2.1.1 Poverty

Socio-economic factors marked by low income levels, low levels of education and poor housing are factors known to impact the vulnerability of affected individuals, communities and populations to environmental stressors (Cutter et al., 2003). Poor and vulnerable communities, for example, are likely to be established on marginal lands that are prone to climate/environmental/natural disasters such as land/mudslides, pollution, and sea-level rise. Unsafe and unhygienic conditions are also likely to be present in such places giving rise to poverty-related diseases. Poor people are also likely to live in places marked by, among other things, poor environmental health considerations and poor access to social services (e.g. energy, sanitation, housing, roads). The various dimensions of poverty (e.g. social, environmental and economic) compromise the ability of affected communities to respond to external stressors thereby increasing their predisposition to excessive impact of climate change and weather related events. Addressing poverty-related issues (e.g. food, water, sanitation, shelter, employment, health, education and pollution) can improve the resilience of affected individuals, communities and populations to climate change.

2.1.2 Health status

People with pre-existing diseases are sensitive and/or susceptible to climate and adverse weather events. For example, those with cardiovascular, respiratory, and mental conditions are known to succumb to the effects of extreme temperature (WHO, 2009a; Doherty and Clayton, 2011; Rocklov et al., 2011). Those with compromised immune systems are also susceptible to climate sensitive diseases. Opportunistic infections including diarrhoeal diseases, which are climate sensitive, are known to develop in malnourished people or in people with immunosuppressing diseases like HIV/AIDS. Kulkani et al (2009) observed that transmission of *Cryptosporidium parvum* surged following flood episodes (Katsumata et al., 1998), and it was the main driver for diarrhoea in HIV/AIDS patients in India. The stage of development is also a predisposing factor for diseases. Young children because of their incomplete physiological development are prone to various diseases, including *c. parvum* related diarrhoea (Katsumata et al., 1998). The elderly are also likely to have increased susceptibility to infections because of declining efficiency of the immune system with age (Gardner, 1980).

Without proper adaptation measures, these inherent susceptibilities may worsen the burden of climate sensitive diseases (e.g. cholera, malaria, and schistosomiasis). With the expected increase in the burden of disease under climate change (Sutherst, 2004; Alexander et al., 2013), it is important that intrinsic predisposing factors such as age and burden of disease are carefully considered in climate-health vulnerability assessments as impacts are likely to be worsened by the existing burden of disease within a population.

2.1.3 Urbanisation, population growth, population displacement and forced migration

Population growth and the associated influx of people, particularly into cities, increases the demand for social services including housing, sanitation, water supply, transportation and energy. Service provision in many cities of the developing world is already limited, stressed and inadequate. Existing systems fail to cope with the increasing demand for services. As a result, the incoming population groups often end up on the peripheries of the cities with no access to basic social services. High levels of poverty are also prevalent in such communities (see section 2.1.1 on poverty above). Conflict over limited resources may also occur. Climate change may lead to loss of livelihoods for rural communities, which are often subsistence communities. Loss of livelihoods may force such communities to migrate to cities, a situation that will exacerbate problems with access to service in cities. Such communities become vulnerable to environmental stressors, poor health and the effects of climate change.

2.2 National Climate Change and Health Adaptation Plan

The DOH is currently in the process of publishing its National Climate Change and Health Adaptation Plan which concentrates on vulnerable groups, urban and rural settlements, the general South African health and environmental situation and includes research needs. This plan aims to facilitate adaptation to the adverse health impacts of climate change. The National Climate Change and Health Adaptation Plan defines nine health risks/concerns for South Africa that are likely to be directly and indirectly impacted by climate change as discussed below.[2]

2.2.1 Heat stress

High temperatures have been shown to induce heat stress and associated morbidity and mortality. Health effects associated with high temperatures include emergency room visits or hospitalisations for, among other things, respiratory and cardiovascular diseases, injury, and death (Chung et al., 2009; Ballester et al., 2011; Son, et al., 2011). There are many factors that affect the heat–health relationship. These factors are often discussed within the vulnerability to heat paradigm, which borrows from the social vulnerability to environmental stressors paradigm (Cutter et al., 2003; Reid et al., 2009). Vulnerability to heat is dependent on social, economic and environmental factors. Social and economic factors known to influence vulnerability to heat include, among others, education status, personal wealth, occupational status, types of occupation, economic sector dependence and access to social services, including type of housing and occupancy ratio, access to air conditioners, and level of development (Cutter et al., 2003; Vincent, 2004; Harlan et al., 2006; Reid et al., 2009; Yardley et al., 2011). Children, the elderly and people with pre-existing diseases including respiratory and cardiovascular diseases, diabetes and mental disorders are particularly vulnerable to the effects of high temperatures (Reid et al., 2009; Son et al., 2011) as are the poor and socially isolated (Reid et al., 2009; Son et al., 2011).

Little is known about the health impacts of high temperatures on the South African population or, indeed, on populations in the tropics in general. Many studies have, however, been performed for populations in temperate areas. Existing studies on heat stress in South Africa are largely confined to occupational environments, such as in the mining sector (e.g. Wyndham, 1965, Mathee et al., 2010). Anecdotal evidence (e.g. News24, 2012; Newling, 2012) suggests that there are incidents of direct health impacts from extreme heat in South Africa. However, there is no known database in South Africa that records and monitors the direct impacts of heat on health. In addition, there are no consistent occupational guidelines for people working outdoors.

Environmental factors important in vulnerability to heat include air pollution, number of open spaces, and tree cover (Cutter et al., 2003; Vincent, 2004; Yardley et al., 2011).

2.2.2 Vector-borne diseases

Little is known about disease vectors in South Africa, including which vectors may be more vulnerable to climate change impacts. Vectors in South Africa include mosquitos (malaria, dengue fever and yellow fever) and ticks (Lyme disease). This report focuses on malaria as an example of a vector-borne disease.

2.2.2.1 Malaria

Malaria in South Africa is seasonal and endemic in the low-altitude northern and eastern parts of the country along the border with Mozambique and Zimbabwe, with transmission taking place mainly in Limpopo, Mpumalanga and KwaZulu-Natal provinces (Blumberg and Frean, 2007; DOH, 2007). The remaining six provinces have very low or no malaria cases. *Plasmodium falciparum* is the most prevalent parasite, accounting for approximately 95% of all malaria cases in South Africa (Coleman et al., 2008; DOH, 2007; Maharaj et al., 2012). Malaria cases in South Africa have dropped by 85% (from 64,622 cases to 9,866) and the number of deaths related to malaria has dropped by 81% (from 458 to 89) between the years 2000 and 2011 (DOH, 2012).

The DOH has a goal of eliminating malaria by 2015 and achieving zero locally transmitted cases by 2013. This does not account for non-locally transmitted cases, which are the majority of cases (~90%) currently in South Africa (Patrick Moonasar, pers. comms. 2013).

2.2.3 Food insecurity, hunger and malnutrition

Food insecure countries, communities and households are prone to hunger and malnutrition, which are factors that undermine the ability to respond effectively to the impact of climate change. South Africa is considered food secure. Despite this, there is a high prevalence of household hunger, indicating that the South African food system is not functioning effectively and efficiently. Potential problems in inefficient food systems may stem from issues such as distribution, prohibitive food prices, and food safety (Gregory et al., 2005; John-Langba, 2012). In order to ensure an effective food system that can withstand the impact of climate change, it is important to address both the social (e.g. affordability, allocation, social value, etc.) and biophysical (e.g. food production and distribution) components of the food system (Gregory et al., 2005).

Malnutrition refers to the compromised status of health resulting from imbalanced intake of nutritional elements necessary for proper human health. The imbalanced intake of nutrients and minerals may lead to either over-nutrition or under-nutrition (depending on excessive or deficient consumption) (Faber and Wenhold, 2007). Under-nutrition is often categorised into protein-energy and micronutrient deficiency malnutrition. Under-nutrition is a major public health problem, particularly given its impacts on childhood development. Diseases associated with micronutrient deficiency include, anaemia, goitre, vitamin deficiency, hypokalemia and hyponatremia (WHO, 2002). Malnourished children often suffer from poor cognitive development, learning disabilities and behavioural problems (Le Roux et al., 2010). Malnutrition also increases the predisposition of children to other diseases (e.g. infectious diseases) and remains the main driver behind global child morbidity and mortality (Caulfield et al., 2006). The effects of childhood malnutrition often transcend different stages of physiological development, resulting in compromised health status marked among other things by diminished cognitive ability and work capacity in adulthood (Caulfield et al., 2006). These conditions perpetuate the cycle of economic hardship, poverty, malnutrition and poor health for affected families (Caulfield et al., 2006).

Malnutrition is a significant public health problem in South Africa (Chopra et al., 2009). The 1999 South African National Food Consumption Survey (SA-NFCS) indicated that approximately 20% of 1–9 year old South African children were stunted while 10% were underweight (Labadarios et al., 2005). Children who were overweight were largely found in urban areas (Labadarios et al., 2007). The highest prevalence of malnutrition was found in the Northern Cape, followed by the Free State and Limpopo (UNICEF, 2008; Chopra et al., 2009; Hall 2012). While variability may exist, the main areas affected by high prevalence of hunger are the Eastern Cape (85%), the Northern Cape (63%), North West (61%), Limpopo (54%) and Mpumalanga (53%) (UNICEF, 2007). The SA-NFCS recommended food fortification as a means to combat the effects of micronutrient malnutrition in South Africa (Labadarios et al., 2007; Faber et al., 2005). The impact of food fortification (fortified maize porridge) has been demonstrated to reduce anaemia and improve iron status and motor development in poor infants in South Africa (Faber et al., 2005).

Socio-economic and demographic factors such as employment status, limited food budgets, household income, household hunger, poverty, education and gender are known drivers behind malnutrition (Chopra et al., 2009). In addition, place of residence, such as living in urban or rural areas and on commercial farms, was found to be an important factor in the development of malnutrition in South African children (Labadarios et al., 2005; 2007). Income and spending habits also play a part in the nutritional status of households in that affluent households tend to spend more of their food budget on refined foods (Martins, 2005), which contributes to over-nutrition, obesity and attendant health problems (Puoane et al., 2002). In contrast, many of the poor and vulnerable households tend to spend most of their food budget on high-calorie-poor-nutrient foods leading to under-nutrition (Martins, 2005; Altman, et al., 2009, Bloem et al., 2010). Malnutrition is also compounded by a complex web of external factors which are often beyond the control of the individual household. These include food production, food market dynamics, population growth, and the economic development of a country (Chopra et al., 2009).

Malnutrition may exacerbate communicable diseases and non-communicable diseases. Protein-related malnutrition, for example, increases the risk of infection and has been found to increase susceptibility to tuberculosis and HIV/AIDS related opportunistic infections (Schaible and Kaufmann, 2007). In addition, micronutrient malnutrition has been found to affect proper functioning of bodily systems, thereby increasing the risk of non-communicable diseases such as obesity, cancer, heart disease and diabetes (Eckhardt, 2006). The impact of malnutrition on communicable and non-communicable diseases is particularly important for South Africa given the country's quadruple burden of disease (Bradshaw et al., 2003).

2.2.4 Natural disasters

Natural disasters are extreme events that originate from atmospheric, geologic and hydrologic sources. Climate-related natural disasters include floods, droughts, fires, storms, landslides, and tsunamis. The onset of a natural disaster can be slow or rapid and result in detrimental health, social and economic outcomes. The health impacts that emanate from natural disasters can be immediate (e.g. death), long-term (e.g. food insecurity/unavailability linked to impacts on agricultural production such as crop yields), direct (e.g. injuries as a result of a landslide) and indirect (e.g. changing vector abundance through habitat destruction or creation). These impacts are hard to predict and compute since there are many secondary effects and delayed outcomes (Hales et al., 2003). After a natural disaster, the immediate morbidity and mortality health outcomes are far smaller than the long-term impacts (e.g. increases in communicable diseases, economic and infrastructure losses and impacts on health) (Hales et al., 2003).

2 One health risk not addressed within this report is the impact of climate change on HIV/AIDS and TB infection levels.

The current reporting structure related to natural disasters in South Africa does not include a detailed account of health impacts and, in general, there is insufficient reporting on disaster events. Information on natural disasters is usually gathered by disaster relief organisations mainly using estimates. This includes multiple sources such as the National Disaster Management Centre of South Africa, the Global Risk Data Platform and the South African Weather and Disaster Observation Service. However, these sources do not report on the direct and indirect health impacts arising from natural disasters. In each government department, there are disaster management units in addition to a national advisory forum on natural disasters. As a result, the legislation for this sector in South Africa is very good.

Communities in developing countries and rural areas are less equipped to deal with extreme weather events (Hales et al., 2003). In numerous areas, the land available to poorer communities is prone to natural disasters. Natural disasters in these areas tend to cause major loss of life and destruction of infrastructure. Migration and urbanisation increase vulnerability in towns and cities resulting in high losses from natural disasters in urban areas (Hales et al., 2003).

2.2.5 *Air pollution*

According to the WHO "air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere" (WHO, 2013c). There are two types of air pollution namely, indoor and outdoor pollution. Sources of air pollution in South Africa include fossil fuel combustion, industrial and chemical processes, solid waste disposal – mainly through incineration – and land surface disturbances giving rise to dust (i.e. unpaved roads, agricultural emissions and other wind-blown emissions) (Scorgie et al., 2004a). In addition, burning domestic fuel is a large contributor to indoor air pollution (Helas and Pienaar, 1996), and a large percentage of lower-income urbanised communities and industries employing workers earning low wages burn coal. South African air quality legislation has identified the following compounds as criteria pollutants: particulate matter (PM), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), benzene (C_6H_6), lead (Pb) and nitrogen dioxide (NO_2). These criteria pollutants are a concern for public health and their concentrations in ambient air are regulated in South Africa. Despite these regulations standards are exceeded which can result in major public health impacts. Table 3 gives additional information on these criteria.

Table 3. Criteria pollutants in South Africa and their impacts on health

Criteria pollutant	Health impact	References
PM	• Respiratory diseases (including lung disease) • Premature death	• Atkinson et al., 2011 • Dominici et al., 2006 • Schwartz, 1994 • Balakrishnan et al., 2011 • Schwartz et al., 1994 • WHO, 2003
SO_2	• Respiratory problems • Eye irritations • Cardiac disease • Premature death	• Fenger, 2002 • WHO, 2011b
O_3	• Increase in morbidity rates • Increase in mortality rates • Asthma • Damage to lung tissue • Bronchitis	• Jacob et al., 1996 • Seinfeld and Pandis, 1998 • Jacob et al., 1996
CO	• Cardiovascular disease • Cerebrovascular impacts • Behavioural impacts	• Australian Government, 2009
C_6H_6	• Skin irritations • Hematologic impacts • Reproductive and development effects • Cancer risk	• US EPA, 2012
Pb	• Neurologic impacts • Hematologic impacts • Gastrointestinal impacts • Cardiovascular impacts • Renal impacts	• WHO, 2013e
NO_2	• Wheezing • Coughing • Colds • Flu • Bronchitis	• WHO, 2013d

South Africa has the largest industrialised economy on the African continent (Venter et al., 2012). Fossil fuel burning – within the residential, industrial and power generation sectors – biomass burning (i.e. agricultural burning and wild fires) and road transport are the major sources of air pollution in the country. Air pollution is a major problem in many parts of the country (Annergan et al., 2007; Martins *et al.*, 2007; Zunckel et al., 2007). Epidemiological studies conducted in areas of South Africa that have been declared national air quality priority areas indicate a relationship between air pollution and human health impacts (Wright et al., 2011). Health impacts resulting from air pollution in South Africa include acute respiratory infection, chronic respiratory diseases and TB (Makri and Stilianakis, 2008).

The most common non-climatic factors that exacerbate health impacts due to air pollution in South Africa include socio-economic factors (e.g. poverty, living conditions and educational level), urbanisation, and land use (Annergan et al., 2007; Martins et al., 2007; Zunckel et al., 2007; Mathee and Von Schirnding, 2003; South Africa's Urban Development Framework, 1997). For example, in informal settlements, where poverty is widespread, and individuals have limited access to basic social services, they resort to using coal, paraffin and wood for household heating and cooking leading to air pollution and human health problems (South Africa's Urban Development Framework, 1997).

2.2.6 *Communicable diseases*

Communicable diseases (also known as infectious diseases or transmissible diseases) are "illnesses that result from the infection, presence and growth of pathogenic (capable of causing disease) biologic agents in an individual human or other animal host" (Wisconsin Department of Health Services, 2013). There is a high burden of communicable disease in South Africa (DOH, 2011b) with the most common communicable diseases being TB, malaria, measles, HIV/AIDS and sexually transmitted infections (STIs) (DOH, 2011b). Viruses, bacteria, fungi, protozoa, multicellular parasites, and aberrant proteins are the main biological agents involved in communicable diseases. Transmission of communicable diseases occurs through:

- Direct physical contact with an infectious person
- The consumption of contaminated foods or beverages
- Contact with contaminated body fluids
- Contact with contaminated inanimate objects
- Inhalation
- Bites from infected insects or ticks.

Determinants of communicable diseases are both social and ecological. Common risk factors associated with communicable disease include unemployment, migration, overcrowding, poor sanitation, access to potable water, and high population rates (Viljoen,et al., 2011; WHO, 2013g). The most common climatic factors related to communicable disease include rainfall and wind (WHO, 2013).

Diarrhoeal-related diseases (e.g. cholera and typhoid) are also common communicable diseases in South Africa (DOH, 2011c) and are one of the major causes of morbidity and mortality in young children (MacIntyre and de Villiers, 2010). This report focuses on cholera as a case study of communicable diseases in South Africa.

2.2.6.1 Cholera

Cholera is a waterborne, acute intestinal disease caused by the bacterium *Vibrio cholerae* following ingestion of contaminated water or food. Most cholera risk factors in South Africa are closely related to poor environmental conditions, poverty, and lack of sanitation and basic infrastructure (Ali et al., 2002; Fernandez, et al., 2012; de Magny et al., 2007). Non-climatic factors, such as human migration, high population density and poor access to safe water, contribute to the spread of cholera in the country (DOH, 2009; Hemson and Dube, 2004). Climatic factors (e.g. rainfall and high temperatures) also contribute to the spread of cholera (DOH, 2009; WHO, 1998a; de

Magny et al., 2007; Kustner et al., 1991). Indeed, cholera transmission is seasonal occurring primarily during rainy seasons. The distribution and survival of *Vibrio cholerae* can be impacted by changes of different bio-physicochemical parameters of water such as temperature, salinity, pH, and abundance of phytoplankton (Mendelson and Dawson, 2008; Patz, 2002). Cholera transmission has also shown a strong association with El Niño events (Pascual et al., 2000).

The first major outbreak of cholera in South Africa occurred in KwaZulu-Natal in 1982 with a total of 12 263 reported cases and 24 deaths (Cottle and Deedat, 2002). In 2009, the country reported 12 752 cases and 65 deaths recorded in all nine provinces (OCHA, 2009). However, these numbers do not reflect the true burden of cholera due to limitations in the surveillance and notification systems of many provinces where the disease is endemic (OCHA, 2009).

2.2.7 Non-communicable diseases

Non-communicable diseases (NCDs) are the leading cause of death in South Africa (see Figure 2) and are an important facet of South Africa's burden of disease. There are several risk factors that make an individual susceptible to NCDs. Of these risk factors, behavioural factors (e.g. smoking and physical inactivity) and metabolic factors (e.g. high blood pressure, weight and high cholesterol) are key (Alwan et al., 2011).

The inception of the South African Health and Nutritional Examination Survey by the Human Sciences Research Council has ensured that NCDs can be monitored and tracked effectively (Mayosi et al., 2012). This survey will encapsulate information on the prevalence of NCDs and their risk factors, the health status of children, and the behavioural and social determinants of health (Mayosi et al., 2012). By attaining mortality and morbidity parameters, NCDs can be combatted to a certain extent (Mayosi et al., 2012).

The South African Declaration on the Prevention and Control of Non-Communicable Diseases has set the following targets to diminish NCDs by 2020 (Mayosi *et al.*, 2012):

- Reduce premature deaths from NCDs by 25%;
- Reduce tobacco use by 20%;
- Reduce per head consumption of alcohol by 20%;
- Reduce mean salt intake to less than 5g/day;
- Reduce the prevalence of obesity and overweight by 10%;
- Increase the prevalence of physical activity by 10%;
- Reduce the prevalence of hypertension by 20%;
- Increase the proportion of people getting treatment for hypertension, asthma and diabetes by 30%;
- Offer screening for cervical cancer to women with sexually transmitted diseases at least once every 5 years or to every woman at least 3 times in their lifetime; and
- Increase the number of people screened and treated for mental illness by 30% by 2030.

2.2.8 Mental health

South Africa is a country of many contrasts with high burdens of disease and poverty, and high unemployment and crime rates while, on the other hand, some of the population are affluent and there are advanced levels of technology. These characteristics encourage the presence of mental health issues. The prevalence in South Africa of lifetime psychiatric disorders is approximately 30%, with anxiety at 15.8%, substance use disorders 13.4% and mood disorders 9.8% (Stein et al., 2008; Tomlinson *et al.*, 2009). Only 25.5% of people with long term (>12 months) mental disorders are likely to seek treatment (Seedat et al., 2008).

The high burden of disease, in particular HIV/AIDS, is associated with a high prevalence of psychiatric disorders including major depression, anxiety, and alcohol abuse and dependency (Myer et al., 2008). Children are particularly vulnerable, with those orphaned by AIDS being affected by concentration difficulties, depression, and post-traumatic stress disorder (Cluver and Gardner, 2006; Cluver et al., 2007). It is expected that by 2025, deaths due to AIDS would have orphaned 1.3 million children in South Africa (IMSA-NHI, 2011), possibly increasing the burden of mental health problems in the country.

A study focusing on impacts of trauma on psychological health indicated that at least 75% of South Africans experience some form of trauma in their lifetime (Williams et al., 2007). Those affected by trauma reported high levels of psychological distress (Williams et al., 2007). Socio-demographics (e.g. sex, race and socio-economic status) were important covariates for experiencing trauma and exacerbating mental health problems (Myers and Naledi, 2007; Williams et al., 2007).

2.2.9 Occupational health

Occupational health is related to health impacts sustained while at work. Common occupational health impacts (impacted by both climatic and non-climatic factors) include heat stress, dehydration and injuries sustained while at the workplace.

Temperature is a common climatic factor that affects occupational health (Bernard et al., 2001, Schwartz, 1999; Parry et al, 2007; Mirabelli and Richardson, 2005; NIOSH, 2005 and 1986, McMichael et al., 2006). Working in hot environments results in more workers being exposed to heat stress and excessive exposure to this environment can result in health effects such as heat fatigue, dehydration etc. (Parry et al, 2007; Mirabelli and Richardson, 2005). Results generated with projected future climate scenarios over South Africa display marked increases in thermal discomfort on more days of the year, and especially in summer months (see *LTAS Phase 1, Technical Report: No. 4, Climate Change Implications for the Agriculture and Forestry Sectors in South Africa*). This will have serious implications for the productivity of workers, particularly in the agriculture and mining sectors.

3. CLIMATE CHANGE IMPACTS ON HUMAN HEALTH

Climate change impacts on human health are potentially many and varied. Expected increases in the frequency, intensity and duration of extreme weather events are likely to result in unprecedented impacts on public health. Impacts are likely to be greatest in the developing countries as a result of poor adaptive capacity.

Climate change exposures are numerous, may be direct and/or indirect, and will include the character, magnitude and rate of climate variability (WHO, 2003). Direct climate change exposures include anomalous temperature and precipitation, storms, cyclones and natural disasters (Samet, 2009; WHO, 2009a). Indirect exposures may include worsening air pollution, increasing pollen production, constraints in the agriculture sector leading to food shortages and malnutrition, an optimised environment for the production and distribution of disease vectors, infrastructure poverty (lack of appropriate infrastructure), and ecosystem changes leading to loss of ecosystem goods and services (Samet, 2009; WHO, 2009a; Abson et al., 2012). Climate change may impact on the nature, magnitude and recurrence of a populations' exposure. Thus it is important to address both direct and indirect climate exposure when dealing with vulnerability to climate change.

3.1 Heat stress

Increases in temperature and occurrences of extreme temperature events (e.g. heat waves) resulting from a changing climate are projected to have large impacts on human health. For example, high temperatures are known to induce heat stress and increase morbidity and mortality rates, as well as result in respiratory and cardiovascular diseases (Chung et al., 2009; Ballester et al., 2011; Son *et al.*, 2011). The impacts on health from increasing temperatures can be varied. Studies on how heat impacts on health in southern Africa are limited. The risk from increasing health impacts from rising temperatures is both a public health and an occupational health concern, and must be dealt with in both spheres. Vulnerability to heat is dependent on existing health status as well as socio-economic and environmental factors.

3.2 Vector-borne diseases

Mosquitos are vectors for a number of diseases and their abundance is impacted by climatic factors. The size of a mosquito population, for example, increases proportionally with rainfall (Hales et al., 2003; Kovats, 2000). The timing of rainfall over the course of a year and other variations in climatic conditions are critical in determining the prevalence of vector-borne diseases (Hales et al., 2003).

3.2.1 *Malaria*

Climatic factors can impact on malaria risk and transmission in many ways, and these impacts can be complicated and non-linear. Alterations in such climatic factors as a result of climate change may lead to changes in the distribution of the vector and hence the disease. Temperature and rainfall are the most studied factors and any change in either factor as a result of climate change has the potential to influence the incidence and prevalence of malaria. Research is still on-going in order to fully understand their impacts. Relative humidity is also considered to be an important factor, but there is little research on its impact.

In general, there are optimal ranges of climatic conditions where malaria risks are highest. And, in order to correctly characterise the impact of climatic variables on malaria, multiple factors need to be considered using similar, high spatial and temporal resolution (Parham and Michael, 2010).

Temperature can have an impact throughout the lifecycle of the parasite and mosquito by impacting on its growth and survival, and there are optimal ranges where transmission is the highest. Parasite development ceases at 16°C and thus transmission of malaria below 18°C is unlikely because mosquitos generally will not survive through the whole transmission cycle. Thermal death of mosquitoes occurs at extremely high temperatures (~40–42°C), preventing transmission (Craig et al., 1999).

Temperature bands and thresholds are used in modelling malaria, though research is still ongoing as it has been found that small changes in temperature can be magnified to larger impacts in health risk (Pascual et al., 2006; Patz and Olson, 2006). Craig et al (1999) reported that when average annual temperatures are below 15°C there will be no transmission of malaria, at 18°C there will only be epidemics in warmer years, and average yearly temperatures of 22°C are needed for stable transmission. These thresholds have been used in modelling, although it should be noted that they are based on annual average temperatures. Changes in temperature during the day have been shown to impact on the risk of malaria transmission (Paaijmans et al., 2009). It is also important to consider temporally resolved temperatures, as it is critical that the appropriate temperatures occur together with the other needed climatic factors (such as rainfall).

The relationship between rainfall and malaria is not linear. A study in Zimbabwe found that the number of reported malaria cases was driven by intense rainfalls (Hoshen and Morse, 2004). Too much rain, however, does not necessarily result in a high number of malaria cases. This is because heavy rainfall may destroy breeding sites, and small amounts of rain after a drought may lead to more malaria than expected where water pools create breeding sites (Thomson et al., 2005). Furthermore, malaria transmission is still possible during periods of low rainfall in areas with permanent water bodies (e.g. lakes and rivers). Many models assume that the minimum level of rainfall needed for seasonal malaria transmission is a monthly rainfall of 80 mm for at least four consecutive months (van Lieshout et al., 2004; Craig et al., 1999; Ebi et al., 2005).

Malaria is strongly impacted by non-climatic factors (e.g. Zacarias and Anderson, 2011; Thomson et al., 2005; Craig et al 2004a; Craig et al., 2004b; Gething et al., 2010; Abellana et al, 2008; Béguin et al., 2011). Gething et al. (2010) reported that during the last century, global temperatures have increased, yet the global range and intensity of malaria transmission has decreased. It was estimated that the projected future impacts on malaria are around two orders of magnitude smaller than the impacts possible from appropriate and effective malaria control measures (Gething et al., 2010). In a study in South Africa it was found that the number of cases of malaria was more strongly related to the level of drug resistance (e.g. chloroquine) and HIV infection, than climatic factors (Craig et al. 2004a, 2004b). In fact, the climatic factors could not explain the number of cases, although they did appear to be significant drivers in the inter-annual variability of incidences (Craig et al. 2004a, 2004b). Land use change, through impacting on microclimatic conditions and creating or destroying breeding habitats, are also very important factors that impact on malaria risk (Pascual et al., 2006; Patz and Olsen, 2006).

Overall, a changing climate could improve the suitability of certain areas of South Africa for the vector and also result in increased migration or displacement of communities. This may hamper the DOH's goal of eliminating malaria in South Africa by 2015.

3.3 Food insecurity, hunger and malnutrition

Climate change is expected to lead to increases in the frequency, duration and intensity of drought spells, as well as high temperatures and reduced precipitation in semi-arid regions (Brown and Funk, 2008). As such, climate change will affect food systems resulting in compromised food availability, food access, and food utilisation; all of which are factors that lead to food insecurity, particularly in the developing world (Gregory et al., 2005). In addition, climate change may improve certain crop yields.

Climate change-related rainfall projections for South Africa indicate that the Western Cape and Northern

Cape are more likely to become drier while the central and eastern plateau and the Drakensberg region are likely to experience an increase in rainfall (Hewitson and Crane, 2006; Lumsden et al., 2009). The change in the distribution of rainfall patterns will affect agricultural activities leading to negative impacts on crop yields (Lobell et al., 2008). Reduced crop yields will lead to, among other things, shortages in food availability and increases in food prices, factors that will result in inadequate or compromised access to food by households leading to malnutrition (Bloem et al., 2010). How these issues are likely to play out in the future regarding malnutrition is not clearly understood.

3.4 Natural disasters

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events (IPCC; 2012). The frequency and intensity of natural disasters are likely to increase in certain areas as a result of climate change. For example, if climate change results in an overall reduction in the number of rainy days per year, but does not affect total annual rainfall being received, this will result in an increase in the intensity of rainfall events as well as increased dry spell duration. Natural disasters are influenced by both climatic (e.g. annual rainfall, temperature and wind speed) and non-climatic factors (e.g. land use patterns, socio-economic status of populations in question and inherent adaptive capacity). Infectious disease outbreaks, for example, are more prevalent in populations that have poor public health infrastructure, poor water and sanitation services, lack of shelter, and that experience overcrowding (Hales et al., 2003).

Natural disasters can have a number of possible health impacts (e.g. see Table 4 for some examples), the likelihood of which are reliant on both climatic and non-climatic factors (Hales et al., 2003; Kovats, 2000). Social mechanisms are critical in interpreting the associations between extreme weather events and disease; however, these mechanisms are difficult to quantify (e.g. floods, droughts and storms often lead to population displacements and migration).

Table 4: Examples of health impacts arising from natural disasters (redrawn from Hales et al., 2003 and Kovats, 2000).

Natural disaster	Examples of health impacts
Floods and storms	• Increased or decreased vector (e.g. mosquito) abundance (e.g. if breeding sites are washed away); • Increased risk of respiratory and diarrhoeal diseases; • Drowning; • Injuries; • Health effects associated with population displacement; • Impacts on food supply; and • Mental health impacts.
Drought	• Changes in vector abundance if vector breeds in dried up river beds; • Food shortages; • Illness; • Malnutrition; • Increased risk of infections; • Death (starvation); and • Health impacts associated with population displacements.
Fire	• Burns and smoke inhalation; • Soil erosion and increased risks of landslides; • Increased mortality and morbidity; and • Increased risk of hospital and emergency admissions.

3.5 Air pollution

Climate change may influence the health impacts from air pollution through altering the concentration of pollutants in ambient air (and, as a result, their impact on human health) by affecting factors such as weather and anthropogenic emissions. Meteorological factors such as temperature, precipitation, clouds, atmospheric water vapour, wind speed, and wind direction influence atmospheric chemical processes. In general, ozone and PM are the two pollutants most focused on regarding climate change. The most cited climatic factors related to ozone and PM include relative humidity, precipitation, temperature and wind speed (Bernard et al., 2001; Koch et al., 2003; Liao et al., 2006; Dawson et al., 2007; Kleeman, 2007; Parry et al., 2007; D'Amato and Cecchi, 2008; Jacob and Winner, 2009; Shan, et al., 2009; Amos et al., 2010). There are many ways in which climate change can influence the level of air pollution. For example, high temperature and humidity result in more air pollutants and high wind speeds, clouds and precipitation reduce air pollutants (Koch et al., 2003; Liao et al., 2006; Dawson et al., 2007; Shan, et al., 2009).

3.6 Communicable diseases

The common climatic factors related to the spread of communicable disease are rainfall, temperature and wind. Weather plays a major role in population dynamics and thus the distribution of diseases. For example, flooding can result in damage to sewage works, thereby contaminating drinking water and resulting in diarrhoeal diseases. Temperature has also been highlighted as an important climatic factor. For example, food-borne diseases like salmonellosis have been observed to be temperature sensitive and increased annual average temperatures may result in increased incidence of such diseases (WHO, 2013f).

Many non-climatic factors influence the spread of communicable diseases (e.g. poverty levels, population density, sanitation, urbanisation, and migration). These are integral components to understand when projecting the impacts of climate change on health impacts from communicable diseases. Climate plays a major role in population dynamics and, as such, the distribution of diseases. Cholera is a well-known example of a communicable, diarrhoeal and water-borne disease in South Africa and is used here as a case study.

3.6.1 Cholera

The transmission of cholera is linked to rainfall and temperature (air and sea surface) in South Africa (Pascual et al. 2000) and, as such, it is likely that it will be affected by climate change-induced changes in rainfall and temperature regimes. Non-climatic factors such as water insecurity, lack of proper sanitation and population density also influence cholera transmission (Ali et al., 2002; de Magny et al., 2007; Fernandez et al., 2012).

3.7 Non-communicable diseases

Climate change can impact NCDs directly and indirectly. Direct impacts may include increased heat stress, higher concentrations of air pollutants, increased exposure to solar ultraviolet radiation, and higher structural damage (extreme weather events such as fires, floods and storms cause structural damage and may lead to injuries thereby increasing an individual's health risk). Indirect impacts may emerge through climate change compromising food production and affecting food security and nutritional status, and through climate change impacts resulting in trauma (see Table 5).

3.8 Mental health

Climate change and weather events do not directly result in mental health problems. Despite this, climate change and weather are likely to impact on mental health by causing many and varied adversities (Berry et al., 2008; 2010). Adverse situations/impacts by climate change and weather events likely to impact on mental health include, among others: heat waves, floods, veld fires, droughts, snow, and mudslides (Figure 4) (Doherty and Clayton, 2011). The adverse impacts of climate change will result in or exacerbate the disruption of social and biophysical life support systems (Doherty and Clayton, 2011) and in this way, lead to mental health problems (Huq et al., 2007; Morrissey and Reser, 2007; Berry et al., 2010; 2011).

It is important to understand the climate change and mental health pathways in order to characterise mental health problems accurately in the context of climate change (Berry et al., 2008; 2010). The main climate change mental health pathways used to describe mental health effects of climate change are the direct, indirect and global threat pathways (Fritze et al., 2008; Berry et al., 2010) described below.

Direct pathways for mental health include acute (e.g. heat-wave) and sub-acute (e.g. prolonged drought) weather events (Berry et al., 2010). Acute climate events such as high temperatures and heat waves have been associated with diminished mental capacity (e.g. absent-mindedness) and increased hospital admissions for, among other things, organic and symptomatic mental disorders, mood disorders, somatoform (mental symptoms suggesting physical illness or injury) disorders, senility and psychological development disorders (Hansen et al., 2008; Dapi et al., 2010). Alcohol and other mind altering substances exacerbate the problem. The effects of climate change and weather events may persist long after the event leading to the onset of post-traumatic stress disorder (Berry et al., 2010).

Indirect climate change mental health pathways include the disruption of the social and physical environment, and of mitigation and adaptation options (Fritze et al., 2008; Berry et al., 2010). While there is little research on this, sub-acute extreme weather events (e.g. prolonged drought) may render large portions of land uninhabitable and/or unproductive, and cause environmental distress, and a disturbed sense of place (Myer, 2002; Berry et al., 2008). Additional problems may include loss of livelihoods, loss of shelter, disruption of family structure and social networks, displacement and migration of populations, environmental refugees, prolonged periods of recovery, financial problems and poor health. These are problems that can directly lead to and/or exacerbate mental health problems such as anxiety, apathy, helplessness, depression and chronic psychological distress (Myer, 2002; Morrissey and Reser, 2007; Berry et al., 2010; Doherty and Clayton, 2011). The impacts are often severe for the most poor and vulnerable (Firtze et al., 2008; Doherty and Clayton, 2011).

The climate change and mental health global threat pathway deals with the understanding of climate change as a global threat that may induce mental health problems (Fritze et al., 2008). Mental health problems expressed as emotional and affective responses may ensue after one has been exposed to visuals of climate change and weather-related disruption and degradation of both the social and biophysical life support systems and human suffering (Moser, 2007; Dunn et al., 2008; Fritze et al., 2008; Doherty and Clayton, 2011; Willox et al., 2013). Apprehension, anxiety and emotional distress about the future may also manifest (Fritze et al., 2008; Doherty and Clayton, 2011; Willox et al., 2013). The impacts can be experienced locally as well as by people living far away from the place where the actual disaster occurred (Dunn et al., 2008).

Myers (2002) estimated that there will be about 200 million global warming-related refugees by 2050. By then, the risk of sea level rise and flooding of coastal zone communities could result in about 162 million environmental refugees by 2050 and the risk of severe drought and other climate dislocations could result in about 50 million environmental refugees. While the estimates are not clear, climate-related displacement of people and forced migration could worsen the global burden of mental health.

The impact of climate change and weather events on mental health, and the responses, are often place-based, individual- and context-specific, and mediated by cultural

Table 5: The direct and indirect impacts of climate change on NCDs (redrawn from Friel et al., 2011).

Climate change impacts	Pathway for climate change to NCDs	NCD outcome	Direction of health risk
Direct			
More frequent and increased intensity of heat extremes	Heat stress	Cardio-vascular diseases (CVD); Respiratory disease (e.g. bronchitis, asthma)	Increased risk
Increased temperatures and less rainfall	Higher ground-level ozone and other air pollutants	CVD; Respiratory disease	Increased risk
	Increases in airborne pollens and spores	Respiratory disease	Increased risk
Changes in stratospheric ozone and in precipitation and cloud cover	Increased exposure to solar UVR	Autoimmune diseases (multiple sclerosis)	Reduced risk
Higher winter temperatures in temperate latitudes		CVD; Respiratory disease	Reduced risk
Extreme weather event (fires, floods, storms)	Structural damage	Injuries	Increased risk
Indirect			
Drought, flooding	Impaired agriculture, reduced food yields, and nutrition insecurity	Poor general health	Increased risk
Extreme weather event (fires, flooding, storms)	Trauma	Mental health (post-traumatic stress disorder)	Increased risk
Extreme weather event (fires, flooding, storms)	Impaired livelihood, Impoverishment	Mental health (anxiety/ depression)	Increased risk

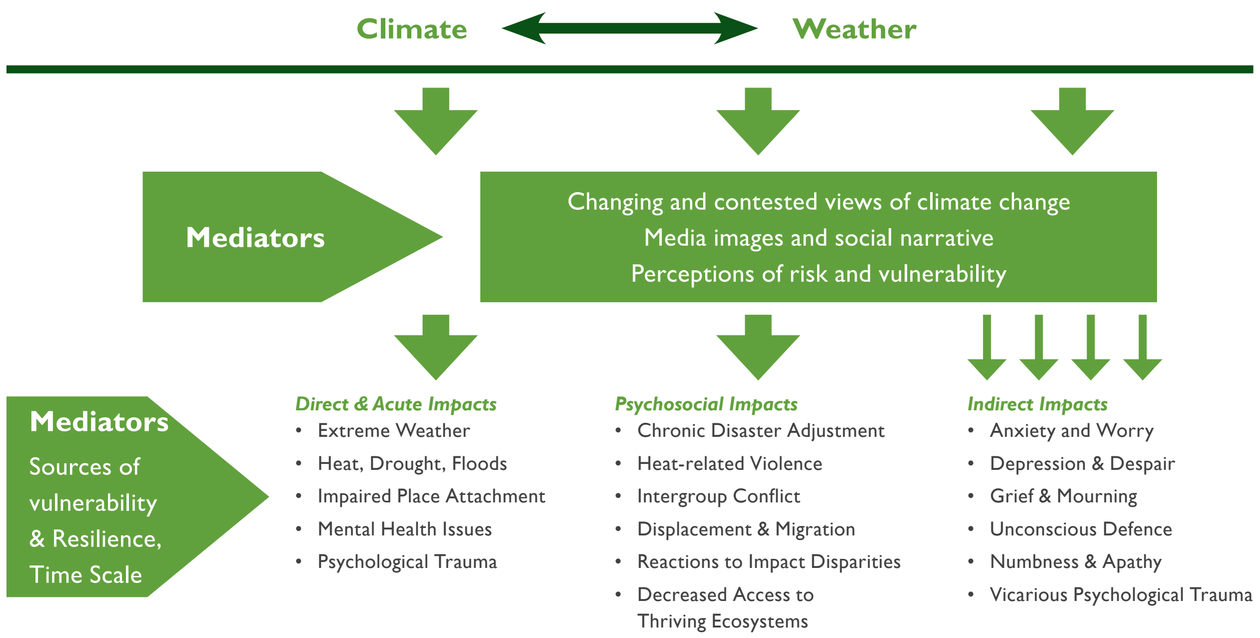


Figure 4: Climate change: differentiating between classes of psychological impacts (Doherty and Clayton, 2011).

background, values, beliefs and norms, and perceptions of risk (Morrissey and Reser, 2007; APA, 2009; Willox et al., 2013). As a result, the mental health impacts of climate change reflect significant variability among individuals, communities, and populations (APA, 2009). These factors need to be considered in addressing mental health problems in the context of climate change (APA, 2009). There is no integrative research policy guideline or framework addressing both direct and indirect mental health effects of climate change (Berry et al., 2008; Fritze et al., 2008).

3.9 Occupational health

Research related to climate change and human health mostly focuses on the health of the general population and often occupational health and safety related issues are overlooked due to lack of data (Schulte and Chun, 2009). There are many potential climate and non-climatic factors that could impact on occupational health and many possible health outcomes (Figure 5; Schulte and Chun, 2009). It is difficult to predict who will be affected by climate change, and when, because of varying individual susceptibility and environmental factors. For example, factors other than just ambient temperature (e.g. radiant heat, air movement, conduction, and relative humidity) can influence heat stress (Schulte and Chun, 2009).

Increased temperatures as a result of climate change will exacerbate the number of incidents of heat stress, fatigue and dehydration and may make working in already warm environments increasingly difficult. Changing temperatures can also affect vector, pathogen, and host habitats (IPCC, 2001; Haines and Patz, 2004). In this way, climate change may influence the spread of infectious diseases (see Communicable diseases above) and insect populations. As a result, outdoor workers may be more at risk of biological hazards (e.g. insects) and vector-borne diseases (e.g. malaria) (Kovats et al., 2003; NIOSH, 2005; Haines et al., 2006; McMichael, et al., 2006). An increase in ambient temperature can also elevate the levels of air pollution, which in turn can further harm human health (Bernard et al., 2001, Schwartz, 1999). For example, outdoor occupations such as transportation, utility maintenance, landscaping, and construction lead to longer exposures to air pollutants due to the amount of time spent outside and the increased breathing rates involved as a result of the work (Bernard et al., 2001).

In addition, cloud cover can be altered by climate change resulting in a variation of solar ultraviolet radiation levels. Reductions in the earth's ozone layer may also increase levels of solar ultraviolet radiation reaching some parts of the earth's surface thereby increasing negative health effects (IPCC, 2005; Parry et al, 2007). According to Wright et al. (2011) "exposure to solar ultraviolet radiation is both an occupational health and safety issue." Workers that perform outdoor duties are vulnerable to skin cancer and eye conditions, because they are exposed to large amounts of solar ultraviolet radiation on a daily basis (Oh et al, 2004).

Work-related factors such as work practices, work/rest cycles, access to water, and access to shade/cooling are non-climatic factors related to exposure to occupational health risks. Factors such as age, weight, physical fitness level, metabolism, use of alcohol or drugs, pre-existing conditions, and the type of clothing worn can make workers susceptible to climate-related occupational health hazards (Schulte and Chun, 2009).

There is an association between weather disasters and death, injury, communicable diseases, malnutrition, famine, and mental health disorders (Curriero et al., 2001; NIOSH, 2005; McMichael, et al, 2006). Workers involved in rescue and clean-up efforts could have more exposure to risky conditions as the frequency and severity of extreme weather events increases. Increases in the frequency and intensity of extreme weather events, floods, and destruction and damage to infrastructure and buildings may have negative impacts on economic activity and employment (Jacobson et al., 2001; Sverke et al., 2002; Ruth et al., 2004).

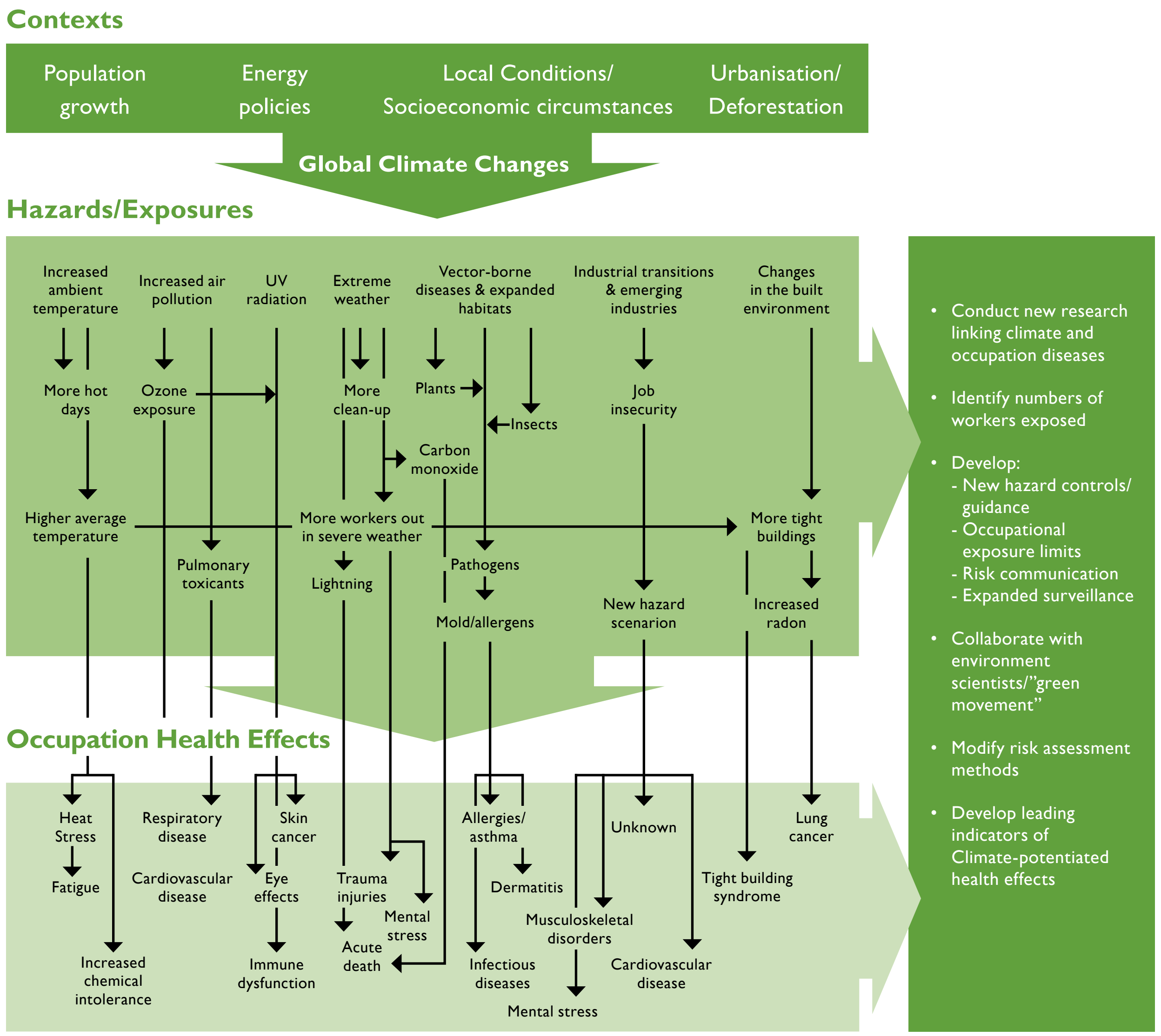


Figure 5: Conceptual model showing potential links between global climate change and occupational safety and health (Schulte and Chun, 2009).

4. CLIMATE CHANGE ADAPTATION RESPONSE OPTIONS

South Africa's National Climate Change Response Policy (NCCRP) has advocated the following adaptation measures that are applicable to the health sector:

- Reduce ambient PM, ozone, and sulphur dioxide concentrations by legislative and other measures.
- Ensure that food security and sound nutritional policies form part of an integrated approach to health adaptation strategies.
- Develop and roll out public awareness campaigns on the health risks of high temperatures and appropriate responses.
- Design and implement "Heat-Health" action plans.
- Strengthen information and knowledge of linkages between disease and climate change through research.
- Develop a health data-capturing system that records data at both spatial and temporal scales.
- Improve the bio-safety of the current malaria control strategy.
- Strengthen the awareness programme on malaria and cholera outbreaks.

Regarding heat-health plans, the WHO has developed an 8-step plan to aid in the development of such action plans. This plan was developed for a European audience; however, it can be tailored to local conditions (WHO, 2009). Adaptation measures applicable to South Africa include providing accurate and timely alerts, and providing care for vulnerable populations. Not all of the adaptation measures suggested in the literature are applicable to the South African situation (e.g. increased air conditioning), and this represents an additional research gap.

Overall, to prevent and reduce the burden of disease associated with a changing climate, improved public health strategies and surveillance systems are required (Haines et al., 2006). The public health responses to climate change need to take into consideration the vulnerability of populations and public health systems, both of which are influenced by social determinants of health.

Many adaptation plans worldwide focus on vulnerability assessment, increased surveillance, increased access to data and multi-sectoral cooperation (e.g. AIACC, 2006; EC, 2007; Kasali, 2008; Samet, 2009; Scottish Government, 2009; LTS Africa, 2010; Australian Government, 2012; UNDP, 2012). This is also true of the South African National Climate Change and Health Adaptation Plan, the key national strategy for adaptation in this sector. Conducting a vulnerability assessment is the first step needed to inform and develop specific adaptation response options for the sector.

4.1 Vulnerability assessments

As climate change is expected to worsen the burden of disease and undermine adaptive capacity in the developing world, it is important that careful consideration is given to the vulnerability of public health in order to improve adaptation. Vulnerability assessments of public health are therefore a critical step to undertake in order to develop an informed approach to adaptation. Approaches to reducing the vulnerability of public health to climate change impacts are likely to be area-specific. Therefore, health vulnerability assessments need to be area-specific. They also need to be informed by vulnerability assessments of other sectors. Overall, intersectoral vulnerability assessments are necessary.

A vulnerability and risk assessment for the health sector is an important first step and research need in order to identify which of the likely impacts climate change will have on the health of South African populations/communities are the most critical to address, and which populations/communities are most vulnerable to them. The WHO's Situational Analysis National Assessment will be the starting point for a vulnerability assessment but it may only be the beginning (WHO; 2009b). Vulnerability and risk assessments of specific diseases to climate change are also required and these will help to identify the key risk factors. There is a need to model impacts (including consideration of non-climatic factors) to determine key risk factors that need to be addressed through adaptation and through addressing basic human needs such as sanitation.

In addition to the adaptation measures listed above, the DoH's Strategic Plan (2010/11–2012/13) has proposed actions to address various diseases which may be aggravated by climate change (e.g. increasing immunisation coverage and improving access to quality care). However, these actions are not informed by climate change considerations nor does the Strategic Plan seek to influence the development trajectory of the health sector in this particular respect and this is a key policy gap. The vulnerability assessment will, once completed, inform the Strategic Plan.

4.2 Monitoring and surveillance

Surveillance of public health is very important in order for policy makers, researchers and health providers to understand the effectiveness of current policies and programmes, and to shape new ones. A number of South African communicable diseases are deemed 'notifiable' (e.g. rabies and yellow fever) and as such need to be reported with 24 hours or seven days (depending on the disease) in order to break transmission cycles. This system is managed by the Epidemiology and Surveillance directorate of the DoH. Notifiable disease registries could be an important source of data for research. Improving this system and the reporting of such diseases is a critical adaptation measure. Overall, there is a need for high-quality surveillance of diseases and key risk factors for successful adaptation planning and the implementation of the plans.

4.3 Access to data

Another requirement is better data and improved access to data to allow for high-quality surveillance of diseases and key risk factors thus ensuring successful adaptation planning. Freely available and easily accessible up-to-date meteorological data is an overarching research need in South Africa.

Additional research is required in order to determine correlations and cause-effect relationships as far as possible between risk factors and health impacts. For example, international relationships between heat and health could be used to model the impact of increasing temperatures in South Africa. However, a limitation is that these relationships are not based on a South African population. While it may be possible to use relationships that were developed for similar climates to those found in South Africa, the vulnerability of communities (including pre-existing conditions, housing, and coping ability) may not be the same as those in other studies conducted in developed nations. The same applies to many of the available projections for cholera and malaria. While the modelling and ability to create projections for these diseases for South Africa are advanced, they are mostly built upon international studies. Not only is better health data needed, but also data on non-climatic factors (e.g. The supply of potable water and information regarding the migration of people into and across South Africa).

4.4 Multi-sectoral collaboration

Multi-sectoral collaboration is imperative not only in research but also in developing and implementing adaptation plans. Coordination between sectors and different levels of government is important. This collaboration will enable data access and sharing, and the successful design and implementation of adaptation measures. For example, collaboration between the agriculture, water and health sectors will be needed when implementing adaptation measures (such as food safety plans) to build the resilience of food safety routines in South Africa and thus avoid potentially severe food-borne health hazards.

Including relevant alignment of adaptation measures that would help to support the health sector in other sector policies could be instrumental in ensuring that health considerations (including climate considerations) are incorporated into decision-making processes at policy level.

4.5 Adaptive capacity

The need to adapt to climate change impacts is determined by the adaptive capacity of an individual/ population. Adaptive capacity refers to the ability to cope, recover and/or be resilient in the face of climate change impacts. Adaptive capacity is determined by the adaptation measures and actions in place aimed at reducing the burden of adverse health outcomes resulting from climate and weather related hazards (WHO, 2003). Both individual and institutional mechanisms are necessary for coping with the adverse effects of climate change. Individual mechanisms may include improving one's socio-economic status in order to afford the necessary means for coping with climate impacts such as medical care, proper nutrition and living in a secure and climate-resilient neighbourhood. Institutional mechanisms may include surveillance and warning systems, vaccination programmes, treatment facilities, environmental limits or standards, sanitation systems, capacity building programmes, training facilities, public education and communication programmes and research and development programmes. The effectiveness or inadequacies of these systems and programmes may alter how sensitive a population's health is to changes in the climate and to adverse weather conditions (WHO, 2003).

Adaptive capacity is also dependent on sectoral policy decisions. Decisions and actions affecting the health of the population are often influenced by decisions taken in sectors other than health, such as energy, transportation and human settlement. Intersectoral collaboration is a key element in building adaptive capacity for public health.

5. RESEARCH REQUIREMENTS

For some of the key health risks discussed in this report (e.g. mental ill health), the research is not yet at the stage required to create projections. However, for others, there are existing models and research that could be used to begin to create projections. Nevertheless, it should be noted that in all cases there are data and research needs. Heat stress, malaria and cholera are health risks where models do exist that may have potential to be used.

There are also numerous linkages between the key health risks and other sectors that need to be taken into account when making projections. Malnutrition and natural disasters are key health risks with a number of cross-sectoral linkages. The key research needs, available research and cross-sectoral linkages associated with the key health risks are described below.

5.1 Heat stress

Indices that combine temperature measurements with wind speed and relative humidity have been found to be related to health impacts. Thus, climatic factors other than temperature and various temperature metrics including maximum temperature, minimum temperature, average temperature or composite indexes have been used in assessing health impacts. For example, apparent temperature which combines temperature and relative humidity has been found to be related to excess mortalities in some studies (Steadman, 1979; Smoyer-Tomic and Rainham, 2001; Watts and Kalkstein, 2004; Ballester et al., 2011). However, there is no agreement on what is the best meteorological indicator to use in studying the effects of temperature on health, as the relationship between these indicators and health impacts varies across populations.

Local studies on heat stress are limited. The only published study that relates mortality to temperature focused on Cape Town. It is not clear how applicable it would be for the rest of the country (McMichael et al., 2008) and research on appropriate adaptation measures and coping strategies suitable to the South African population is needed.

Projections of climatic factors are available; however, they have not been linked to health (see the chapter on Climate Scenarios). There are projections from the present to 2100 on the potential impact of climate change on increasing the number of "hot days". This method uses a series of threshold temperatures derived for the United States to discuss potential health impacts in South Africa (Matooane et al., 2011; Matooane et al., 2013). The study indicates that heat-related impacts (heat stress symptoms) are likely to increase in the future, and that these impacts are likely to be exacerbated by socio-economic vulnerability of the population. However, the relevance of this temperature-health impact relationship and the vulnerability factors applicable to the South African population are not well known.

It is thus important to create projections based on South African population data in order to gain a better perspective on the potential impact of high temperatures on health in the country. The most important data needs are those required to develop a relationship between high temperatures and health impacts in South Africa that include the impacts from non-climatic factors. Once this relationship is developed, then the potential health impacts from high temperatures can be projected. Among other things, data are required on spatially resolved mortality estimates.

5.1.1 Potential metrics to project and monitor health impacts of high temperatures

Temperature and other meteorological factors can be projected and can be easily monitored, and thus could possibly be used as metrics (e.g. number of days above a certain temperature threshold). However, using these as metrics will not describe the impact on health. In addition, policies and adaptation policies cannot impact on these metrics. Thus, health outcomes would be a better metric. However, a better understanding of the population specific relationship between heat and health is necessary in order to determine health impacts from these factors. It would be critical to determine which specific health outcome(s) should/could be used as a specific metric for heat impacts. In international literature, for example, there is a robust relationship between high temperatures and total mortality.

5.1.2 *Key cross-sectoral linkages*

Linkages across sectors that are important to consider include:

- Water
- Human settlements (housing type, material and infrastructure such as windows, blinds and shading can be a significant non-climatic factor in reducing or increasing heat stress for communities e.g. thermal performance of housing)
- Agriculture, forestry and fisheries (impact of heat on occupational health of workers)
- Disaster risk reduction (important for heat waves, as they can be considered a natural disaster)
- Occupational health in general (e.g. mining, outdoor workers from many sectors)
- Business or health (food storage and transportation).

5.2 Vector-borne diseases

One critical point to consider with vector-borne diseases is the use of chemicals (e.g. pesticides), which themselves may have negative health impacts, in their control strategy. The National Climate Change and Health Adaptation Plan lists to "improve the bio-safety of the current malaria control strategy" as a priority. The use of DDT as an adaptation strategy for malaria and the need for other strategies that do not use harmful chemicals is a critical research and policy need.

Malaria is the vector-borne disease most focused on in South Africa yet very little is known about other vectors. Thus, a critical research need is to understand existing disease vectors in South Africa and how they may be affected by climate change.

In 1997, the Medical Research Council together with malaria control programmes (namely, the Limpopo, Mpumalanga and KwaZulu-Natal malaria programmes) developed a malaria information system. This system is used for capturing malaria case data collected by control programme agents and at health facilities (Sharp et al., 2000; Khosa et al., 2013).These data are also available at provincial and national departments of health for statistical purposes.

There are models and projections of malaria available including global and regional models (e.g. Tanser et al., 2003; van Lieshout et al., 2004) that are used to estimate malaria risk. In general, the future spread of malaria is projected to be into the regions bordering on current malaria areas, where it is currently too cold for transmission (Tanser et al., 2003; van Lieshout et al., 2004; Hoshen and Morse, 2004; Zhou et al., 2004 Ebi et al., 2005; Pascual et al., 2006; Paaijmans et al., 2009).

There are also models that have been used on smaller spatial scales. Craig et al. (1999) describes a fuzzy logic model using the thresholds described above. This technique has been applied by many other researchers in the literature. For example, Ebi et al. (2005) applied such a model to Zimbabwe to model the climate suitability for stable malaria transmission. Current models would suffice to begin to project malaria, though key considerations would still be non-climatic factors and vulnerabilities. To properly characterise the impact of climate change on malaria into the future, not only are spatially and temporally resolved climate projections needed, but so are projections of non-climatic factors, such as land use and control measures, and socio-economic, demographic and vulnerability information.

5.2.1 *Potential metrics to project and monitor malaria*

Many different metrics have been used to model malaria, such as

- Climate suitability for transmission;
- Malaria risk;
- Malaria incidence;
- Person-months of exposure; and
- Many metrics of lifecycle.

Many of these would not be helpful for monitoring or for evaluating the impact of adaptation measures. Malaria is monitored in South Africa by the number of cases (which can be further divided into locally transmitted and imported cases).

5.2.2 *Key cross-sectoral linkages*

There are many potential and important cross-sectoral linkages to consider for mitigating the health impact of malaria. Some key linkages are with:

- Land use;
- Built environment; and
- Disaster risk reduction.

5.3 Food insecurity, hunger and malnutrition

Projections of future malnutrition trends often focus on the medium-term (2020 or 2030) (Ebi, 2008) and are either based on historical trends or econometric modelling techniques. The modelling often assumes three malnutrition scenarios, namely, status quo, optimistic scenario and pessimistic scenario. Optimistic and pessimistic scenarios take into account potential future development trajectories in the world food situation. Such trajectories are often based on assumptions about the expected changes in: i) agricultural sector activities including agricultural research and investments, technology developments, food production, prices of food; ii) population growth; and iii) socio-economic development, among other changes (Ebi, 2008).

There are no specific projections for malnutrition in South Africa. Global malnutrition estimates indicate that malnutrition will decrease significantly in the future (IFPRI, 2000). However, Sub-Saharan Africa may experience an increase despite interventions aimed at curbing the problem (IFPRI, 2000). Earlier projections based on 1980s developing world child malnutrition profiles, indicated that 184 million children were expected to suffer from child malnutrition by 1990, a figure that was expected to rise to 200 million children by 2020.

Garcia (1994) used different scenarios (optimistic and pessimistic) to determine the potential future outlook on child malnutrition by 2020. Under the optimistic scenario, 100 million pre-schoolers were expected to suffer from protein-energy malnutrition by 2020 (Garcia, 1994). Under the worst case scenario, 200 million children were expected to be underweight by 2000 (Garcia, 1994). A decline in absolute numbers of underweight children was expected across all continents by 2020, except in sub-Saharan Africa where, because of high population growth (3%), 34 million children were expected to remain malnourished (Garcia, 1994).

While there are no specific climate change-related malnutrition projections for South Africa, there are projections for the agriculture sector in South Africa. Lobell et al. (2008) suggest that maize and wheat (staples) production levels will decline in the absence of adaptation to climate change in southern Africa by 2030. Rain-fed maize crop yields are expected to decline in 2050 (compared to 2000) in the Free State (Johnston et al., 2012). North West Province is, however, expected to experience a significant increase in rain-fed maize crop yields in 2050 compared to 2000 (Johnston et al., 2012). Wheat production yields are expected to decline significantly in the Western Cape and increase in the Free State and Mpumalanga in 2050 compared to 2000

(Johnston et al., 2012). How these changes will affect malnutrition in the future is not yet clear.

In order to address malnutrition effectively, it is important to take into consideration the food system components (namely, issues of food access and food availability), and not only the agricultural sector issues (Gregory et al., 2005). In addition, the burden of disease, particularly infectious diseases, is an important consideration in dealing with malnutrition.

5.3.1 *Potential metrics to project and monitor malnutrition*

Modelled estimates indicate the absolute number of cases of malnutrition, prevalence of underweight children (IFPRI, 2000), and relative risk of malnutrition in the future (Ebi, 2008).

5.3.2 *Key cross-sectoral linkages*

In order for malnutrition projections to be possible many disciplines need to work together. These include health and nutrition, demography, agriculture, fisheries, economics, and climate sciences. The impact of the vulnerabilities of these sectors to climate change and their influence on the South African food system needs to be addressed if malnutrition is to be effectively addressed. In particular, it is important to gain a better understanding of issues pertaining to food access such as affordability, allocation and preference; food availability (production, distribution and exchange) and food utilisation (nutritional value, social value and food safety) (Gregory et al., 2005); and how these contribute to malnutrition and vulnerability to climate change. The role of infectious diseases and diseases of lifestyle in relation to malnutrition under climate change also needs to be addressed.

5.4 Natural disasters

Research is ongoing to project extreme events in South Africa (e.g. see Figure 6 showing a predicted increase in extreme rainfall events across most of South Africa and Mozambique). To project health impacts data linking health impacts to natural disasters would be necessary.

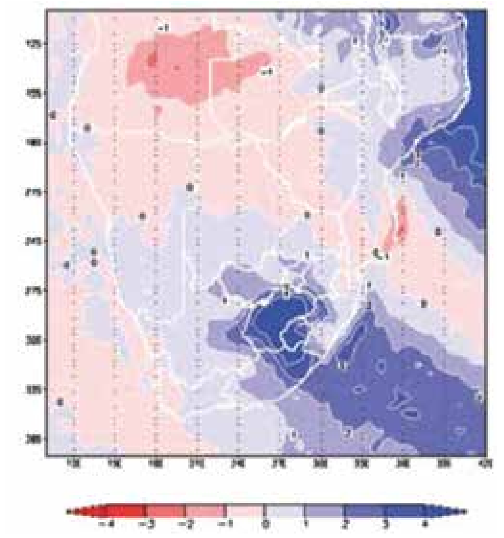


Figure 6: Projected change in the annual frequency of extreme rainfall events (>20mm day^{-1}) by 2071–2100 compared to 1961–1990 over the southern African region (Davis, 2011).

It is important to note that once a natural disaster occurs it is not easy to determine the health impacts that result from these extreme events. Several stakeholders need to work together to gather information which is useful and can aid in future projections and in establishing mechanisms to mitigate the effects associated with natural disasters. Linking a health impact or outcome to the source is always difficult due to the delayed and secondary consequences involved. Information systems can play an important role by capturing essential information on a natural disaster, and in eventually being able to pin-point the source of the health effect or outcome. Existing surveillance systems are inadequate and need to be strengthened. While the systems are able to capture the occurrence of a disaster well, they fail to capture associated health impacts well.

The research and development community needs to address the linkage between natural disaster and health impacts, particularly secondary impacts which are not always clear. In addition to studies that address health impacts of natural disasters it is important to gain a better understanding of the vulnerability of communities potentially at risk from natural disasters.

5.4.1 *Potential metrics to project and monitor health impacts from natural disasters*

There are many potential metrics to monitor the health impacts arising from natural disasters, both for immediate and long-term health effects. Immediate effects may include displacement, increased hospital admissions, and number of lives lost. Long-term effects are often indirect and harder to define or monitor, making modelling and projection of these effects complicated.

5.4.2 *Key cross-sectoral linkages*

Extreme events impact on numerous sectors, and linkages are needed to these sectors to minimise the detrimental health impacts of these events. Sectors that need to be linked with extreme events are (Midgley et al., 2007):

- Water resources and hydrology;
- Agriculture;
- Forestry;
- Terrestrial ecosystems and biodiversity;
- Rural and urban livelihoods and impacts on the environment;
- Building and construction;
- Early warning systems (extreme events);
- Economic or business;
- Defence and security.

The type and extent of involvement of different sectors will depend on the type, magnitude and location of a natural disaster. A risk and vulnerability assessment needs to be completed and the findings communicated to the necessary authorities to ensure that the issues of concern are addressed in a timely manner. This will also facilitate the development of appropriate mitigation actions.

5.5 Air pollution

The impact of air quality on health in South Africa has not been comprehensively researched and constitutes a gap. There are health studies that have been performed in South Africa, many of which have been ad hoc. Several of these studies have indicated adverse health effects or nuisance effects of air pollution, particularly in the priority areas and the urban areas of South Africa (e.g. Zwi et al., 1991; Terblanche, 1998; Mathee and Von Schirnding, 2003; Naidoo et al., 2006; Oosthuizen et al., 2008; Wright, 2011).

Predicting air quality plays an important role in the management of our environment and is of growing importance to society. Prediction of air quality has improved significantly because currently atmospheric chemistry, transport, and removal processes are well understood (Carmichael, 2006).

An early warning system would be beneficial to reduce the prevalence of diseases caused by atmospheric pollutants. The success of an early warning system that provides forecasts and alerts local inhabitants depends on the reliability and the availability of up-to-date meteorological information and pollution data. For instance, medical practitioners can advise patients to minimise outdoor activities during days of high levels of pollutants and smog, based on the prediction of the early warning system (Bernard et al., 2001). A study conducted by Xing et al. (2011) used a model called the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model to make projections for 2020 and 2030 in Europe. The model addresses air pollution impacts on human health arising from fine PM and ground-level ozone, damage to vegetation caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions. This model describes the interrelations between these multiple effects and the pollutants that contribute to these effects at the European scale.

Internationally, modelling air quality projections is possible. However, it is not yet possible to model air quality in South Africa because of the lack of detailed and up-to-date emission inventories for the country. Additionally, local data on the health impacts associated with air pollution is lacking preventing modelling of impacts at local level. There have been some studies in South Africa, and this information could be used, however, additional local data would be needed to strengthen this relationship.

Meteorological data that would be needed for projections include water vapour, wind speed, temperature, pressure, clouds and precipitation. In addition, emissions data are key and constitute a research gap for air quality modelling in South Africa (Streets and Waldhoff, 2000; Bernard et al., 2001; Klimont et al. 2001; Carmichael, 2006; Ohara et al. 2007, Xing et al, 2011, Vong et al., 2012). A national emissions inventory database is required to determine health indicators and develop local models. Ultimately, data needs will be dictated by the modelling approach.

5.6 Communicable diseases

It has been suggested that environmental conditions for cholera may be predicted by monitoring or forecasting the seasonal abundance of zooplankton in aquatic environments using remotely sensed vegetation images (Colwell 1996; Lobitz et al. 2000). Currently, there are models that can be used to project the number of cholera cases on short time scales (e.g. 3–10 years) (e.g. Rinaldo et al., 2012). These models take climatic and non-climatic factors into account. However, it is very difficult to predict cholera over long periods of time because this requires health data with high spatial resolution in order to make the environment-health linkages.

In South Africa, the CSIR has developed a model based on knowledge captured from literature reviews, discussions with experts and historical data on cholera outbreaks and environmental conditions in the KwaZulu-Natal Province in South Africa (Fleming, et al., 2007) that can predict relative risks. Further work on this model will incorporate remote sensing data that can supply input surfaces for some of the variables (e.g. surface temperatures of water sources large enough to be detected on satellite images and phytoplankton) (Fleming, et al., 2007).

It is important to take into account the situation within neighbouring countries when modelling cholera in South Africa. This is because a cholera outbreak in a country bordering South Africa is likely to spread into South Africa. Therefore research needs to focus on both spatial and temporal scales. Furthermore, quantification of the environmental impacts based on correlation studies, cause-effect relationships and other dynamics is missing. As a result, correlation studies focusing on temperature and/or rainfall do not accurately predict future cholera outbreaks (LTAS, 2013). Table 6 below describes the types of data required to project cholera outbreaks or the likely transmission of the disease. It is important to note that the exact data needs will be dictated by the modelling approach.

Table 6: Types of data needed to do cholera projections (Colwell 1996; Lobitz et al., 2000; Fleming, et al., 2007; Rinaldo et al., 2012; Tennenbaum et al., 2013).

Environmental data	General data needed	Climate data
Sea surface height	Monthly discharge of the river	Sea surface temperature
Shortwave and downward long-wave radiations	Pathogen transmission rate	Air temperature
Salinity	Maximum contamination rate	Land surface temperature
Plankton blooms	Local fraction of households without access to piped water	Rainfall
Algal blooms	Demographics	Relative humidity
Tide		Winds
pH		Pressure
Oxygen, oxidation reduction potential		UV light
Iron presence		

Non-climatic data (e.g. regarding water access, sanitation, urbanisation and infrastructure) are important because they play a vital role in the transmission of cholera and should be taken into consideration when doing projections. Climatic and environmental conditions trigger the start of cholera but the transmission of the disease is ultimately determined by non-climatic factors, as is the transmission of other diarrhoeal diseases. Thus the vulnerability and risk of communities to diarrhoeal diseases in general is a critical research need.

A positive relationship was found among cholera occurrence, precipitation and sea surface temperature in KwaZulu-Natal (Mendelson and Dawson, 2008). Furthermore, other studies conducted in Zambia showed an association among cholera occurrences, higher precipitation and temperature (Fernandez et al., 2012). These two studies found that an increase in temperature and rainfall resulted in a higher number of cholera cases (Fernandez et al., 2012). Conversely, low precipitation (e.g. drought) has also been found to play a role in cholera outbreaks in Iran (Pezeshki et al., 2012).

Research on combining human related models and environmental models to form dynamic models for predicting cholera and health effects are key research needs. Importantly, the vulnerability of communities and socio-economic pathways need to be considered in projections of the disease. Therefore, a vulnerability assessment should be the first step.

5.6.1 *Potential metrics to project and monitor cholera*

The potential metrics for projecting and monitoring cholera include monthly cases of cholera, reported hospitalised cases, hospitalised deaths and infection rate.

5.6.2 *Key cross-sectoral linkages*

The following sectors are key linkages that need to be considered for cholera:

- Water;
- Rural development, education, and home affairs;
- Disaster risk reduction, management and response; and
- Human settlements, infrastructure and service delivery.

5.7 Mental health

While mental health issues are prevalent in South Africa, it is very difficult to gauge the impact of climate change on mental health in the country given that there is little research on this issue. Although there is little funding for mental health services and research in South Africa (Seedat et al., 2004; Tomlinson et al., 2009) it is important that the mental health research community starts to address this gap in the current body of knowledge. In doing so, both the direct and indirect impacts of mental health resulting from climate change should be addressed. Vulnerability factors pertinent to the development of mental health issues should be given equal importance. Ignoring this important issue will undermine efforts targeted at reducing the risk of increases in the climate-related burden of disease (Moser, 2007).

It is important to gain a better understanding of the distribution of mental illnesses in the future. To date, climate change and weather-related mental health projections do not exist for South Africa, which remains an important gap in the current body of knowledge.

5.7.1 *Key cross-sectoral linkages*

Mental health issues permeate every facet of society. Thus, all sectors, including those addressing natural disasters, agriculture, economic development, social development, communication, and demography are important and relevant to mental health. The vulnerabilities in any one sector are likely to have a direct and indirect impact on mental health. Climate change and related weather events will exacerbate the vulnerabilities in these sectors and in turn affect mental health issues. It is thus important that efforts aimed at dealing with mental health issues in South Africa take cognisance of all vulnerability issues in other sectors.

6. CONCLUSION

Climate change will directly and indirectly impact the transmission, occurrence and distribution of key health impacts in South Africa with knock-on implications across sectors. However, the relationship between climate change impacts and these diseases is not yet well-understood for South Africa. For many health risks in South Africa research is not yet at a stage where the health impacts stemming from climate change can be accurately projected. At present, however, models and/or methodologies exist to begin projecting the impacts of climate change on heat stress, cholera and malaria, with the modelling of the latter being the most robust. Importantly, non-climatic factors need to be considered in such projections, as these factors often play a more important role in the transmission/spread of the disease than climatic factors. Furthermore, there are also numerous linkages between the health risks and other sectors that need to be taken into account when making projections.

The World Health Organisation (WHO), in conjunction with the DoH, is in the early stages of developing the first vulnerability assessment of the health sector in South Africa. The first step is a situation analysis and needs assessment (SANA) process. This, however, will need to be expanded to include vulnerability and risk assessments of specific diseases to climate change and impact modelling (including consideration of non-climatic factors) to determine risk factors and health impacts that need to be addressed through adaptation. Including adaptation measures that support the health sector in other sector policies will be instrumental in ensuring that health-climate considerations are included in future development and adaptation planning, and in building the climate resilience of vulnerable communities in South Africa. Malnutrition and natural disasters pose as key health risks. These have a number of cross-sectoral linkages in particular with the water and agriculture sectors. Multi-sectoral collaboration is therefore needed in conducting research and in developing and implementing adaptation plans.

Annex 1. Breakdown of available projections, research requirements, possible metrics and cross-sectoral linkages for health risks and/or conditions.

Key Health Risk	Available Projections	Research Needs	Possible Metrics to Track Impact	Key Cross-Sectoral Linkages
Heat stress	• Projections of temperature • Thresholds above which health impacts are realised, though not for South Africa.	• Relationship between high temperatures and health in SA • Vulnerability factors applicable to the South African population.	• Temperature (e.g. number of days above a certain temperature threshold). • Health outcomes (however, research is needed to determine which health outcomes would be best suited to track).	• Water • Human settlements (housing type, material and infrastructure such as windows, blinds and shading can be a significant non-climatic factor in reducing or increasing heat stress for communities e.g. thermal performance of housing) • Agriculture, forestry, mining and fisheries (impact of heat on occupational health of workers) • Disaster risk reduction • Occupational health in general • Business or health (food storage and transportation)
Vector-borne diseases: Malaria	• Global and regional models on malaria projections.	• Research on adaptation strategies that do not use potentially harmful chemicals. • Vectors in SA and how they might be affected by climate change.	• Climate suitability for transmission. • Malaria risk. • Monthly cases of Malaria. • Person-months of exposure. • Many metrics of lifecycle.	• Land use • Built environment • Disaster risk reduction
Food insecurity, hunger and malnutrition	• Rainfall projections for SA • Projections of maize and wheat production in South Africa.	• Projections of climate change-related malnutrition. • Links between climatic projections and food insecurity.	• Number of cases of malnutrition. • Prevalence of underweight children. • Relative risk of malnutrition in the future.	• Health and nutrition • Demography • Agriculture • Fisheries • Economics • Climate sciences
Natural disasters	• Extreme rainfall projections for South Africa.	• Existing surveillance systems are inadequate and require strengthening. • Reporting and communication structures related to natural disasters are poor in SA. • Natural disaster projections with links to health impact.	• Displacement. • Hospital admissions. • Number of lives lost.	• Water resources and hydrology • Agriculture • Forestry • Terrestrial ecosystems and biodiversity • Rural and urban livelihoods and impacts on the environment • Building and construction • Early warning systems (extreme events) • Economics • Defence and security

Key Health Risk	Available Projections	Research Needs	Possible Metrics to Track Impact	Key Cross-Sectoral Linkages
Air pollution	• Some air quality impact studies, though not comprehensive.	• Air quality projections for SA. • Impact of air quality on health. • National emissions database.		
Communicable diseases	• Influence of water and temperature on cholera transmission in SA. • Models that take into account climatic and non-climatic factors to project the number of cholera cases over short time periods. • Cholera outbreaks and environmental conditions in KZN.	• Vulnerability of SA communities to diarrhoeal-related diseases. • Non-climatic factors influencing the spread of communicable diseases. • High spatial resolution health data. • A vulnerability assessment of communities and socio-economic pathways to cholera. • Population and environmental models need to be combined to form dynamic models for predicting cholera and health effects.	• Monthly cases of cholera. • Reported hospitalised cases. • Hospitalised deaths. • Infection rates.	• Water • Rural development, education, and home affairs • Disaster risk reduction, management and response • Human settlements, infrastructure, service delivery
Mental health		• Climate change and weather-related mental health projections for SA.		• All sectors, including those addressing: - natural disasters - agriculture - economic development - social development - communication; and - demography

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