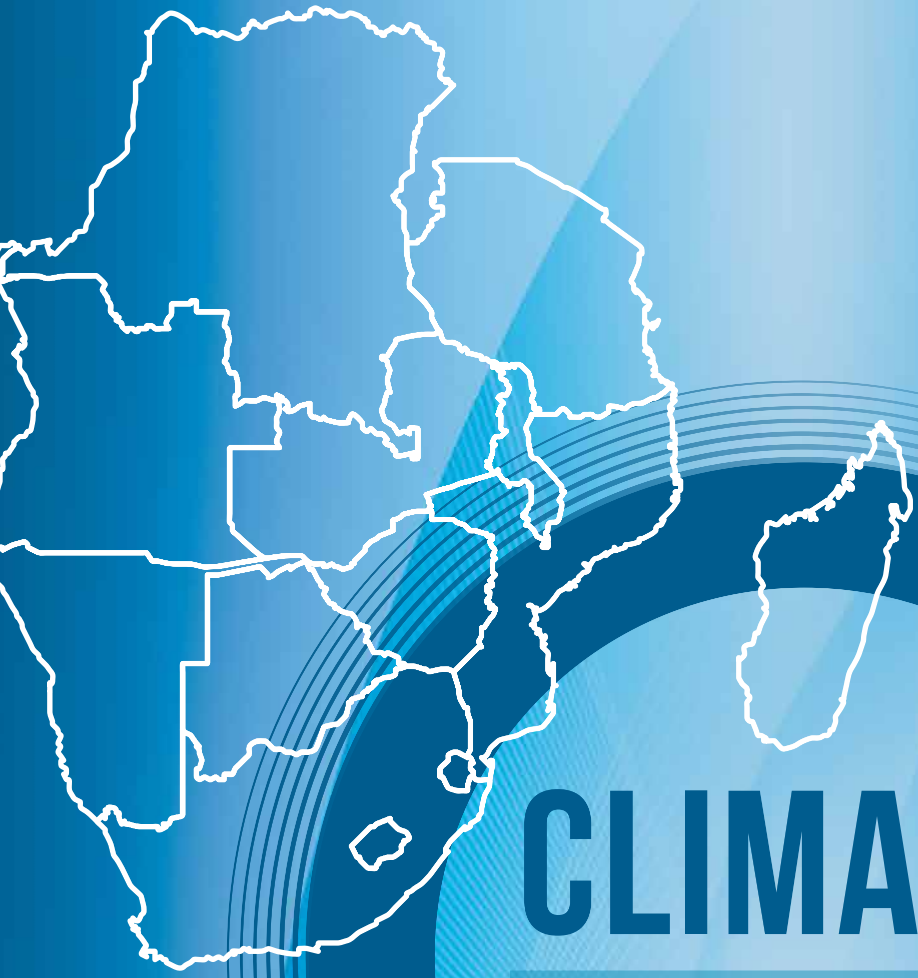

CLIMATE
RISK AND VULNERABILITY

A HANDBOOK FOR SOUTHERN AFRICA

SECOND EDITION

2nd Edition
Lead Authors: Claire L Davis-Reddy and Katharine Vincent

CLIMATE
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A HANDBOOK FOR SOUTHERN AFRICA

Second Edition

Citation: Davis-Reddy, C.L. and Vincent, K. 2017:
Climate Risk and Vulnerability: A Handbook for Southern Africa (2nd Ed),
CSIR, Pretoria, South Africa.

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ISBN 978-0-620-76522-0 (electronic version)

ACKNOWLEDGEMENTS

The project is funded by USAID with the support of the Department of Science and Technology (DST), South Africa. The authors would like to acknowledge the Applied Centre for Climate and Earth Systems Science (ACCESS), the Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL), and the Future Climate for Africa UMFULA (Uncertainty Reduction in Models for Understanding Development Applications consortium) project for supporting the research presented in the handbook. The authors would like to thank the reviewers for their valuable comments.

This work was [partially] carried out under the Future Climate for Africa UMFULA project with financial support from the UK Natural Environment Research Council (NERC), grant refs NE/M020010/1 and NE/M02007X/1, and the UK Government's Department for International Development (DFID).

Pictures courtesy of Timm Hoffman, Katharine Vincent, Claire Davis, Ute Schmiedel, Francois Engelbrecht, Simon Bundy, Emma Archer, James Irlam and Katinka Lund Waagsaether.

FOREWORD

It is clear that global warming and climate change may no longer be ignored. The climate of southern Africa has undergone significant warming. The impact of this warming world now touches every facet of regional social and economic progress. The vulnerability of southern African societies and ecosystems is critical. Future sustainable development is contingent on the capacity to adapt to the impacts of climate change. The second edition of the *Handbook for Southern Africa on Climate Risk and Vulnerability* follows on the entry into force of the Paris Climate Change Agreement of 2015. The handbook launches a series of re-definitions, concepts and programmes for addressing climate change.

The handbook is presented in three parts and guides the reader through a simplified understanding of climate risks, vulnerability to climate change and actions to cope with the impact of climate change by connecting adaptation, mitigation and sustainable development, regional climate change strategies, climate change adaptation and disaster risk reduction, climate financing, sustainability and corporate governance. Key sectors are selected to illustrate best practices in assessing vulnerability – agriculture and livestock, commercial forestry, terrestrial ecosystems and biodiversity, water resources, the coastal zone, settlements, human health, energy and air quality.

This handbook serves as an important guide for climate and development practitioners, students and policy-makers.

David Lesolle
Department of Environmental Science,
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INTRODUCTION

The second edition of the handbook presents the latest efforts to better understand the nature of climate change and the implications for southern Africa, with a strong focus on new scientific knowledge.

Climate change is acknowledged by the United Nations as the defining human development challenge of the 21st century. Its impacts are ranked among the most urgent issues facing decision-makers worldwide. In a recent report by the World Economic Forum, the failure of climate adaptation, rising greenhouse gas emissions, extreme weather events, mismanaged urbanisation, and food and water insecurity are listed as some of the most likely and consequential risks facing decision-makers today (WEF, 2015). Addressing climate change is one of the 17 Global Goals of the 2030 Agenda for Sustainable Development and seeks urgent action to combat climate change and its impacts.

The Intergovernmental Panel on Climate Change (IPCC) – the global scientific body that regularly assesses and reports on the scientific developments around climate – presents strong scientific evidence that recent changes in climate are likely attributable to human activities and that increasing greenhouse gas concentrations in the atmosphere have resulted in increased annual global temperatures, as well as associated increases in temperature extremes. The scientific evidence also indicates that Africa will be drastically impacted by climate change during the 21st century, owing to high levels of vulnerability and low adaptive capacity. The African Union's Agenda 2063 acknowledges that even though the continent contributes less than 5% of the global carbon emissions, it will suffer some of the worst impacts in the absence of effective adaptation responses. These challenges will be central to the southern African region and drastic mitigation measures in combination with robust adaptation actions are required to reduce vulnerability and enhance resilience.

Southern Africa[1] is marked by economic regional imbalances with small and little-diversified economies, pronounced inequalities and poverty (UN, 2012). According to the SADC Regional Indicative Strategic Development Plan (2010), the region is among the poorest in the world, with nearly 45% of the total population in the region living on less than one US dollar per day (SADC, 2010a). These critical vulnerabilities may exacerbate the effects of climate change in most sectors due to the direct dependence on the natural environment for livelihood support, among other factors. Understanding the way in which climate is likely to change in the future and the possible impacts on society, coupled with existing stressors, is essential in southern Africa to improve strategic adaptation response.

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[1] The Southern Africa subregion, for purposes of this handbook, is defined as the total geographical area occupied by the 15 Member States of the Southern Africa Development Community (SADC).

PURPOSE OF THE HANDBOOK

For science to remain relevant and to advance, the outcome of climate research needs to both reflect and address the information requirements of decision-makers.

The handbook ("*Climate Risk and Vulnerability: A Handbook for Southern Africa*") was conceived and designed with the intent to provide decision-makers with up-to-date information, appropriate for country planning, on the impacts and risks of climate change and variability. Reliable and accessible climate information (refer to Box 1 for details) is an important tool in responding to the impacts of climate change and the development of robust mitigation and adaptation strategies.

The handbook translates the latest climate change information in a manner that is relevant to decision-makers to build knowledge in the region. The handbook also serves as a reference guide for practitioners within the SADC member states who are currently engaged in impacts research and development of both mitigation and adaption policies and strategies. The content has been produced by a team that comprises climate scientists, social scientists with experience in impacts, vulnerability and adaptation, as well as communications experts.

PROGRESS SINCE THE FIRST EDITION

The information made available through the first edition of the handbook has begun to serve the increasing requests by stakeholders in southern Africa for information about climate change and its impacts on key sectors in the region. At the regional level, this work has helped support SADC-level engagement partly through providing source material for the SADC Climate Change Think Tank in early 2012; as well as the SADC Climate Change Science, Technology and Innovation (STI) Response Framework (refer to Chapter 13 for details). The handbook has provided information relevant to a number of studies in the region and has been widely disseminated in Malawi, Mozambique, Namibia, Zambia and Zimbabwe (as the core part of customised training courses), as well as in other countries through related events.

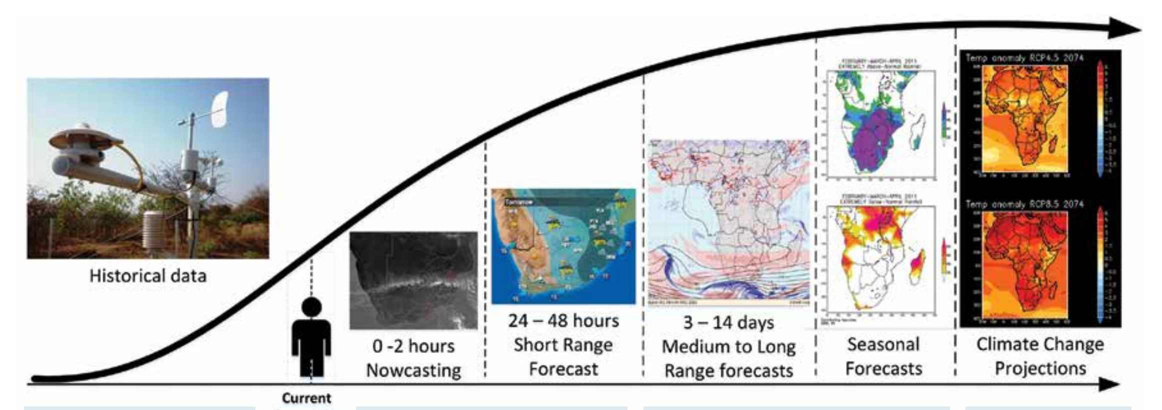
Since the publication of the first edition, increased public attention has been directed toward climate change, partly due to the COP17 held in the region in Durban in 2011, and the 2015 COP21 in Paris at which a new climate agreement was agreed. Significant progress has been made in projecting and understanding climate change for southern Africa, providing an increasingly robust basis for strategy and policy in various countries as well as in the subregion. Updated observed climate data sets and developments through the Coordinated Regional Downscaling Experiment (CORDEX) have served to fill some of the gaps in the understanding of regional climate change. The Intergovernmental Panel on Climate Change released its Special Report in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) and the Fifth Assessment Report (AR5).

Box 1: Climate information needs in southern Africa

Climate information refers to the collection and interpretation of weather- and climate-related data. Climate information, including observations, analysis and forecasts at different time scales, is important for assessing impacts and planning associated adaptation in various socio-economic sectors. Weather and climate data are mostly derived and predicted on three different time scales, namely observational (meteorological monitoring), short-term (daily to seasonal forecasts) and long-term (climate variability and climate change projections) – refer to figure below. There are several research institutions that produce and disseminate climate information in southern Africa (refer to Table S.1 provided in the supplementary information).

Climate information is becoming increasingly available and the gap between climate providers and the information requirements of decision-makers is narrowing due to a number of programmes across Africa and the subregion. User needs assessments, however, continue to stress a common set of findings when assessing the translation of data into information and the uptake of climate information, for example:

1. Improving the quality of climate data products;
2. Assisting in the interpretation and application of climate information (seasonal forecasts and climate change projections);
3. Increasing regularity in the dissemination of information and value-added products (such as this handbook);
4. Enhancing accessibility of climate information; and
5. Finer spatial scale information required for small-scale studies.



Reliable long-term data from *in situ* weather station observation is important to understand climate variability and trends.

Short-term climate information is commonly used for daily management decisions and management of extreme weather events such as flash floods. Users are increasingly looking for locally relevant and high accuracy information.

Medium-term seasonal forecasts are used for annual planning in order to prepare for expected above or below normal rainfall conditions, for example. Seasonal forecasts are often combined with agricultural and hydrological forecasts.

Long-term decisions need to consider decadal climate variability such as El Niño as well as future climate change.

Types of climate information available: short-term weather forecasts (days), medium-term seasonal climate forecasts (week to months), and long-term climate variability and change (decades).

SCOPE AND ORGANISATION OF THE SECOND EDITION OF THE HANDBOOK

The content of the handbook covers the likely physical manifestations of climate change in southern Africa, together with an understanding of how social vulnerability and adaptive capacity affect how such changes translate into impacts. The second edition of the handbook presents the latest efforts to better understand the nature of climate change and the implications for SADC countries, with a strong focus on new scientific knowledge. There is great value in revisiting and updating the early climate change trends and projections presented in the first edition to improve the understanding of sector-based impacts and the suitability of adaptation responses.

The second edition of the handbook is divided into three parts: (i) Understanding the climate risks to southern Africa, (ii) understanding the vulnerability of southern Africa to climate change, and (Iii) responding to climate change. An **Executive Summary** highlights the scientific progress made in understanding climate change and provides an integrated overview of the vulnerability of southern Africa to climate change. Details on methods and additional sources of content are provided in the **supplementary information** at the end of the handbook.

Part One presents the latest scientific information relating to recent historical trends and future projections in climate over southern Africa. The assessment of trends in climate (Chapter 1) is based on a range of comprehensive observed data sets of historical climate for the period 1961 to 2014 (Chapter 1). Climate change projections for the region are based on the latest global climate models from the IPCC AR5 as well as fine-scale (50 km resolution) downscaled products (Chapter 2). A multi-model ensemble approach[2] is taken in this chapter to describe the range of uncertainty associated with climate change projections. While this does not provide discrete answers, it provides a valuable perspective on the range of potential climate futures, which are equally plausible. The updated projections allow for the identification of plausible climate futures for each of the SADC countries, and in some cases, the identification of actionable messages for adaptation. In the second edition more emphasis has been placed on extreme climate-related events and a detailed assessment has been provided of the costs and trends of disasters in the SADC region (Chapter 3), in order to provide a context for understanding future changes in extreme events.

The observed trends in climate and future projections, as well as evidence of changes in extremes, are integrated in the assessment of the impacts and risks of climate change in **Part Two**. This section begins with a description of the theoretical and conceptual framings of risk and vulnerability as well as common approaches that have proven successful in understanding vulnerability and risks of climate change in southern Africa (Chapter 4). A review of the most significant climate change risks and vulnerabilities (both biophysical and social) is presented for the following sectors (Chapters 5 through to 12) – Agriculture and Livestock; Forestry; Water Resources; Terrestrial Ecosystems and Biodiversity; Coastal Zone; Human Health; Urban and Rural Settlements; and lastly Energy and Air Quality. This section differs from the first edition by firstly including a more detailed assessment of vulnerably for a larger group of sectors, and secondly through the inclusion of best practice guidelines for conducting vulnerability assessments in a southern African context. The assessments are focused on the regional scale and, where possible, country-level details are presented to demonstrate the spatial distributions of vulnerability across southern Africa.

Part Three is concerned with how we can respond to climate change to reduce its adverse impacts. To provide context, a review and description of the progress made to date with regard to climate change-related initiatives and strategies at the SADC level, such as the SADC Climate Change Strategy and Action Plan, are provided at the start of this section (Chapter 13). The remaining sections of the handbook focus on the responses to climate change, including mitigation (reduction in the causes of climate change), adaptation (reduction of the impact of climate change), and disaster risk management (Chapters 14 and 15), and how these initiatives can be practically integrated and financed (Chapter 16). It is important to remember that, with appropriate responses, climate change need not always be detrimental, and indeed proactive responses can exploit opportunities for human development.

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[2] An ensemble of models is used to project different (but equally plausible) climate futures.

PART I:

UNDERSTANDING CLIMATE RISKS OVER SOUTHERN AFRICA

CHAPTER 1:
OBSERVED TRENDS IN CLIMATE OVER SOUTHERN AFRICA

AUTHOR: CLAIRE DAVIS-REDDY

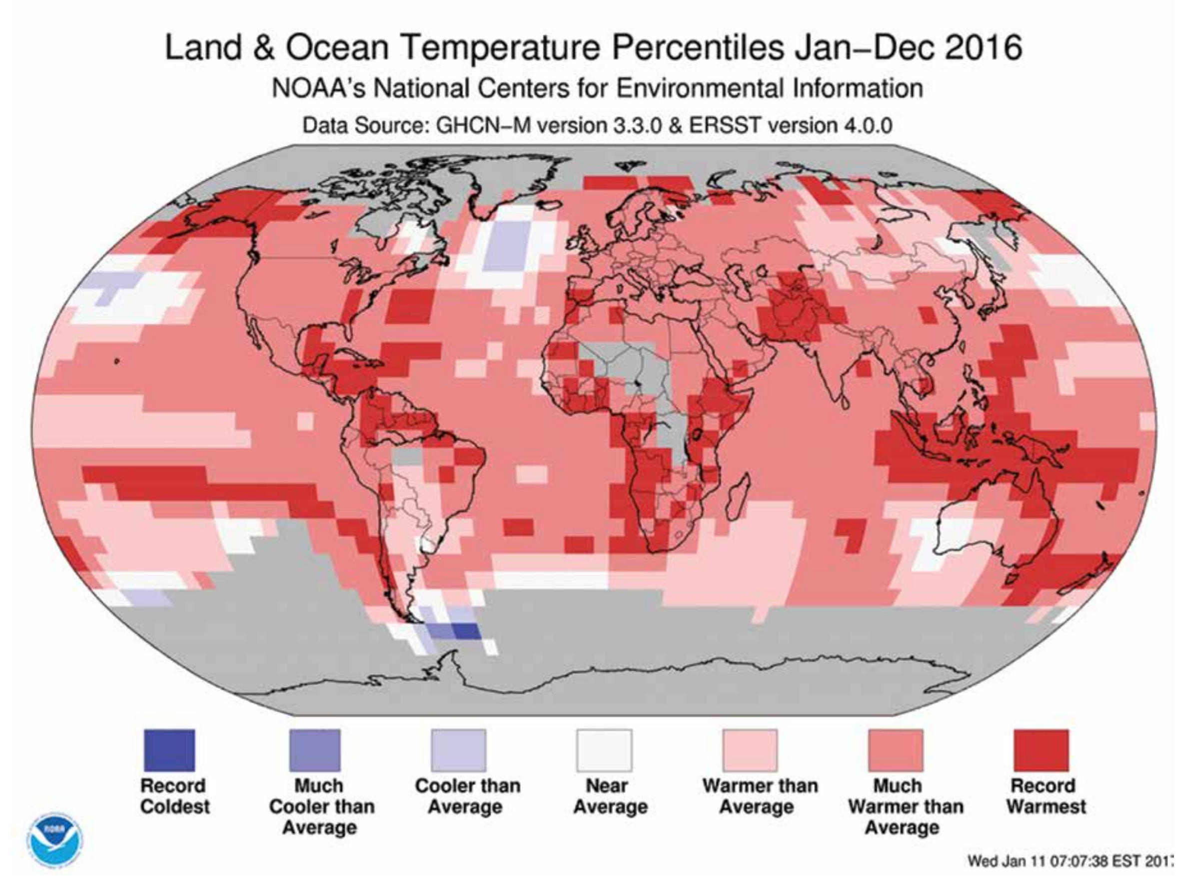
Southern Africa has been warming significantly over the last century. For the period 1961 to 2014, temperatures over the region have increased at a rate of 0.4 °C per decade. Historical rain patterns are characterised by strong inter-annual and inter-decadal variability and there is little evidence for a substantial drying or wetting over the region.

1.1. Introduction

The body of work on historical climate trends has been steadily increasing during the last decade. Global mean annual temperatures have increased by 0.85°C since 1880 and are projected to increase by 0.3 to 2.5 °C by 2050, relative to the 1985-2005 climatological average (Stocker et al., 2013). Along with 1998 and 2010, 2014, 2015 and 2016 are widely recognised as the warmest years on record. The regional distribution of temperature increases is not uniform, however, and some regions have experienced greater change than others.

For the African continent, the recent studies of Jones et al. (2012) and Engelbrecht et al. (2015) are indicative of drastic increases in surface temperature (in the order of twice the global rate of temperature increase). Over southern Africa a decrease in late summer rainfall has been reported over the western regions including Namibia and Angola (Niang et al., 2014). Where records are of sufficient length, there have been detectable increases in average rainfall intensity and the length of the dry season (New et al., 2006; Tadross et al., 2009). Recent studies for South Africa have detected decreases in rainfall and the number of rainfall days over parts of the country (MacKellar et al., 2014). There is also evidence from other studies which shows that inter-annual rainfall variability over southern Africa has increased since the late 1960s and that droughts have become more intense and widespread in the region (Fauchereau et al., 2003).

2016 was the warmest year on record, continuing the long-term warming trend (Source: NOAA)



This chapter presents:

- An analysis of observed trends in land- and sea-surface temperatures as well as rainfall across southern Africa over the last five decades using gridded climate products (CRU TEMv4, CRU TS 3.2, and HadSST);
- Estimates of the rate of relative sea level rise around the southern tip of Africa.

Evidence for recent changes in climate presented here, provides a context for the projections of future regional climate change and changes in climate extremes provided in later chapters.

1.2. Overview of the climate of southern Africa

Southern Africa has a warm climate, with the greater part of the region experiencing an average annual temperature above 17°C (Figure 1.1). In summer, temperatures are highest over the desert regions of Namibia and Botswana and exceed 40 °C during the day. In winter there is a latitudinal gradient, where temperatures decrease southwards and are coldest in the high-altitude regions of South Africa, Lesotho and Zimbabwe. Summer is from December to February (DJF), autumn from March to May (MAM), winter from June to August (JJA), and spring from September to November (SON).

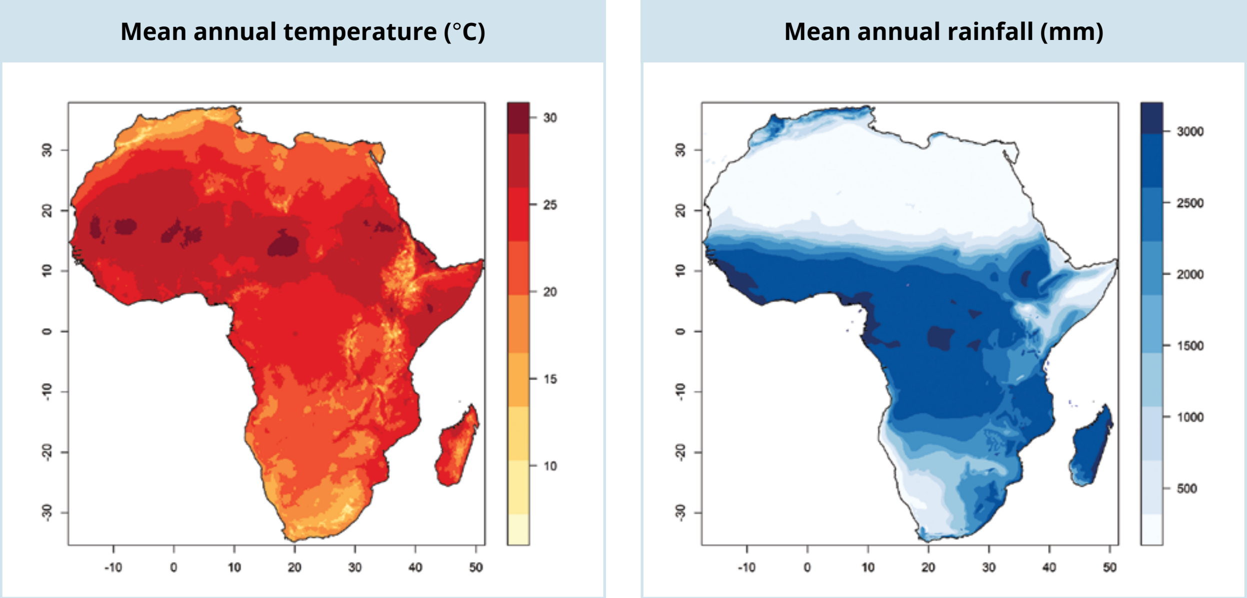
There is a high degree of spatial variation in rainfall across southern Africa due to the influence of the ocean currents and prevailing winds. The highest amount of rainfall occurs in the tropics towards the equator and in eastern Madagascar, which can receive up to 3 100 mm per year (Figure 1.1).

The majority of southern Africa has two distinct rain seasons – a wet season in the summer half of the year from roughly November to March and a dry season during winter from April to October. Areas around the equator and eastern Madagascar experience rainfall all year round, the Cape region of South Africa experiences winter rainfall due to the influence of mid-latitude cyclones, and areas in Tanzania have two rainy seasons — one from March to May and another lighter one from November to January (Hobbs et al., 1998). Tropical cyclones occasionally make landfall on the Mozambican and South African coastlines, bringing significant rainfall and associated flooding to Mozambique, the northern parts of South Africa, western Madagascar, and Zimbabwe.

Part of the reason for the diversity in southern Africa's climate is the dependence on a wide range of distinct climate systems. The average climate is strongly determined by four main factors (Nicholson, 2000):

i) The position of the subcontinent in relation to the major circulation patterns of the southern hemisphere (quasi-stationary high-pressure systems);
ii) The migration of the Inter-Tropical Convergence Zone (ITCZ), which affects the timing and intensity of rainfall;
iii) The complex regional topography (ranging from sea level to a plateau at 1 250 m, and mountains exceeding 3 000 m); and
iv) The influence of the warm Indian Ocean on the east coast and the cold Atlantic Ocean on the west coast – which leads to higher and lower rainfall respectively.

These factors interact to produce a wide variety of climate zones within the region: arid coastal desert from about 32 degrees of latitude to the border of Namibia with Angola, a semi-arid temperate climate over the interior central plateau, a humid subtropical climate over the low-lying coastal regions of the south-east, and a Mediterranean climate in the southern part of South Africa. Superimposed upon the subregional diversity of climate is the role of inter-decadal patterns of natural variability, notably El Niño-Southern Oscillation (see Box 1.1), the Indian Ocean dipole, and the inter-decadal Dyer-Tyson system.


Mean annual temperature (°C)

Mean annual rainfall (mm)

Figure 1.1: (a) Average annual and seasonal temperatures (°C) over Africa (Source: Hijmans et al., 2005) and (b) Mean annual and seasonal rainfall expressed as millimetres (mm) (Source: FAO/Agrhymet Network and ESRI).

Box 1.1: El Niño-Southern Oscillation (ENSO)

The El Niño-Southern Oscillation (ENSO) is a recurring natural climate phenomenon that has important consequences for weather, with extreme events (floods and droughts) occurring in various locations around the world. While largely unpredictable at long time ranges (initiation is observable up to six months before), it occurs approximately every two to seven years (Schreck & Semazzi, 2004).

The ENSO cycle is characterised by spatially coherent and strong variations in sea-surface temperature (SST), rainfall, air pressure and atmospheric circulation across the equatorial Pacific. El Niño refers to the warm phase of the cycle, in which above-average SSTs develop across the east-central tropical Pacific Ocean and below-average SSTs occur across the western Pacific Ocean, due to a change in wind patterns. The opposite state is called La Niña; the cold phase of the ENSO cycle. Each phase lasts approximately one to two years, with some events being larger in amplitude and lasting longer than others.

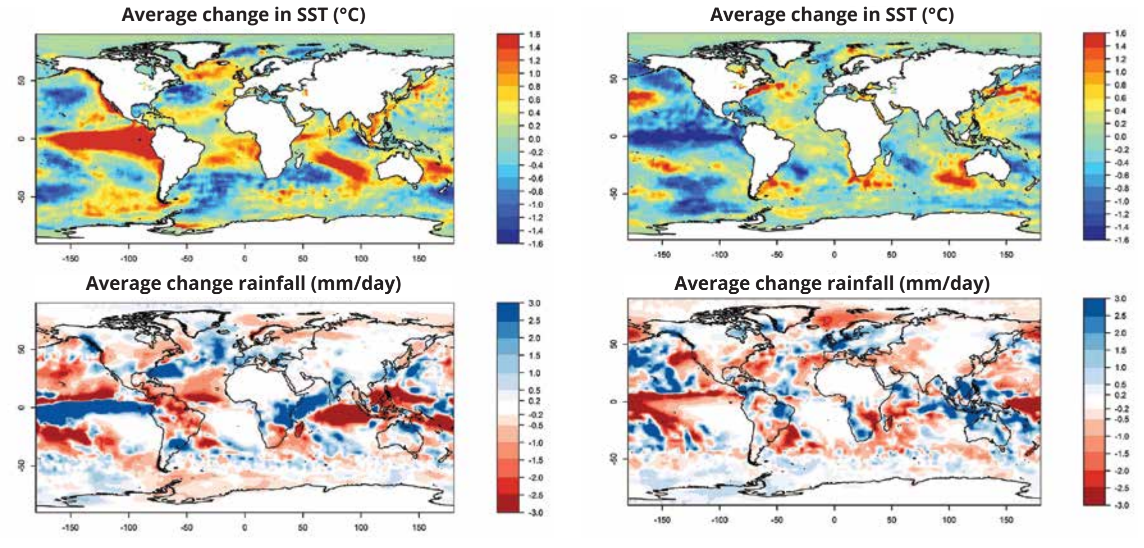
Over southern Africa, El Niño conditions are generally associated with below-average rainfall years over the summer rainfall regions, while La Niña conditions are associated with above-average rainfall conditions (see figure below). For example, in 1982/83 and 2015/16 below-average rainfall and droughts in many parts of the region coincided with strong El Niño events. Recent evidence suggests that ENSO also modulates rainfall in the winter rainfall region of South Africa, with El Niño (La Niña) years being associated with higher (lower) than normal rainfall amounts in May, June and July (Philippon et al., 2011).

The size, duration and intensity of El Niño are not well correlated with the intensity and spatial extent of drought. A large El Niño event does not necessarily result in a larger impact as other factors such as land-surface temperatures, availability of food, political stability (among others) affect the vulnerability of a region to drought.

Example of average SST and rainfall anomalies during an:

El Niño Year

La Niña Year



1.3. Analysis of observed trends in climate over southern Africa

One way to investigate how regional climate could change in future is to examine how it has changed in the past. As described in the introduction, observational records have already provided evidence of a changing global climate over the last century. Reconstructions of past climatic fluctuations and evidence of more recent changes, based on available observational records together with scientific research about the drivers of change can help scientists understand how greenhouse gas induced climate change has already influenced regional climate (particularly for changes in temperature). For details on the methodology and trend assessment techniques used here, see Section 1 of the Supplementary Information.

1.3.1. Land-surface temperature

The CRUTEM4 (Climatic Research Unit Temperature, version 4) land-surface temperature data set (Jones et al., 2012; Osborn & Jones, 2014) was used to assess changes in temperature over Africa.

There is strong evidence that the average land-surface temperature has increased across Africa over the last century (Figure 1.2), and that this warming has been particularly marked since the 1970s with the decade of the 2000s being the warmest (Figure 1.4). The regional distribution of temperature increases is uneven and some regions have experienced greater change than others. The largest trends, of 0.4 °C per decade, are observed over subtropical southern Africa, subtropical North Africa and parts of central Africa (Figure 1.2). Temperature trends across seasons show a slightly larger warming in summer (DJF) and autumn (MAM) compared with the other seasons (Figure 1.3 and Figure 1.5). Analysis of other data sets (refer to Figure S.1 through to Figure S.4) supports this trend.

The rate of change in temperature over Africa is more than twice the global estimates of temperature increase of 1.12 per century and 0.42 per century for the northern and southern hemispheres respectively (Jones et al., 2012; Osborn & Jones, 2014). These trends are consistent with detected increases in regional temperatures since 1900 (Niang et al., 2014; MacKellar et al., 2014; Engelbrecht et al., 2015). Projections of future temperature change for Africa (refer to Chapter 2) indicate that temperatures are expected to continue to increase. Associated with these increases are increases in evapotranspiration across the region, which have important implications for water stress (Niang et al., 2014; Matsoukas et al., 2011).

Spatial differences between the data sets occur in areas (see Box 1.2) where observational sampling is geographically incomplete, for example areas in Tanzania and Botswana. This suggests that the confidence in the finer spatial detail of the trends is lower in these regions. Temperatures also exhibit substantial decadal and inter-annual variability, where two different periods may exhibit different spatial patterns and differing magnitudes of warming. Differences between the data sets are larger in earlier periods (for example 1900-1960) due to the lack of observational records: this is true globally, but is particularly evident over Africa (Stocker et al., 2013a).

Evidence from some studies in the region (for example New et al., 2006) have demonstrated that minimum temperatures are increasing at a faster rate than maximum temperatures across the interior southern Africa. This has resulted in a decrease in the diurnal temperature range (DTR) for many parts of the globe. Two recent studies in South Africa (Kruger & Sekele, 2013; MacKellar et al., 2014) found no clear consistent pattern with regards to changes in DTR and suggested, along with the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (hereafter referred to as the IPCC AR5), that this topic requires further exploration and research.

Box 1.2: Data-related challenges

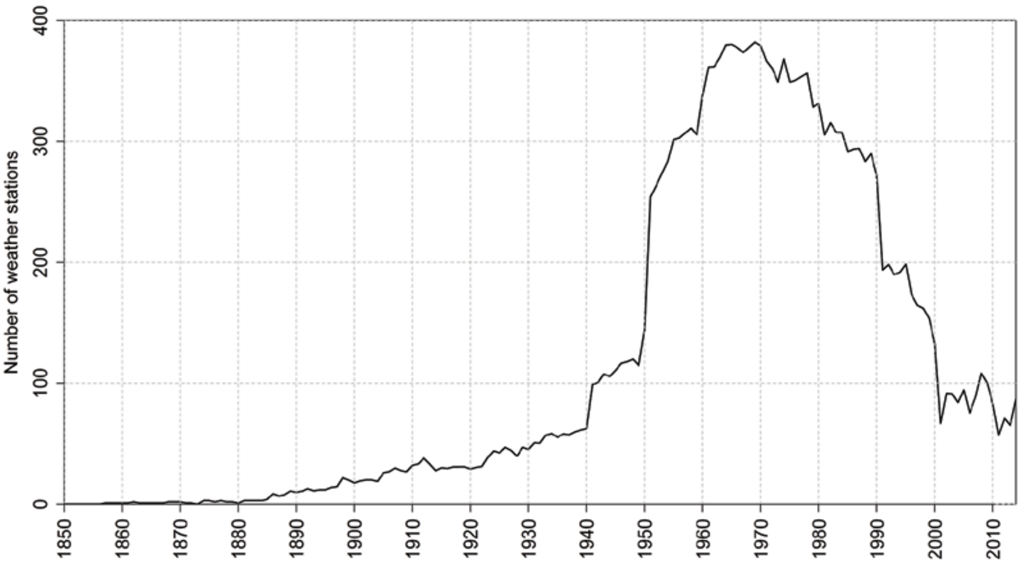
Detecting and attributing regional climate trends in Africa is subject to challenges of data availability. Firstly, there is a lack of an accurate, long-term, well-maintained and dense spatial network of observational stations. Since each station represents only a single point, the information collected may not be adequately representative of the surrounding region. Furthermore, the number of weather stations across southern Africa has decreased drastically since the 1980s, meaning that there are relatively few stations available that have sufficient data for analysis spanning several decades.

Secondly, in southern Africa many climate variables, particularly those related to rainfall, exhibit very high variance on time scales ranging from daily through to multi-decadal (see Box 1.1 on the influence of ENSO). Climate change is superimposed on this variability, which makes it challenging to understand how the regional climate is changing. Scientists are seeking to understand how climate change interacts with these natural drivers to influence southern African climate, but this is very challenging given limited data availability.

The location of NOAA's Global Historical Climate Network (GHCN) weather stations, as used by CRU, across Africa.

GCHN weather station database

The number of weather stations collecting daily temperature records across southern Africa from 1850 to 2014 used in the gridded CRUTEM4 product. Station density increased consistently from the start of the 20th century and peaked in the 1970s, after which it began to decline.



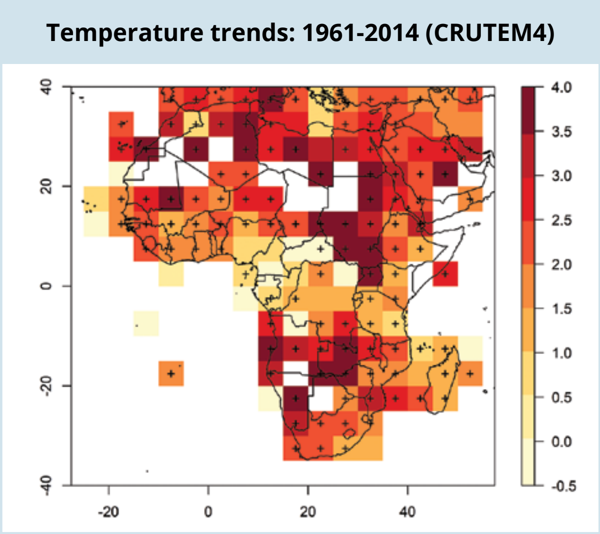
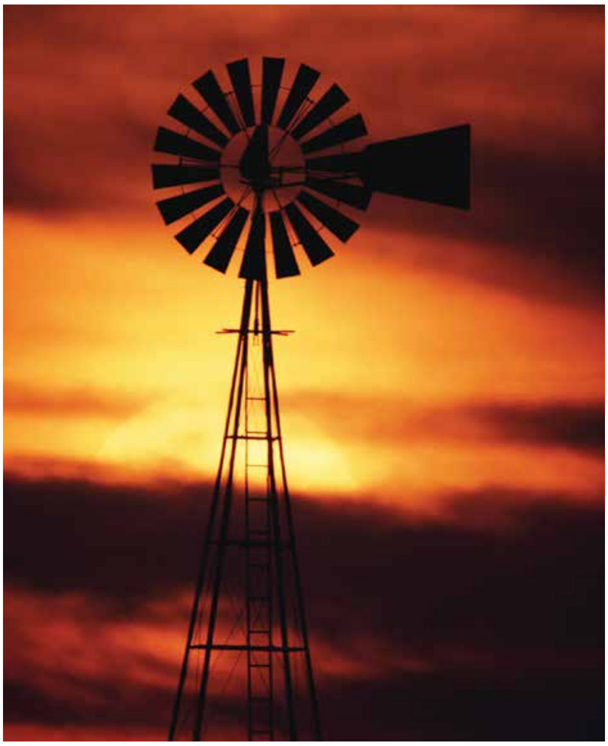


Figure 1.2: Observed trends in annual average near-surface temperature (°C per decade) over Africa for the period 1961-2014 based on CRUTEM4v data. Crosses indicate grid boxes where the trend is statistically significant. White areas indicate incomplete or missing data.



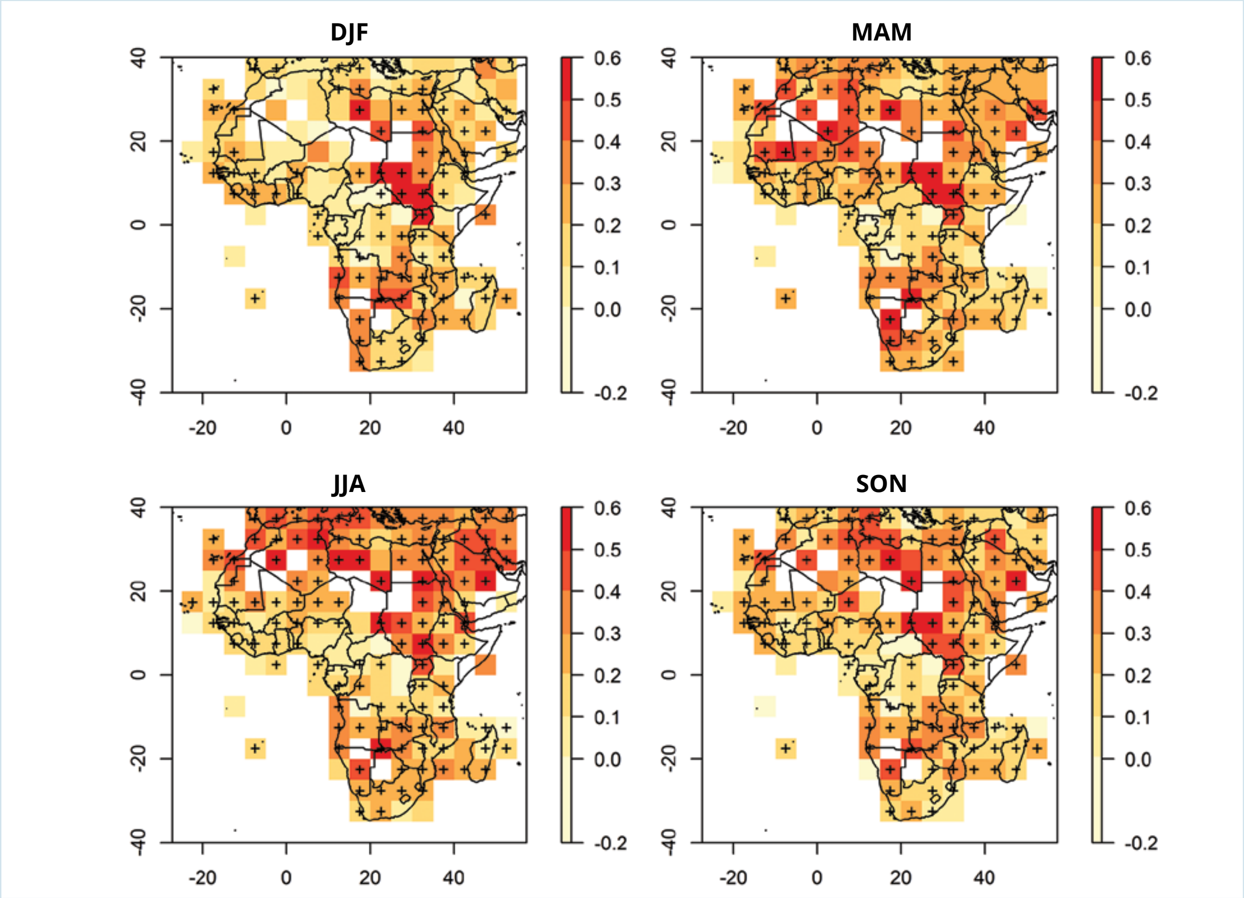


Figure 1.3: Observed trends in seasonal average near-surface temperature (°C per decade) over Africa for the period 1961-2014 based on CRUTEM4v data. Grid boxes where the trend is statistically significant are indicated by crosses. Seasons are given as summer (December-January-February), autumn (March-April-May), winter (June-July-August), and spring (September-October-November). White areas indicate incomplete or missing data.

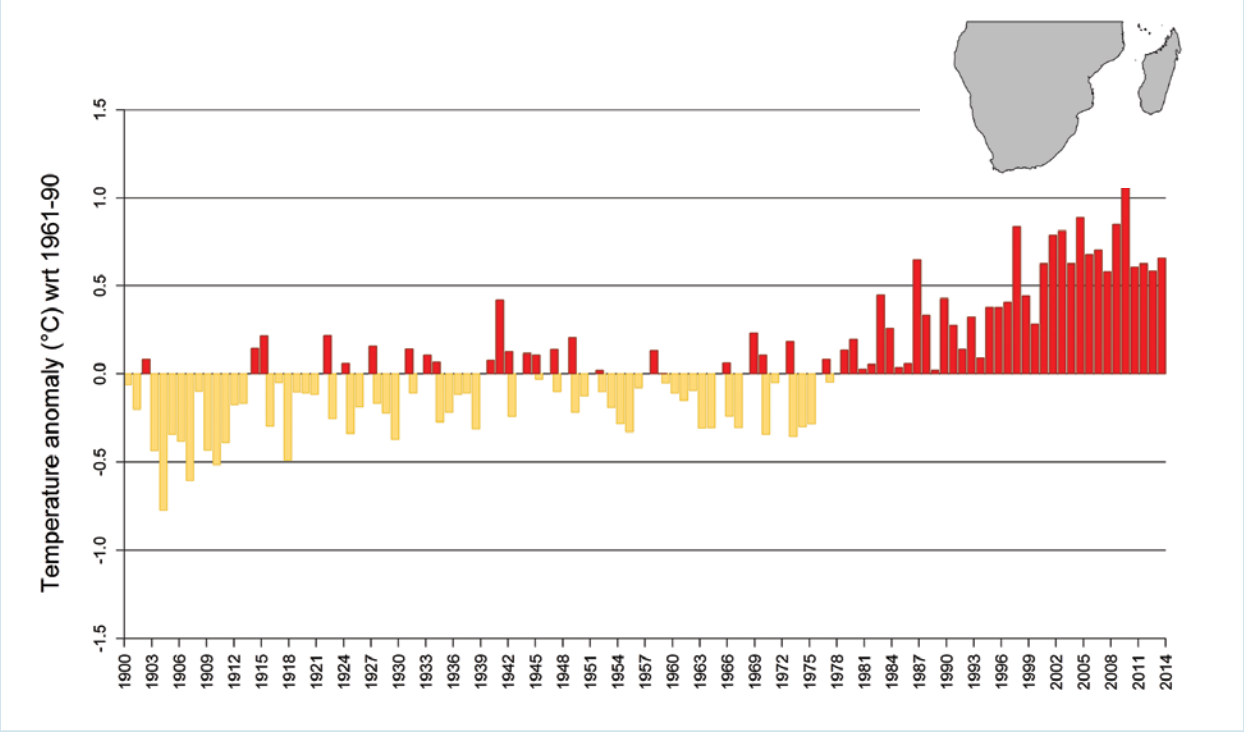


Figure 1.4: Mean annual temperature anomaly (°C) over southern Africa from 1901 to 2014 with respect to the long-term average climatology 1961-1990; based on the gridded CRUTEMv4 data set. Red represents a positive anomaly and yellow a negative temperature anomaly.

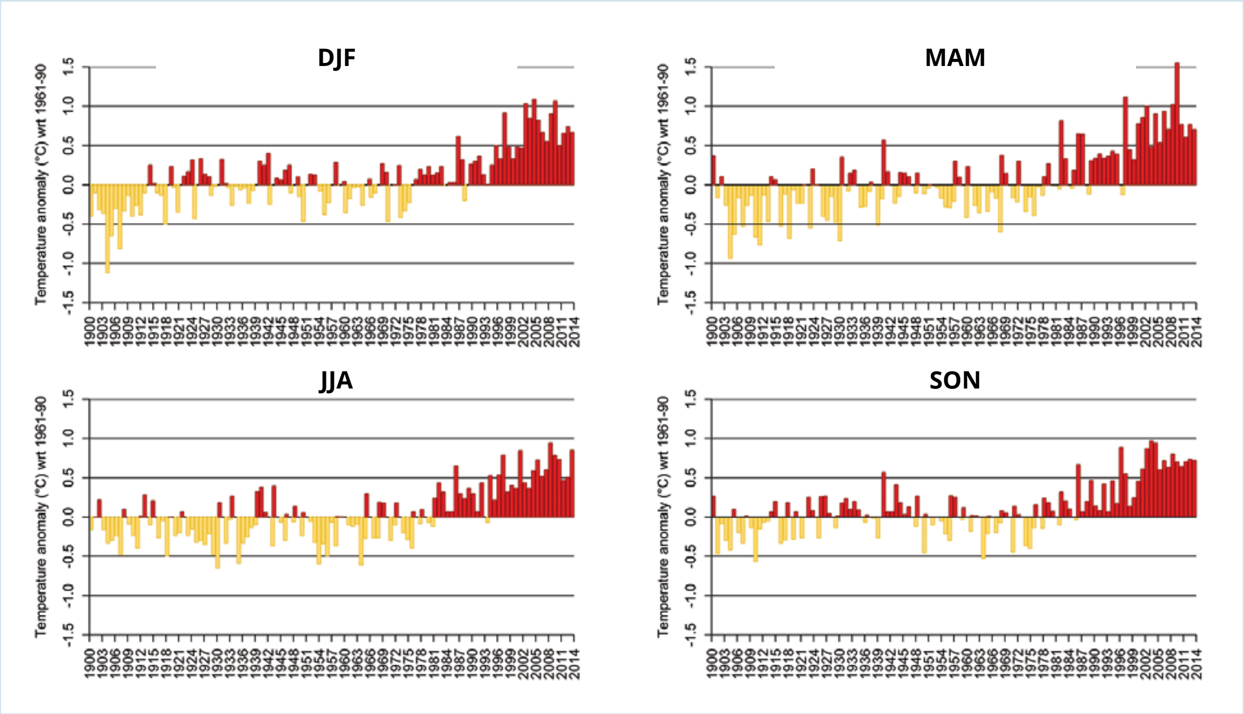


Figure 1.5: Seasonal temperature anomalies (°C) over southern Africa from 1901 to 2014 with respect to the long-term average climatology 1961-1990; based on the gridded CRUTEMv4 data set. Red represents a positive anomaly and yellow a negative temperature anomaly. Seasons are given as summer (December-January-February), autumn (March-April-May), winter (June-July-August), and spring (September-October-November).

1.3.2. Sea-surface temperature

Trends in sea-surface temperature (SST) demonstrate warming at all latitudes along the entire African coastline (Figure 1.6). The highest increases in SST are observed in the northern Atlantic and the north-west and south-west Pacific. Increasing SSTs are also observed over the Indian Ocean. Noting some differences between data sets (see Figure S.5 in the supplementary information), negative or lower magnitude positive trends are observed in the eastern Pacific along the coastlines of the Americas. These trends are consistent with those reported elsewhere (Strong et al., 2000; Good et al., 2007; Stocker et al., 2013a; Roxy et al., 2015), and which are expected to continue with climate change. Changes in SST have important implications for the upwelling strength in the Benguela Current system as well as the Agulhas Current, both of which are important drivers of climate for southern Africa.

SST trends (Tau): 1961-2014 (HadSST3))

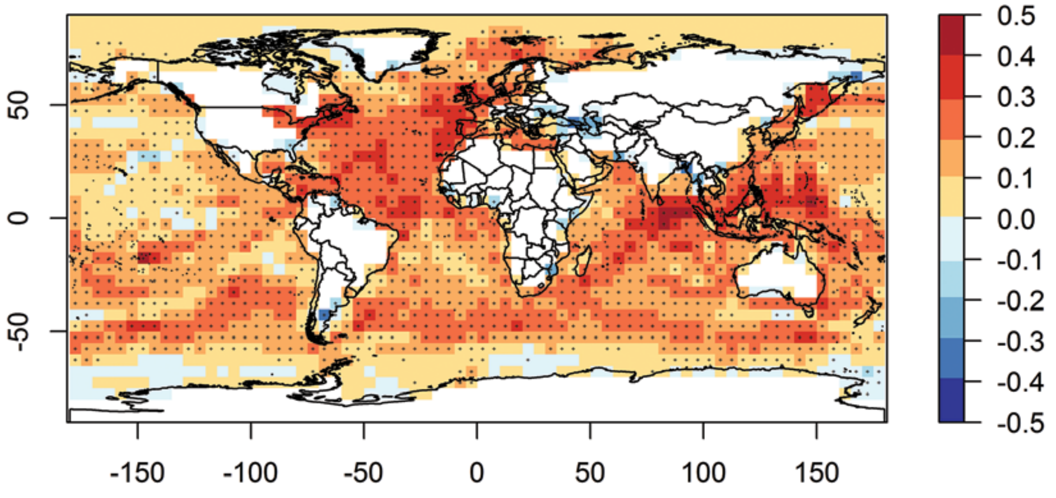


Figure 1.6: Observed trends in sea-surface temperature based on the Mann-Kendall test[3] for the period 1961-2014 based on HadSST 3.1.1.0 data set. Grid boxes where the trend is statistically significant are indicated by crosses.

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[3] Values refer to Mann Kendall's correlation coefficient , which ranges from 1 to +1 where a value of +1 indicates a trend that consistently increases and never decreases. The opposite is true of a value of -1. A value of 0 indicates no consistent trend.

1.3.3. Observed changes in relative sea-level rise

Global sea-level rise (SLR) over the last decade has been 3.3 ± 0.4 mm/year (Rahmstorf et al., 2007). The IPCC AR5 (Stocker et al., 2013a) concludes that anthropogenic global warming and sea-level rise will continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations are stabilised or reduced (Figure 1.7).

The geological environment of the oceans and coasts is also important when definitions of SLR are made. If the SLR is measured with respect to the Earth's centre, it is called *eustatic* or *absolute* sea-level change and refers to climate-related global changes (Bollmann et al., 2010). If the vertical movements of the Earth's crust are taken into account, it is called *relative* sea-level change (Bosboom & Stive, 2015). Relative SLR is the combined effect of both absolute SLR and land subsidence or uplifting and is thus the locally perceived sea-level change (Bosboom & Stive, 2015). Limited research has been done in southern Africa regarding SLR. Some literature regarding the topic may be found in Brundrit (1984), Hughes et al. (1991; 1995), Mather (2008); Mather et al. (2009), and Mather & Stretch (2012).

The west, south and eastern coast of southern Africa can expect different rates of relative sea-level rise when vertical local movements of the Earth's crust are considered, as well as the recorded changes in atmospheric and barometric pressure (Mather et al., 2009).

Both crust movements and barometric pressure varied around the southern tip of Africa, resulting in a varying *relative sea-level* rise of:

- +1.87 mm/year for the South African west coast (based on intermittent data from 1959 to 2006);
- +1.48 mm/year for the South African south coast (based on intermittent data from 1957 to 2006); and
- +2.74 mm/year for the South African east coast (based on intermittent data from 1967 to 2006).

The absolute sea-level rise values predicted by Mather (2007) compare well with global value predictions (Bollmann et al., 2010; Stocker et al., 2013a).

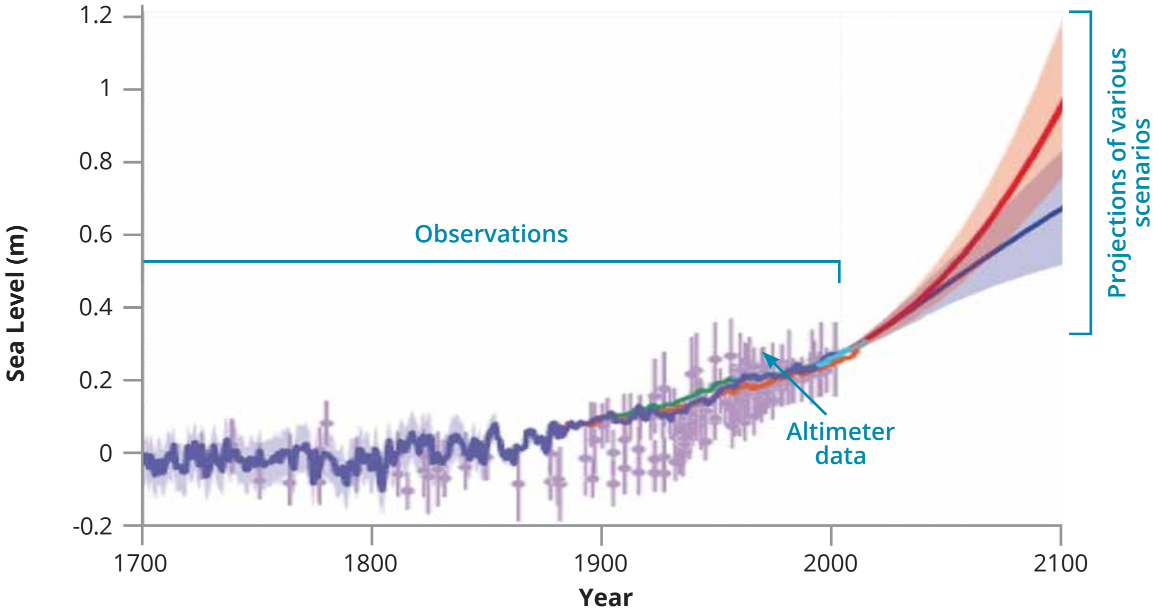

Figure 1.7: Example of measured and projected sea-level rise adapted from IPCC AR5 (Stocker et al., 2013a). The measurements are a compilation of paleo sea-level data (purple), tide gauge data (blue, red and green), and altimeter data (light blue). The projections of the absolute mean sea-level rise over the 21st century relative to 1986–2005 formulated on process-based models together with the error ranges are indicated in the shaded areas and the corresponding mean value as a solid horizontal line (Stocker et al., 2013a). All these values are relative to the pre-industrial values.

1.3.4. Rainfall

Changes in rainfall are typically harder to detect because compared with temperature, rainfall has higher variability, both spatially and from year to year (Fauchereau et al., 2003). Trends in rainfall across Africa need to be treated with caution as most of the continent lacks sufficient observational data to draw robust conclusions on the trends over the past century.

The CRU TS 3.23 (Climatic Research Unit time series version 3) dataset for the period 1900 to 2014 (Harris et al., 2013) was used to assess changes in rainfall over Africa.

For southern Africa, the rainfall time series (Figures 1.8 and 1.9) is characterised by strong inter-annual and inter-decadal variability with periods of above and below average rainfall, for example 1973–1976 and 1993 respectively. The alternating patterns of above normal/below normal rainfall periods clearly illustrate the rainfall cycles prevalent in southern Africa where extreme wet and dry years have been recorded, which resulted in floods and droughts (refer to Chapter 3). There is little evidence from the CRU TS 3.23 time series of a substantial overall wetting or drying trend over the period. Furthermore, trends are not consistent across different observed precipitation data sets and any signals of change are weak and statistically insignificant. Box 1.3 highlights the results of country-specific studies on rainfall trends.

The multi-decadal variability in rainfall over southern Africa is explored further in Figure 1.10. The decade 1960-1969 was characterised by below-normal rainfall over most of the region, except for Angola, Malawi, Zambia, Democratic Republic of Congo and Tanzania. Later in the 1970s this rainfall anomaly pattern was reversed, with parts of southern Africa experiencing above-normal rainfall. Southern Africa was considerably drier in the 1990s compared with the other decades, likely owing to the 1991/1992 drought. The 2000s were wetter for most of the region except for the countries along the south-western coast of Africa and eastern coastline of Tanzania.

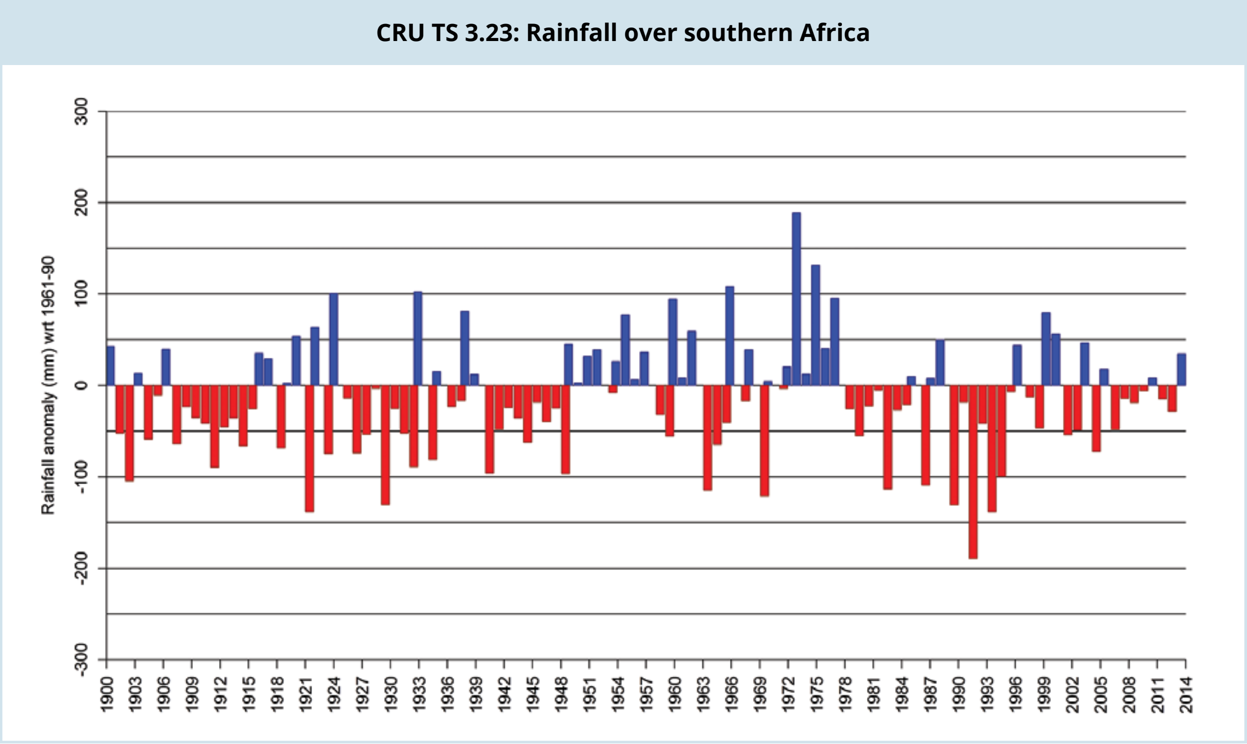
CRU TS 3.23: Rainfall over southern Africa

Figure 1.8: Mean annual rainfall anomaly (mm) over southern Africa from 1901 to 2014 with respect to the long-term average climatology 1961-1990; based on the gridded CRU TS 3.23 data set. Red represents positive anomaly and blue a negative anomaly in temperature.

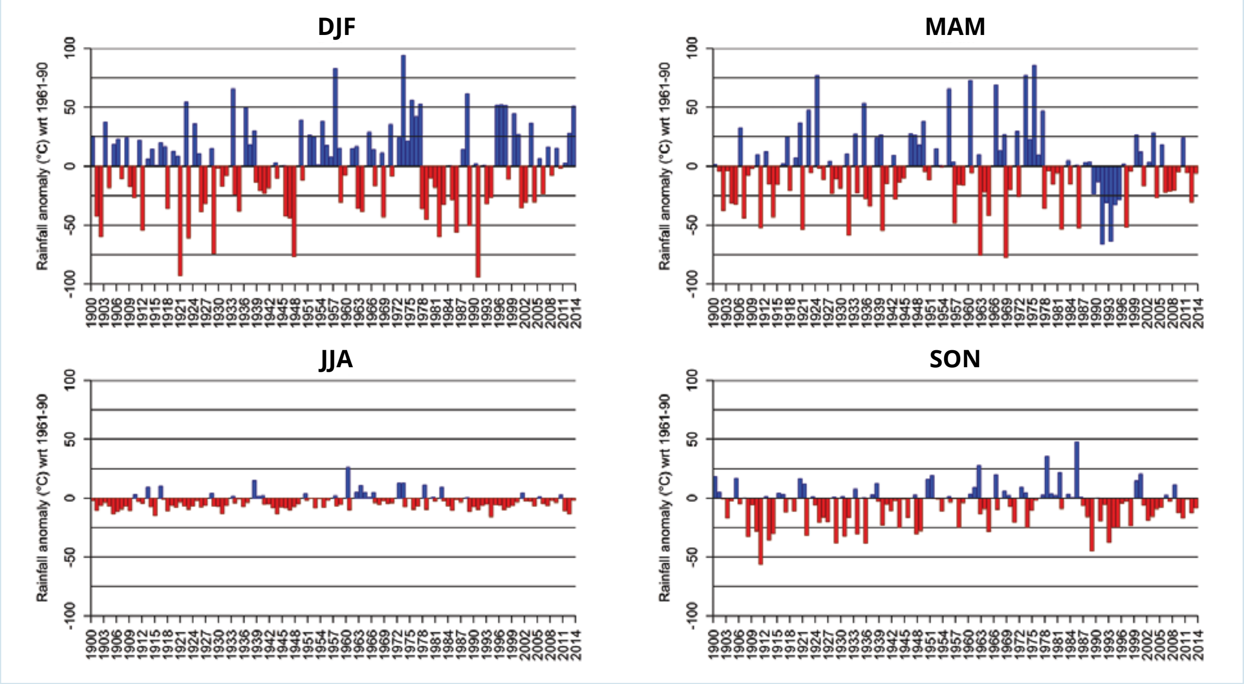

Figure 1.9: Seasonal rainfall anomalies (mm) over southern Africa from 1901 to 2014 with respect to the long-term average climatology 1961-1990; based on the gridded CRU TS 3.23 data set. Red represents positive anomaly and blue a negative anomaly in temperature. Seasons are given as summer (December-January-February), autumn (March-April-May), winter (June-July-August), and spring (September-October-November).

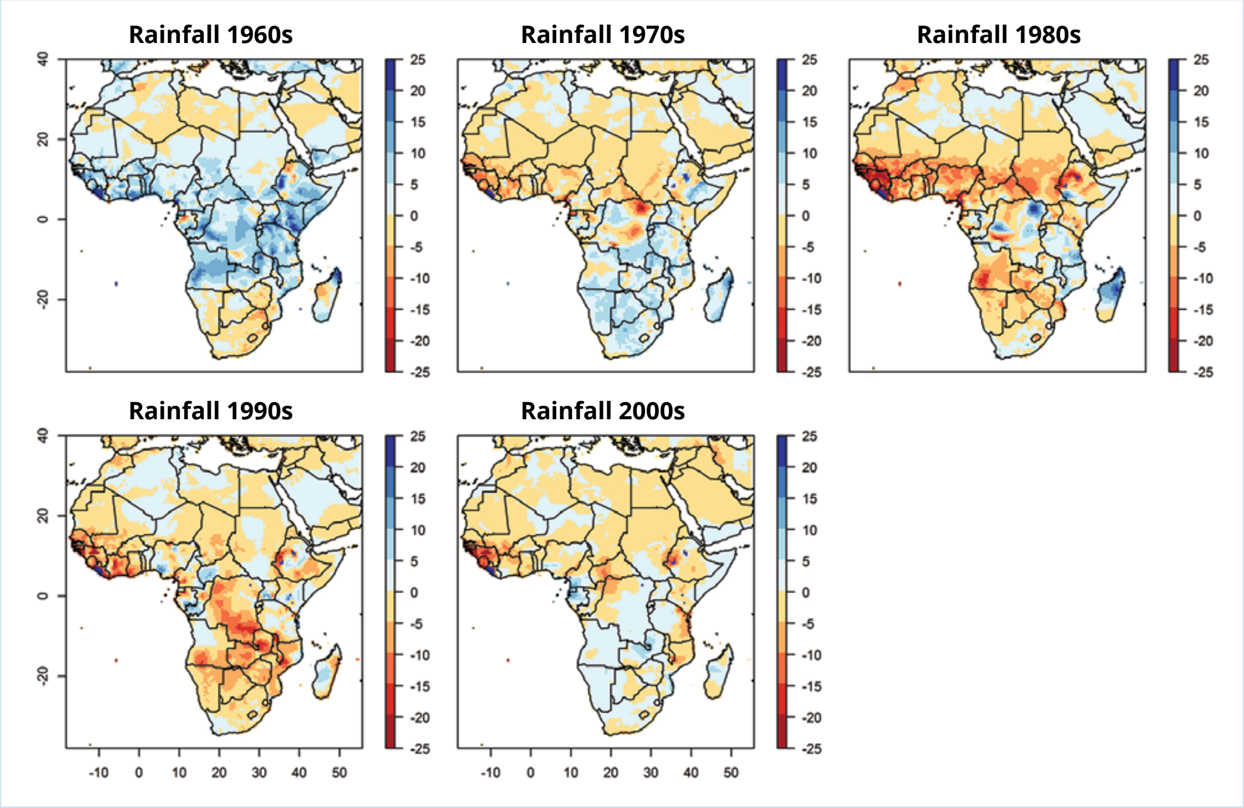

Figure 1.10: Decadal anomalies in rainfall with respect to the long-term average climatology 1961-1990; based on CRU TS 3.23 data.

Box 1.3: Country-specific rainfall trends in southern Africa

South Africa	• Between 1960 and 2010 decreases in rainfall and the number of rainfall days have been observed over parts of the country (MacKellar et al., 2014) • Positive trends in annual rainfall totals over the southern interior of the country and a drying trend in the north and north-east were observed over the period 1921 to 2015 (Engelbrecht et al., 2016, in press).
Botswana	• Rainfall data between 1975 and 2005 indicate a trend towards decreased rainfall and the number of rainy days throughout the country (Batisani & Yarnal, 2010).
Zimbabwe	• Some studies have concluded that average rainfall has declined (for example Unganai, 1996), but more recent studies using weather station records ranging from 1941 to 2000 from across the country have not found significant trends (Mazvimavi, 2010; Mapurisa & Chikodzi, 2014).
Mozambique	• Analysis of weather station data between 1960 and 2005 shows indications of a later start date of the rainfall season by up to 45 days in some areas (Tadross, 2009). • Decrease in mean annual rainfall between 1960 and 2006 due to a decrease in summer rainfall totals (McSweeney et al., 2010). • Increase in high-intensity rainfall events between 1960 and 2006, with the largest increases observed in summer (McSweeney et al., 2010).
Malawi	• Inter-annual rainfall variability is very strong and studies have found no evidence from rainfall records (1960-2000) of a change in rainy season totals, season length or duration of dry or wet spells (McSweeney et al., 2010; Vincent et al., 2014; Sutcliffe et al., 2016).
Namibia	While data from 1901 to 2000 show no directional change, trends based on rainfall station data between 1960 and 2006 have indicated (DRFN, 2008): • Shorter rainfall seasons in most regions of the country; • A decrease in the number of consecutive wet days; and • An increase in measures of rainfall intensity.
Angola	• Decrease in rainfall between 1960 and 2006 due to decreases in autumn rainfall (McSweeney et al., 2010).
Zambia	• Decline in rainfall between 1960 and 2006 over the country largely due to decrease in summer rainfall (McSweeney et al., 2010; Phiri et al., 2013).
Tanzania	• Significant decline in annual rainfall between 1981 and 2014, with greatest decreases observed in the southern region of the country (McSweeney et al., 2010; Harrison, 2015).
Madagascar	• Rainfall is highly variable particularly as a result of single extreme rainfall events due to tropical cyclones. • Total rainfall as well as the length of dry spells during winter and spring has been steadily decreasing between 1961 and 2005 (Tadross et al., 2008).
Mauritius	• There is no trend in annual rainfall evident between 1960 and 2006 (McSweeney et al., 2010). • Decline in rainfall over October-November-December between 1960 and 2006 (McSweeney et al., 2010).
Democratic Republic of Congo (DRC)	• Insufficient data to conduct analysis of changes in annual, seasonal or daily rainfall characteristics.

1.3.5. Extreme events

Sparse operational records in southern Africa (refer to Box 1.2) limit the ability to detect trends in extremes with sufficient confidence. Some changes are more evident with clear long-term trends (e.g. higher frequency of hot days), while changes in other smaller-scale events are more difficult to detect (e.g. thunderstorms).

There is strong evidence to suggest that the number of hot extremes have increased and the number of cold extremes have decreased, which is consistent with the global warming trend (Field, 2012; Stocker et al., 2013). Low temperatures, including the number of frost days, have decreased in frequency and are expected to become less frequent in the future (New et al., 2006).

The analysis of HadGHCNDEX data (refer to Figure S.6) reveals statistically significant increases in the following indices:

- Percentage of days when TX 90th percentile of the baseline average (TX90p)
- The number of days when TX>25 °C (SU25)
- Annual count days with at least six consecutive days (WSDI)

Some studies have shown that an increase in both maximum and minimum temperatures has resulted in a decrease in the DTR in many parts of the globe (Blunden et al., 2012; Easterling et al., 1997; Karl et al., 1993). Two recent studies in South Africa (Kruger and Sekele, 2013; MacKellar et al., 2014), on the other hand, found no clear consistent pattern with regards to changes in DTR and suggest that this topic requires further exploration and research in the southern African context.

Changes in extreme rainfall events are harder to detect because rainfall demonstrates a high degree of spatial and temporal variability (Fauchereau et al., 2003; Field et al., 2014; Stocker et al., 2013). Evidence suggests that the frequency of dry spells as well as daily rainfall intensity has increased (New et al., 2006). Climate change is expected to alter the magnitude, timing, and distribution of storms that produce flood events (Engelbrecht et al., 2013; Fauchereau et al., 2003; Stocker et al., 2013).

There is some evidence to suggest that droughts have become more intense and widespread over southern Africa (Fauchereau et al., 2003; Hulme et al., 2001; Masih et al., 2014; New et al., 2006), but more recent evidence is lacking. An increased frequency in droughts is projected due to the projected increases in temperature combined with a decrease in rainfall in parts of southern Africa (Engelbrecht et al., 2015; Shongwe et al., 2011; Stocker et al., 2013).

CHAPTER 2:
PROJECTED CLIMATE CHANGE FUTURES FOR SOUTHERN AFRICA

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Warmer conditions associated with more frequent very hot days (> 35 °C) are likely over most of the interior of southern Africa in the future. A decrease in rainfall is projected over central southern Africa (e.g. Northern Botswana, Namibia, southern Zambia and Zimbabwe), while an increase in rainfall is projected over northern Mozambique and Tanzania.

2.1. Introduction

Observed changes in climate presented in the previous chapter are projected to increase into the future. Global Climate Models analysed in IPCC AR5 project that mean annual global temperatures will increase by 0.3 to 2.5 °C by 2050, relative to the 1985-2005 climatological average (Stocker et al., 2013b). Over Africa temperatures are expected to rise at a faster rate than the global mean increase.

Since the first edition of the *Climate Risk and Vulnerability Handbook for Southern Africa*, significant progress has been made in projecting and understanding climate change for the region, providing an increasingly robust basis for strategy and policy in various countries as well as in the subregion.

The focus of this chapter is:

To communicate the latest climate change projections for the region and to summarise the areas of agreement between the different sources in order to provide a storyline of climate change that can be used in decision-making.

Key messages are drawn from recent subsets of future climate projections for the southern Africa region. Material in this chapter is drawn from the latest IPCC Assessment Report (Stocker et al., 2013b), the latest dynamically downscaled projections from the CSIR (NRE)[4], using the conformal-cubic atmospheric model (CCAM) (McGregor, 2005), as well as recently released studies comparing multiple GCMs, dynamical and statistically downscaled models (Hewitson et al., 2014). A multi-model ensemble approach[5] is taken in this chapter to describe the range of uncertainty (see Box 2.1) associated with climate change projections.

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[4] A set of six climate simulations has been performed by the Climate Studies, Modelling and Environmental Health Research Group of the Council for Scientific and Industrial Research (CSIR) in South Africa. In these experiments, a variable-resolution atmospheric global circulation model, CCAM, was applied as a regional climate model (RCM) to simulate both present-day and future climate over southern Africa and its surrounding oceans.

[5] An ensemble of models is used to project different (but equally plausible) climate futures.

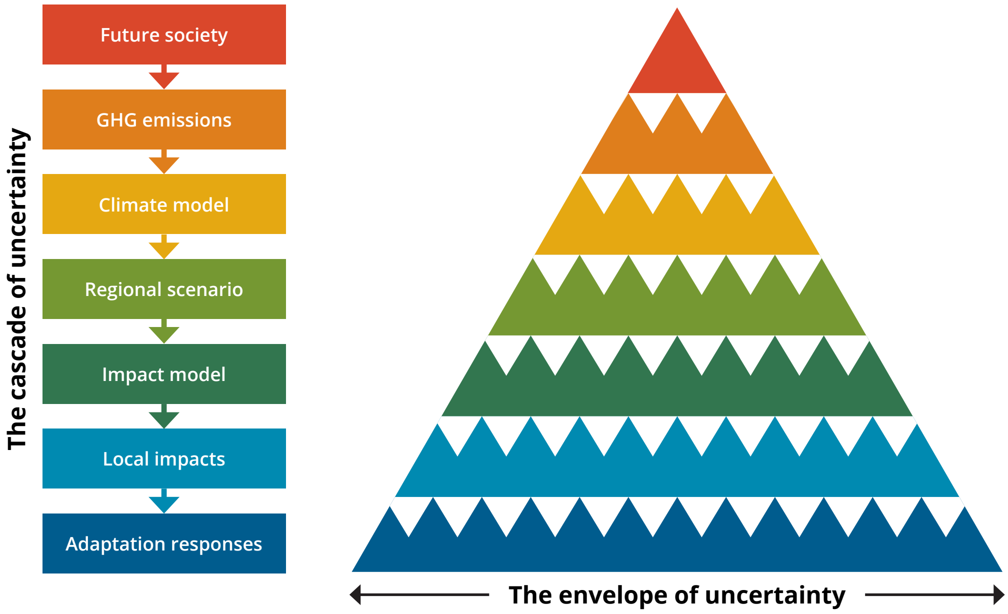
Box 2.1: A note on (un)certainty

The issue of uncertainty is crucial to understanding future climate change, especially when designing adaptation strategies that will benefit both present and future socio-economic situations.

Uncertainty does not mean that there is no confidence in the projections of future climate. Rather, it implies there is a probability or level of confidence associated with a particular outcome. Indeed, all climate projections (and even short-range and seasonal forecasts), are couched in terms of the probability of particular climate conditions occurring in the future. This is a common framework within which humans operate; determining likely future risks and opportunities, and used in many different applications, for example in financial and investment decision-making.

The degree of certainty in each finding presented in this chapter is based on the consistency of evidence such as observed climate, mechanistic understanding of how the climate works, models of the climate, expert judgement and the degree of agreement between the different models and approaches to downscaling. Simply stated, there is a greater confidence in the direction (rainfall) and magnitude (temperature) of future change in instances where all sources of information agree.

The cascade of uncertainty in projecting future climate change illustrating the increasing envelope of uncertainty from different socio-economic and demographic scenarios to local impacts and adaptation responses (Source: Wilby & Dessai, 2010).



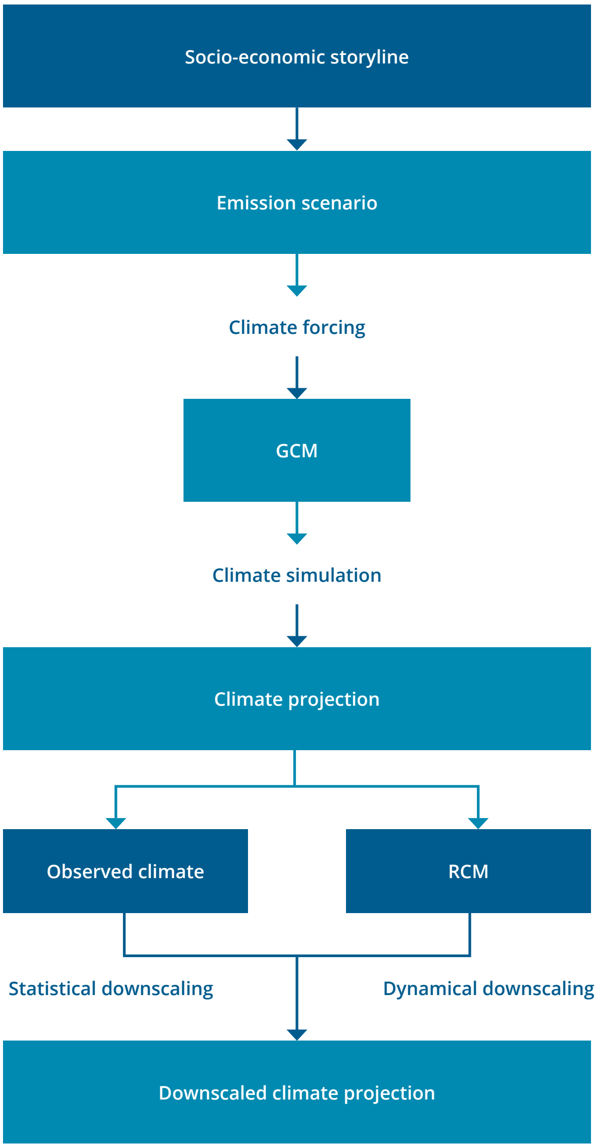
2.2. Determining future climate

Global climate models (GCMs) comprise the fundamental tools used for assessing the causes of past change and to project long-term future change. These complex computer models represent interactions between the different components of the climate system, such as the land surface, the atmosphere and the oceans. Projections[6] of future climate change by GCMs may provide insight into potential broad-scale changes in the atmosphere and ocean, such as shifts in the major circulation zones and the magnitude of sea-level rise.

Projected changes in climate are dependent on the future levels of greenhouse gas emissions in the atmosphere, which in turn are crucially dependent on society's behaviour and policy choices, whether we continue to depend on fossil fuels or switch to renewable energy sources, for example. GCMs simulate climate under a range of emission scenarios, each representing a possible future.

The IPCC Special Report on Emissions Scenarios (SRES) described four possible 'storylines' (A1, B1, A2 and B2), each assuming different paths of development for the world. Each scenario has an associated future emissions pathway which describes the amount of greenhouse gases emitted through human activity (Nakicenovic et al., 2000). This is largely why the IPCC reports project future global average temperature change to be within a certain range. The lower estimate is based on an emissions scenario where behaviour and policy translate into lower emissions of greenhouse gases. The higher estimate comprises a 'worst case' scenario, where emissions continue to increase at a rapid rate. It is very important to clearly understand that there are a range of future possibilities, as it follows that we can only suggest futures that may be more likely than others (Tadross et al., 2011:28).

In the IPCC AR5 (Stocker et al., 2013b), Representative Concentration Pathways (RCPs) replaced the SRES emission scenarios and were used as the basis of the climate projections presented in AR5. The RCPs are named according to their 2100 radiative forcing level[7].



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[6] The term 'projection' refers to estimates of future climate possibilities decades into the future.
[7] Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere.

There are four pathways – RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP 2.6 describes a scenario of very low greenhouse gas concentration levels, RCP 4.5 and 6.0 describe a future with relatively ambitious emission reductions, whereas RCP 8.5 describes a future with no reductions in emissions. Emissions in RCP 2.6 peak between 2010 and 2020; RCP 4.5 emissions peak around 2040, then decline; in RCP 8.5 emissions continue to rise throughout the 21st century (Meinshausen et al., 2011; Stocker et al., 2013a; Stocker et al., 2013b). While RCPs have replaced the SRES emission scenarios in current assessments, the outputs of older SRES GCM simulations and associated downscaled models remain valid[8] as they describe a different subset of possible future climates.

2.3. Determining regional climate change

Global climate models (GCMs) can reliably project changes in temperature, since the warming response is widespread and the physical processes responsible for warming are well-captured by these models. These models are, however, often less-skilled in translating the gathered information into changes in rainfall and other parameters at the local scale. This is because GCMs are applied at spatial scales of 200-300 km, and they often cannot capture the physical processes and features of the landscape which are important determinants of local and regional climates. For example, thunderstorms occur on spatial scales which are too small or localised for GCMs to resolve. It thus follows that GCMs tend to be unreliable estimators of rainfall in regions where convection (the physical process which produces rainfall in thunderstorms) is important. This limits the application of GCM projections for assessments of change at the local scale. For this reason, **'downscaling'** techniques, which translate changes in the large-scale atmospheric circulation (which GCMs generally reproduce well) to finer spatial scales, are widely preferred for projections of climate change at local and regional scales (Tadross et al., 2011, p.28). Two main types of downscaling methodologies may be employed, namely statistical (empirical) and dynamical downscaling.

Statistical downscaling refers to the process where large-scale climate features are statistically related to the local climate of a region – historical observations are utilised. **Dynamical downscaling** refers to the process where a dynamic climate model (either a higher resolution limited-area model or variable resolution global model) is nested/nudged within a GCM. For further explanations of these methodologies, refer to page 30 of the first edition of the handbook.

Downscaled projections are increasingly being used in studies of regional impacts and adaptation, and it is thus critical that the limitations of these data sets are well understood. Firstly, a common misconception is that high-resolution or downscaled projections are better than the coarser projections from GCMs. Although downscaled simulations are in theory expected to provide a more accurate description of regional climate and its expected future change, the higher resolution offered by these simulations does not necessarily mean higher confidence in the projections. This is as the performance of downscaling techniques are highly dependent on the quality of the input data and this means that downscaled data may inherit assumptions and errors in the GCM simulations.

Secondly, choosing the single 'best' GCM is problematic as future scenarios are all linked to the representation of physical and dynamical processes within that specific model – this may create the impression of a narrowly determined future, which may not fully span the range of potential future change. A better approach in any impact and adaptation assessment is to use the largest number of possible GCMs (excluding those that can be shown to be unsuitable) and that future change is expressed either as a range of future changes or as a summary statistic (e.g. percentiles) of the distribution of projected changes, with some measure or recognition of the spread of possible future climates also provided.

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[8] Since there is no current method of validating the different future climate change projections, there is no reason to assume that the more recent projections based on RCPs are more trustworthy than the previous estimates.

2.4. Regional climate projections

2.4.1. Comparisons between GCMs, statistically and dynamically downscaled projections for different RCPs

This section presents key messages drawn from recently released studies comparing multiple GCMs, dynamical and statistically downscaled models (Hewitson et al., 2014). The simulated climates are taken from an ensemble of 16 GCMs, an ensemble of statistical downscaling of 10 of these GCMs, and an ensemble of a single RCM downscaling of 8 GCMs generated through the Coordinated Regional Downscaling Experiment (CORDEX) of the World Climate Research Programme (WCRP). All simulations utilised both the RCP 4.5 and 8.5 scenarios and whilst some of the RCM downscaling used GCMs not included in the GCM ensemble, these model future climates are still plausible and help to address a wider range of possible future climates.

Before discussing projected changes in climate over southern Africa, it is important to recognise that both the magnitude and spatial distribution of simulated changes are dependent on which future period is interrogated in the GCM ensemble. Simply stated, changes in rainfall will vary across the region and over time; short- to medium-term versus long-term projections are dependent on decadal variability in the models and choice of future period in which to calculate the average change.

Given multi-decadal variability, it is important to recognise when in the future a model's mean state significantly deviates from its mean state during the baseline period. Without this measure it is unclear as to what degree any differences are due to variability on shorter timescales. Figure 2.1 shows the 20-year moving average rainfall in 14 GCM simulations (using RCP8.5), with simulated mean differences (with the base period 1985-2005) significant at the 95% confidence coloured orange (insignificant differences coloured blue). It is clear from the figure that significant negative differences in rainfall only become apparent in three models around 2016, with 10 models indicating mean drying by 2050. No models indicate mean wetter futures throughout the simulated period.

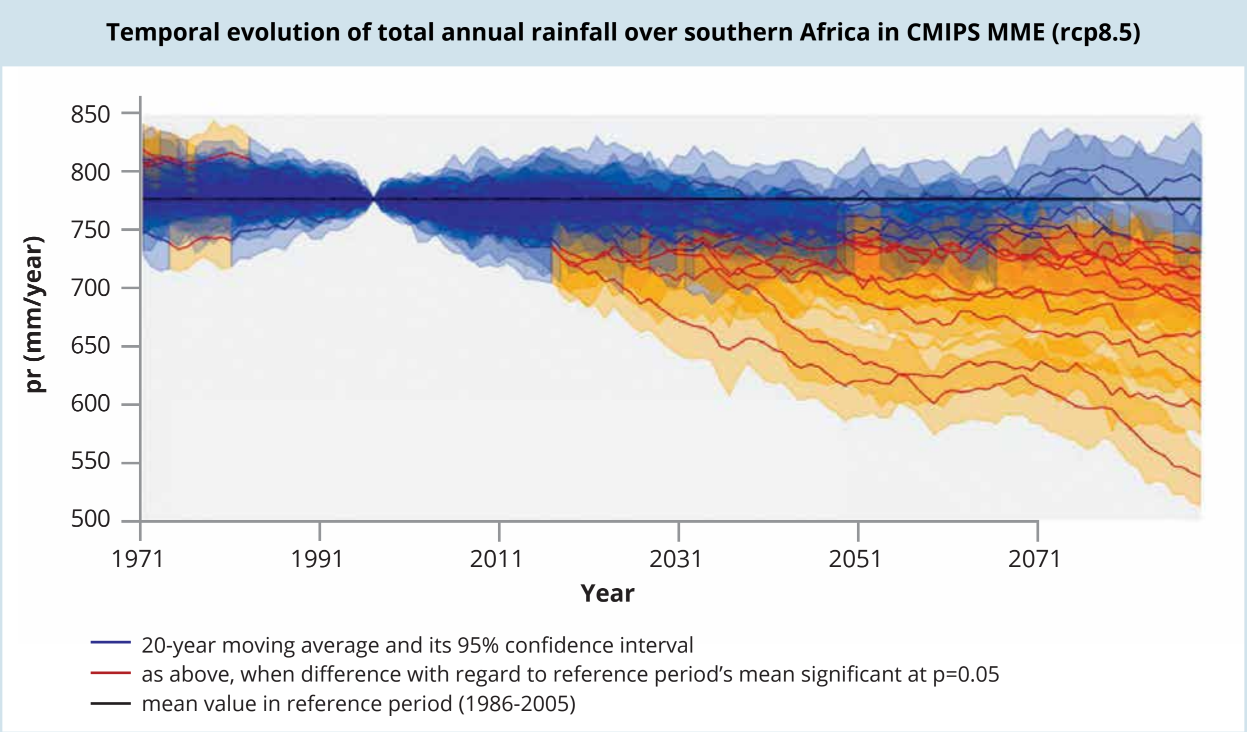
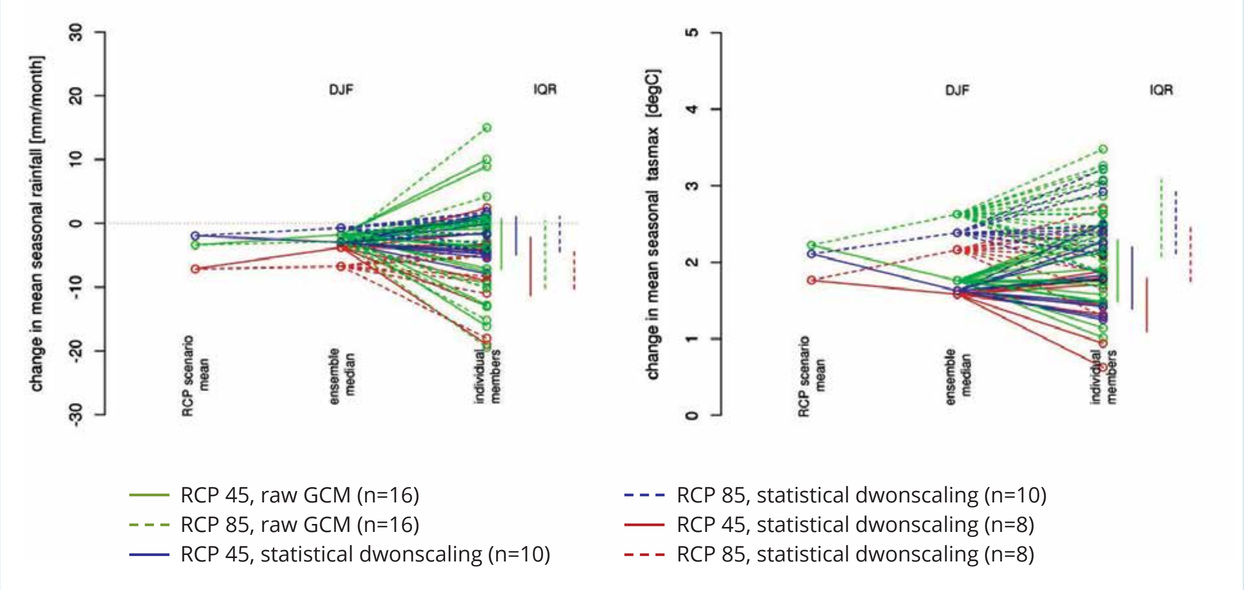


Figure 2.1: 20-year moving average rainfall, simulated by 14 GCMs (RCP8.5), averaged over a domain covering the land body of southern Africa (35°-20°S, 10°-40°E). Mean model (solid line) differences with the 1985-2005 period significant at the 95% confidence level (shaded plumes) are coloured orange; insignificant differences coloured blue.

Figure 2.2 indicates the future changes (2041-2070 period relative to 1976-2005 period) in DJF rainfall and temperature simulated by the different ensembles, the RCP scenario as a whole, and the individual ensemble members, averaged over southern Africa. For rainfall, the medians for each ensemble and scenario indicate a reduction in rainfall, but it is evident that some of the individual ensemble members (particularly in the GCM ensemble) simulate an increase in rainfall. Without further information on how these models simulate the current climate, it is difficult to assess how representative they may be and we must assume they are equally plausible representations of the future climate. However, taking the interquartile range (central 50% of model simulations) as an indication of what may be the most likely future would suggest a reduction in rainfall.

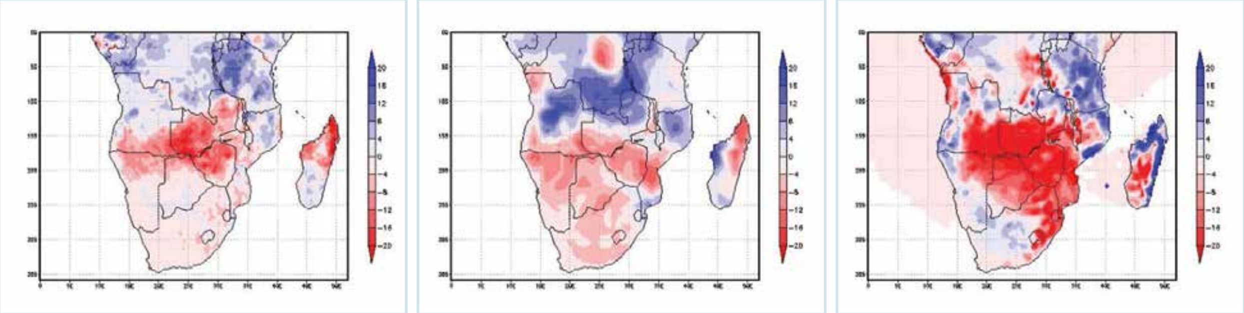
For maximum temperatures all scenarios, ensemble medians and individual models suggest an increase in the future (Figure 2.2). The GCM ensemble again encompasses the range of simulations in the statistical and dynamically downscaled ensembles, with the exception of two dynamical downscalings of the RCP 4.5 scenario. Nevertheless, taking the inter-quartile ranges, the hyper ensemble suggests increases in maximum temperatures of between 1 and 3 °C. Projections based on CCAM downscalings show that for the period 2040-2060 temperatures are projected to increase by 2 to 4 °C. By the end of the century (2080-2100), temperatures are projected to increase up to 8.5 °C over interior arid regions under RCP 8.5 (refer to Figures S.7 and S.8 in the Supplementary information).

Figure 2.3 shows maps of median simulated changes in seasonal (DJF) rainfall in each of the three ensembles for the RCP 8.5 scenario. The GCM ensemble change is shown for the same 10 GCMs used for the statistical downscaling. While there are some regional differences in simulated rainfall between the different ensembles, there are clearly also areas of convergence. The median of the GCM ensemble indicates drying over much of the region south of 15 °S, with mostly wetting further north. The statistical downscaling ensemble indicates a similar drying region (mostly concentrated in a band across central southern Africa extending further north), whereas the dynamical downscaling ensemble has a tendency for more extreme drying over central and south-eastern southern Africa, with wetting towards the southwest. Central southern Africa (e.g. northern Botswana/Namibia, southern Zambia and Zimbabwe) is consistently projected to be drier in all three ensembles, with Tanzania and parts of northern Mozambique projected to be wetter in the future. It is notable that these regions of consistent drier/wetter modelled changes are also consistent with the results simulated for DJF by CCAM downscalings under an assumed A2 scenario as well as RCP4.5 and 8.5 (refer to Figure S.9 in the Supplementary information), suggesting the simulated changes are robust under a wide range of modelling approaches. Differences between the three ensembles below, however, serve as a reminder that simulated changes in some regions may be dependent on both the GCMs used to make an assessment, as well as the method for producing the rainfall estimates, and additionally, might reflect transient effects associated with multi-decadal natural variability as illustrated in Figure 2.3.



CMIP5 data, southern African domain (2041-2070 vs. 1976-2005)

Figure 2.2: Change in mean monthly rainfall (left) and maximum temperature (right) for DJF for two RCP scenarios: 16 GCMs, 10 statistical downscaling realisations and 8 regional climate model realisations averaged over the domain covering the land body of southern Africa (35°-20°S, 10°-40°E). Bars on the right-hand side of the graphs mark the inter-quartile range for each ensemble/RCP combination.



Future-past anomaly in somsd10 MME rcp85 DJF pr (mm/month)

Future-past anomaly in gcm10 MME rcp85 DJF pr (mm/month)

Future-past anomaly in rcm8 MME rcp85 DJF pr (mm/month)

Figure 2.3: Maps of ensemble median of change in rainfall (2041-2070 period relative to 1976-2005 period), in statistically downscaled ensemble (left), GCM ensemble (middle) and dynamically downscaled ensemble (right), for DJF, under RCP 4.5.

2.4.2. Projected changes in climate extremes

Changes in many extreme weather events have been observed since 1950 and there is mounting evidence suggesting that the frequency and intensity of some events will change in the future.

The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (Field, 2012; Seneviratne et al., 2012) provides a comprehensive assessment of climate extremes. For southern Africa, there is:

- High confidence that heat waves and warm spell durations will increase and that the number of cold extremes will decrease;
- Medium confidence that droughts will intensify in some seasons due to a reduction in rainfall and/or an increase in evapotranspiration; and
- There is some evidence to suggest that heavy rainfall events will increase, but there is low confidence in this finding.

Extreme temperatures

Projections, based on CCAM downscalings, suggest that the annual frequency of very hot days (number of days when the maximum temperature exceeds 35 °C) will increase into the future. Even under the more conservative RCP4.5 scenario, increases as high as 80 days per year by the end of the century are projected by some models. For sectors currently sensitive to extreme temperatures, exposure to such events will almost certainly pose an increased risk in the future.

Heavy rainfall events

Projections, based on CCAM downscalings, suggest that an increase in the frequency of extreme rainfall events (20 mm of rain falling within 24 hours) will occur over the eastern parts of southern Africa including Mozambique, Tanzania, parts of Zambia and Zimbabwe, north-east corner of South Africa, and west coast of Madagascar. The increase in extreme wet days over the eastern region is driven by modelled changes in the landfall of tropical cyclones originating in the Indian Ocean (Malherbe et al., 2013).

Whilst changes in thunderstorms (including hail and lightning) are difficult to project as they occur at resolutions finer than those of the GCM (IPCC, 2012; Stocker et al., 2013a), some studies suggest that an increase in the frequency of more intense thunderstorms is possible over tropical and subtropical Africa in a warmer climate (e.g. Engelbrecht et al., 2013). This is in keeping with a global trend towards more heavy rainfall events, which are expected in a warmer atmosphere that can hold more water vapour (Stocker et al., 2013a).

Tropical cyclones

Future changes in tropical cyclones (intensity, frequency, and duration) are highly uncertain (Field, 2012). Tropical cyclones are very difficult to simulate even under current climatic conditions and there are large uncertainties on projected changes (Stocker et al., 2013). The general increase in temperature and water vapour however suggests an increase in heavy precipitation associated with tropical storms and cyclones. Further research is needed in order to better understand changes in the characteristics of tropical cyclones occurring over the southwest Indian Ocean (Malherbe et al., 2013; Tadross et al., 2011).

Coastal storm surges

Coastal storm surges are expected to increase globally due to sea-level rise and an increase in the frequency and intensity of sea storms, accompanied by increases in wave heights (IPCC, 2012; Stocker et al., 2013). These storm events and associated surge events are region-specific and at this stage the region-specific projections are made with a relatively low confidence level (Stocker et al., 2013). Even if the intensity of sea storms remains unchanged, higher sea levels will mean that smaller storms are likely to have an increased impact on the coastline (Theron, 2011).

Droughts

Since droughts in southern Africa are often linked to strong El Niño conditions, an important question is whether a warmer climate will result in more frequent and more intense ENSO events. Researchers across the region are conducting ongoing research into climate dynamics and extreme events including ENSO in order to understand the mechanisms and consequences of climate dynamics in the region on short- to long-term time scales (CSIR, 2015). The SREX report states that there is low confidence in projections of changes in the behaviour of ENSO because of insufficient agreement between different model projections (Field, 2012).

Fires

The occurrence of fires is closely linked with climate and increases in temperature combined with an increase in dry spells may result in wildfires affecting larger areas, and fires of increased intensity and severity (IPCC, 2012). The frequency of high-fire danger days is projected to increase across southern Africa and is consistent with the increases in heat-wave days (Engelbrecht et al., 2015).

2.5. Key messages

Box 2.2 provides a summary of the climate projections for the region. Assuming that emissions of anthropogenic greenhouse gases continue rising at current or higher levels, central southern Africa is likely to be drier in the future during mid-summer, with parts of Tanzania and northern Mozambique likely to be wetter. As demonstrated in the first edition of the handbook, winter rainfall in the Western Cape of South Africa is expected to decline in future. Temperatures are projected to continue to increase into the 21st century. Warming is likely to be greatest towards the interior, and less in coastal areas, a finding consistent with earlier results for the region.

As stated earlier, projected changes in rainfall for the long term presented in this chapter may on occasion disagree (for example, rainfall) or be consistent (for example, temperature), depending on the downscaling or model used. The difference in rainfall projections may be attributed to the way in which surface rainfall is related to the physical processes which produce rainfall, as well as the choice of GCMs used in the downscaling ensemble. Even so, here we find greater consistency between projections using different modelling approaches than was found in earlier work (Tadross et al., 2011), suggesting that convergence may be enhanced through the use of more GCMs and through refinement/development of modelling approaches and downscaling tools.

Box 2.2: Summary of the climate projections for the region

<table>
<tr><th></th><th>GCM</th><th>Statistical downscalings</th><th>Dynamical downscalings</th></tr>
<tr><td rowspan="2">Temperature</td><td>⬆</td><td>⬆</td><td>⬆</td></tr>
<tr><td colspan="3">Increase in mean, maximum and minimum temperatures</td></tr>
<tr><td rowspan="2">Rainfall</td><td colspan="3">⇧
Increase in rainfall over Tanzania and parts of northern Mozambique</td></tr>
<tr><td colspan="3">⇧
Decrease over central southern Africa (e.g. northern Botswana, Namibia, southern Zambia and Zimbabwe) and southwestern Cape of South Africa.</td></tr>
<tr><td>Extreme temperatures</td><td>⬆
Increase in very hot days and heat waves</td><td>Not available</td><td>⬆
Increase in very hot days – above 35 °C</td></tr>
<tr><td>Heavy rainfall</td><td>Low confidence that heavy rainfall events will increase</td><td>Not available</td><td>⇧
Increase in the frequency of extreme rainfall events (20 mm of rain falling within 24 hours) over eastern parts of southern Africa</td></tr>
<tr><td>Droughts</td><td>⇧
Medium confidence that droughts will intensify</td><td>Not available</td><td>Not available</td></tr>
<tr><td colspan="4">The black arrows (⬆) indicate high confidence in projected change, with all model ensembles indicating the same directional change (e.g. increase in temperature). The grey arrows (⇧) indicate some agreement between models, but there is less confidence in those projections.</td></tr>
</table>

CHAPTER 3: SOCIO-ECONOMIC IMPACTS OF EXTREME WEATHER EVENTS IN SOUTHERN AFRICA

AUTHORS: CLAIRE DAVIS-REDDY, KATHARINE VINCENT AND JULIA MAMBO

Southern Africa is susceptible to extreme weather events – particularly floods, droughts, fires and large storms, which have cost an estimated USD 10 billion in damages between 1980 and 2015 (based on data from EM-DAT). Integrating climate change adaptation and disaster risk reduction through a risk-management approach is important to help reduce future losses from climate extremes.

3.1. Introduction

Southern Africa is susceptible to extreme weather events with the most common being floods, large storms, droughts and wildfires (Figure 3.1 and Box 3.1). Climate events account for the largest percentage (67%) of natural disaster deaths. In the past four decades (1980-2015), the southern African development community experienced 491 recorded climate-disasters[9] (meteorological, hydrological, and climatological) that resulted in 110 978 deaths, left 2.47 million people homeless and affected an estimated 140 million people[10] (EM-DAT CRED, 2016). In South Africa, extreme weather-related events have cost the insurance industry over R1 billion in claims in the 2013/2014 financial year (Uys, 2014).

The region's exposure to weather-related events, particularly floods, droughts, wildfires and storm surges (Figure 3.2), is likely to increase into the 21st century.

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[9] Climatological refers to droughts and wildfires, hydrological to floods and landslides, and meteorological to extreme temperatures and storms.

[10] People requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance (EM-DAT CRED 2016).

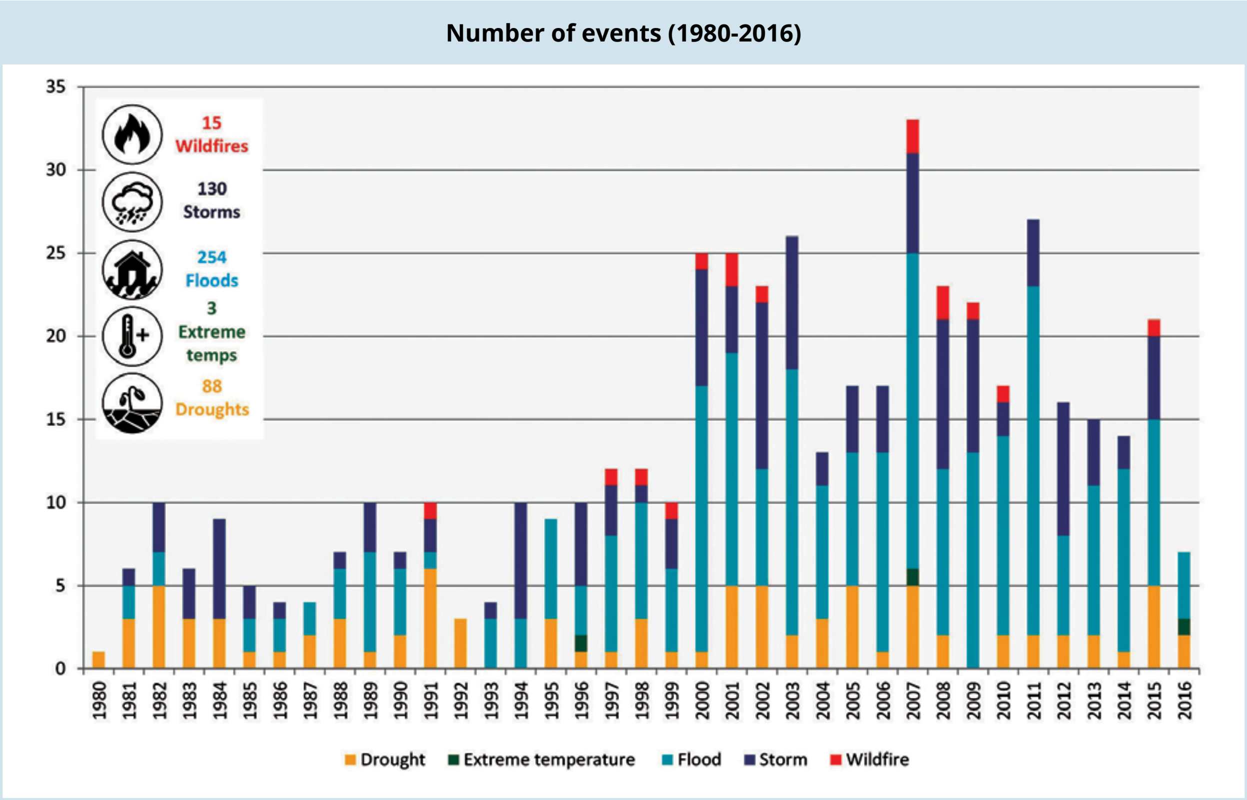
As indicated in the previous chapter, climate change is projected to increase the frequency and magnitude of extreme weather events, which, without reductions in vulnerability, will increase the risk of disasters (Vincent et al., 2008).

The expected increase in weather-related disasters poses significant challenges for disaster risk management in southern Africa and is expected to negatively impact infrastructure and the transport, agriculture, health, tourism and insurance sectors, among others. The increased exposure combined with an increasing population, poor land-use practices, and an increasing number of people living in exposed areas are likely to augment the current levels of disaster risk.

This chapter presents:

- A recent analysis of the past disasters in SADC based on data from the Centre for Research on the Epidemiology of Disasters (CRED)/Emergency Events Database (EM-DAT); and
- The potential long-term impacts of changes in extreme weather over southern Africa.

The chapter focuses on the four main categories of weather-related disasters: floods, droughts, fires and storm surges. In view of projected increases in frequency and severity, these four types of events are considered key areas of interest and are priority areas for enabling adaptation and building resilience to future events.



Number of events (1980-2016)

Figure 3.1: Number of recorded climate-related events over southern Africa since 1980 (Source: EM-DAT CRED, 2016). 'Wildfires' refers to any uncontrolled and non-prescribed burning of plants in a natural setting; 'storms' to tropical, extra-tropical and convective storm events; 'floods' to riverine, flash and coastal flood events; 'extreme temperature' to both cold waves and heat waves; and 'droughts' to extended periods of unusually low precipitation that produce a shortage of water.

Box 3.1: Description of the four major categories of weather-related events included in this study

Type	Description
Flood	***Rapid-onset floods:*** These include flash floods, tidal surges, floods provoked by cyclones or accompanied by strong winds, high runoff from heavy rainfall, dam bursts and overtopping, canals and rivers bursting their banks. Typically, water rising to dangerous levels within 48 hours (Smith, 2009). ***Slow-onset floods:*** Prolonged rainfall causing low-lying areas to gradually become flooded over a period of days or weeks (Smith, 2009).
Drought	***Meteorological drought:*** Less than 70% of normal rainfall is received (Bruwer, 1993). ***Agricultural drought:*** A reduction in water availability below the optimal level required by a crop during each different growth stage, resulting in impaired growth and reduced yields (Wilhite and Glantz, 1985).
Wildfires	The occurrence of fires is closely linked with high temperatures and dry spells, for example during berg wind conditions. Originally most fires were caused by lightning, but today more than 90% of fires are lit by people, either deliberately or accidentally (Forsyth et al., 2010).
Storms	The classification of storms includes severe thunderstorms, cyclones, tornados, convective storms, frontal systems and cut-off low events which often cause flash floods. For the purposes of this report, storm surges, hail storms and severe cold fronts (including some instances of snow) are included in the classification of storms. Storm surges are an irregular rise in sea level produced by a storm and characterised by heavy rains and high winds (Theron, 2011).

Box 3.2: Sources of information on disasters and disaster losses

In keeping with commitments to monitor disaster occurrence and losses (as mandated in the Sendai Framework for Disaster Risk Reduction), there are a number of accessible databases:

Global Assessment Report Risk Data Platform (http://risk.preventionweb.net)

This interactive Risk Viewer provides the global risk data from the Global Assessment Reports, presented in an easily accessible manner. Risk and exposure indicators can be overlaid with hazard data from earthquakes, cyclones, surges, floods, tsunamis and volcanoes. Other country-specific data can also be downloaded, including future projections of return periods, etc.

DesInventar (http://www.desinventar.net)

DesInventar is a Disaster Management Information System for generating National Disaster Inventories and constructing databases that capture information on damage, loss and general effects of disasters. It is also used to store the data sets that are reported on in the Global Assessment Reports on Disaster Risk Reduction. With increased understanding of disaster trends and their impacts, better prevention, mitigation and preparedness measures can be planned to reduce the impact of disasters on the communities. It covers Mozambique and Madagascar in southern Africa.

EM-DAT: The International Disaster Database (http://www.emdat.be)

EM-DAT contains essential core data on the occurrence and effects of over 18,000 mass disasters in the world from 1900 to present. The database is compiled from various sources, including UN agencies, non-governmental organisations, insurance companies, research institutes and press agencies. Users can download data and create their own tables and figures by selecting from among the data sets.

PREVIEW Global Risk Data Platform (http://preview.grid.unep.ch)

The PREVIEW Global Risk Data Platform contains spatial data information on global risk from natural hazards. Users can visualise, download or extract data on past hazardous events, human and economical hazard exposure and risk from natural hazards. It covers tropical cyclones and related storm surges, drought, earthquakes, biomass fires, floods, landslides, tsunamis and volcanic eruptions.

Box 3.3: Early warning systems in southern Africa

Early warning of extreme events is crucial for developing and implementing various preparedness and response strategies and ultimately reducing the risk of death and damage. Early warning systems (EWS) in the region are a result of cooperation between international, regional and national organisations, and comprised the development of new systems and the improvement of current systems for preparedness and response (OCHA, 2015). Themes covered by the early warning systems in the regions include food production and security, multiple hazards, weather forecasting and humanitarian (OCHA, 2015; see figure below).

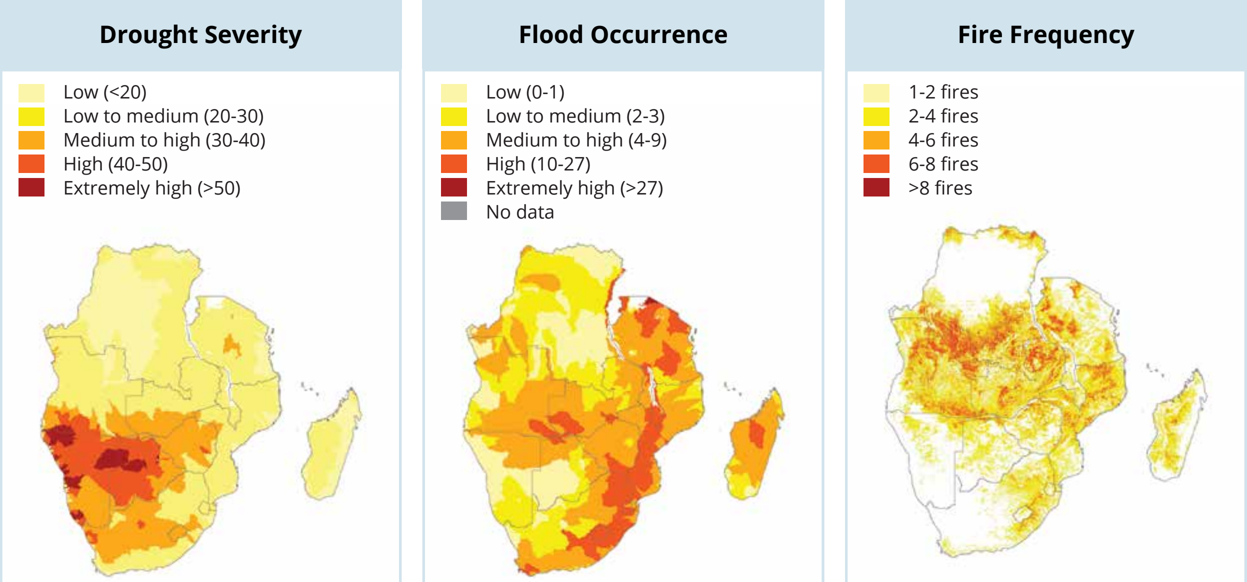
For EWS to be effective, they should address four key elements as defined by the United Nations International Strategy for Disaster Risk Reduction (UNISDR): (i) risk identification, (ii) monitoring and warning system, (iii) warning dissemination, and (iv) response actions (Seng & Stanley, 2012). EWS have evolved considerably over the last two decades and there are a number of systems in operation, covering the majority of natural hazards in southern Africa.

One example of a recent EWS is the Advanced Fire Information System (AFIS), which is a real-time satellite-based fire monitoring system for southern Africa. AFIS was developed in partnership with Eskom, the Council for Scientific and Industrial Research (CSIR) – Satellite Application Centre (SAC) to monitor fires across Africa in real time (Davies et al., 2008; Frost and Annegarn, 2007). Active fires are detected using remotely sensed satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS). The information from AFIS has been used by the South African Broadcasting Corporation (SABC), for example, to show fire maps as part of the weather bulletin, as well as by Fire Protection Associations (FPAs) and the officers of the Working on Fire programme in South Africa. A mobile application for both Google Android and Apple iOS platforms was launched in September 2013. Active fires are also immediately published on a web page.

Box 3.3: Early warning systems in southern Africa (continued)

Name	Host	Main Purpose	Link
Regional Specialized Meteorological Centre (RSMC) La Réunion	Météo-France	**Multi-Hazard Early Warning System:** Provides real-time weather advisories and is responsible for tracking tropical cyclones in the south-west Indian Ocean.	http://www.meteofrance.re/accueil
Climate Services Centre (CSC)	Southern African Development Community (SADC)	**Weather Forecasting Early Warning:** Provides operational, regional services for monitoring and predicting extremes in climate condition. The Centre develops and disseminates meteorological, environmental and hydrometeorological products, and hosts the Southern Africa Regional Climate Outlook Forums (SARCOF), which are designed to develop region-wide consensus on climate outlooks in the near future. The Real Time Extreme Weather and Climate Monitoring System (MONIS) is the key tool used to gather and visualize all meteorological data for analysis and early warning.	http://www.sadc.int/sadcsecretariat/services-centres/climate-services-centre/
Regional Integrated Multi-Hazard Early Warning System (RIMES) for Africa and Asia	RIMES Member States	**Multi-Hazard Early Warning System:** RIMES provides regional early warning services and builds capacity of its Member States in the end-to-end early warning of tsunami and hydro-meteorological hazards.	http://www.rimes.int/
Famine Early Warning Systems Network (FEWS-NET)	US Agency for International Development (USAID)	**Food Security Warning System:** Provides objective, evidence-based analysis related to food security and famine to help Government decision-makers and relief agencies plan for and respond to humanitarian crises.	http://www.fews.net/
Locust Watch	Food and Agriculture Organization (FAO)	**Food Security Warning System:** Provides timely information on the movement of locust swarms and the potential impacts these swarms may have on food security.	http://www.fao.org/ag/locusts/ en/info/info/index.html

Source: OCHA Regional Office for Southern Africa (ROSA)
http://reliefweb.int/sites/reliefweb.int/files/resources/Disaster_Response_and_Preparedness_in_Southern_Africa-A_Guide_to_International_Tools_and_Services_Available_to_Governments.pdf



Drought severity estimates the average of the lenght times the dryness of droughts from 1901 to 2008). Drought is defined as a coninuous period where soil moisture remains below the 20th percentile, lenght is measured in months, and dryness is the number of percentage points below the 20th percentile.

Sources: Sheffiels and Wood 2007

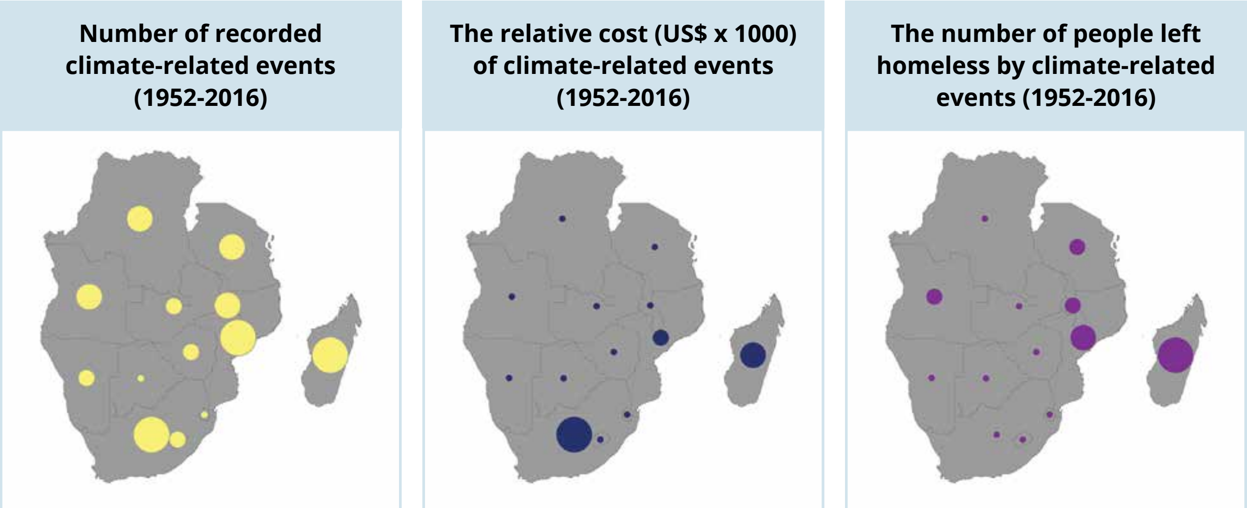
Flood occurence is s count of the number of floods recorded from 1985-2011.

Sources: Brankenridge, Dartmouth Flood Observatory 2011

Fire frequency refers to the number of times an individual MODIS pixel was classified as burned from April 2000 to March 2012.

Sources: Archibald S.; Sholes, R.; Roy, D.; Roberts, G. and Boschetti, L. Southern African fire regimes as revealed by remote sensing International Journal of Wildland Fire, 2010, 19, 861-878.

Figure 3.2: Distribution of droughts, floods and fires across southern Africa.



Fire frequency refers to the number of times an individual MODIS pixel was classified as burned from April 2000 to March 2012.

Sources: Archibald S.; Sholes, R.; Roy, D.; Roberts, G. and Boschetti, L. Southern African fire regimes as revealed by remote sensing International Journal of Wildland Fire, 2010, 19, 861-878.

Figure 3.3: Summary of the climate-related events per country in southern Africa since 1980 (Source: EM-DAT CRED, 2016).

3.2. Impact of climate-related disasters in SADC

The impacts of extreme weather events are wide-ranging and affect multiple sectors. The impacts range from primary or direct effects, such as damage to infrastructure and death, to secondary or indirect effects, such as health issues and the loss of livelihoods (Easterling et al., 2000). There are also differences between countries in terms of impacts (Figure 3.3). Past impacts of climate-related events in SADC countries are a good indication of the types of hazards and their impacts that can be expected in the future.

Reliable statistics on the scope and prevalence of hazard events are difficult to compile owing to the lack of reporting and the lack of consistency in reporting structure, especially on costs of disasters. Conservative indication can, however, be produced based on international databases such as the Emergency Events Database (EM-DAT) of the Office of Foreign Disaster Assistance/Centre for Research on the Epidemiology of Disasters (OFDA/CRED) International Disaster Database (www.emdat.be). These record disasters where ten or more people are reported killed, 100 or more people need to be evacuated, provided with humanitarian assistance or otherwise affected, or the State declares an emergency or calls for international assistance.

Figure 3.3 shows the number of recorded climate disasters per country, highlighting the impacts on Mozambique, Madagascar, Malawi and Tanzania in particular (refer to Table S.1 for data per country). Although South Africa has the highest number of recorded climatological events, it accounts for a small percentage of deaths. This can be attributed to lower levels of social vulnerability and more adaptation and disaster risk management strategies compared with its SADC counterparts.

Figure 3.4 provides a summary of the cost for each of the four major categories of extreme weather events in southern Africa – droughts, floods, fires and storms – over time. The number of people affected and the number of people displaced by each of the major categories are shown in Figure 3.5 and Figure 3.6 respectively. While floods (riverine, flash and coastal) have tended to be the most frequent type of climate disaster (Figure 3.1), droughts have resulted in the highest economic cost of damages and have affected a larger proportion of the region's population. Between 1980 and 2015 an estimated 107 million people (37% of the SADC population[11]) have been affected by drought, whereas floods have affected an estimated 21 million people (7.6% of the SADC population). This can be attributed to the nature of droughts, which are slow-onset disasters and affect more than just the people in the immediate locality. Despite these numbers, the SREX report states that drought events in southern Africa are under-reported compared with other regions (Field, 2012).

The four categories of disasters have resulted in approximately US$10 billion in economic damages, with costs associated with droughts and floods amounting to approximately US$3.4 billion and US$3.3 billion respectively (based on data from EM-DAT). These damage and recovery/rehabilitation costs reflect the reactive costs of disasters and highlight the need for more investment in proactive measures and disaster risk reduction to mitigate the impacts of disasters.

Storms (including tropical cyclones) have been responsible for displacing the vast majority of people; an estimated 1.7 million people have been left homeless between 1980 and 2016. Flooding events have left an estimated 780 000 people homeless since 1980. Table 3.1 summarises the relative impacts of different climate-related events between 1980 and 2015.

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[11] Population of SADC countries is estimated at 277 million (Source: SADC Statistics Yearbook 2011 http://www.sadc.int/information-services/sadc-statistics/sadc-statiyearbook/).

Table 3.1: Summary of impacts of climate-related events on southern Africa between 1980 and 2015 (Source: EM-DAT CRED, 2016)

Most frequent	**Most costly**	**Affect the most people**	**Displace the most people**	**Cause the most deaths**	**Injure the most people**
Floods	Droughts	Droughts	Storms	Droughts	Storms

Floods have tended to be the most frequent type of climate-related disaster, while droughts have resulted in the highest economic cost of damages and have affected a larger proportion of the region's population. Storms have been responsible for displacing the vast majority of people.

This conceals the diversity of the hazard landscape in southern Africa, which experiences a far broader range of localised hazards (Pharoah et al., 2013). Examples include:

- The tornado in October 2011 in Duduza, Gauteng, South Africa resulted in the death of one child, the injury of 160 people, and left hundreds homeless (Extreme Planet, 2012).
- The hail event on 28 November 2013 in Gauteng resulted in a loss in the insurance industry estimated at R 1.4 billion due to claims in the motor and property sectors (PwC, 2014).
- Slow-onset flood events which occur regularly in informal settlements. These settlements are often located in low-lying, flood-prone areas. Houses are regularly flooded or destroyed leaving families displaced, and resultant stagnant water has led to outbreaks of cholera, for example in Keko Machungwa informal settlement in Dar es Salaam (Sakijege et al., 2012).

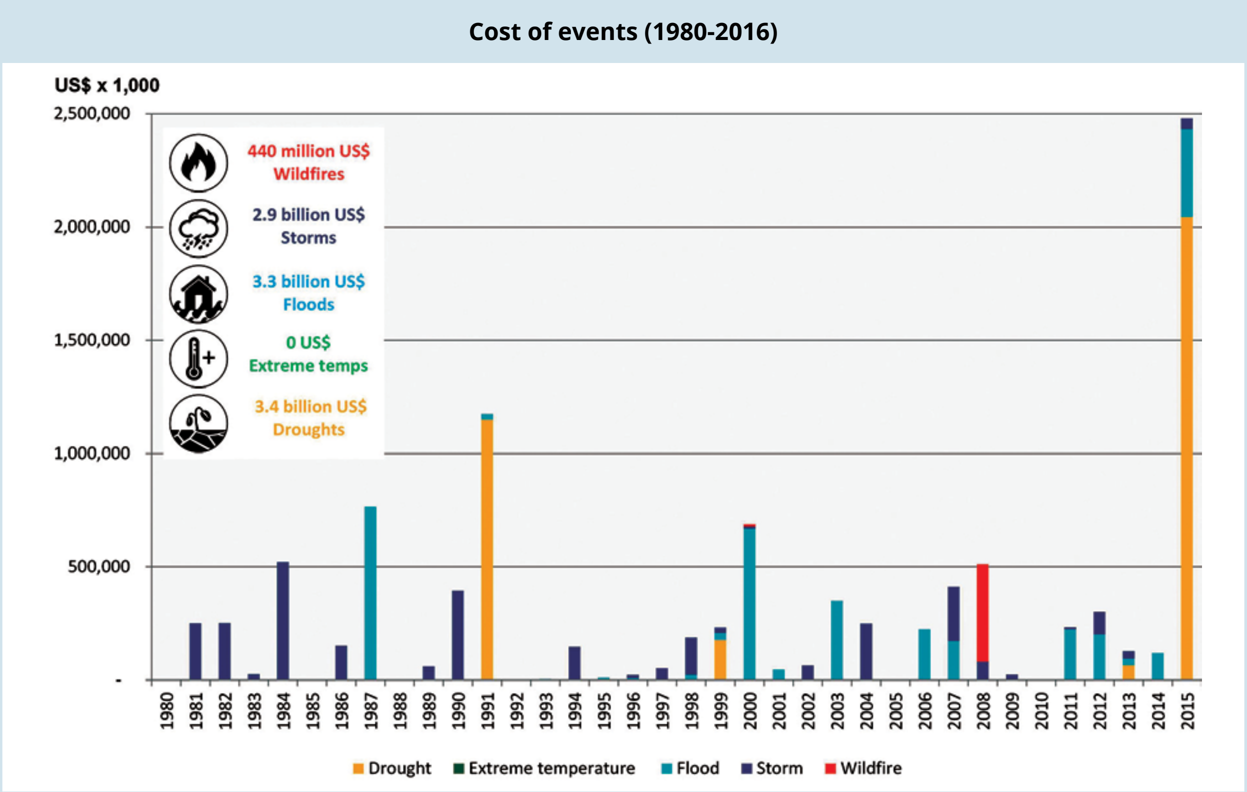


Figure 3.4: The relative cost (US$ x 1 000) of the major categories of climate-related events – wildfires, storms, floods, extreme temperature, and droughts – in southern Africa since 1980 (Source: EM-DAT CRED, 2016).

Number of people affected (1980-2016)

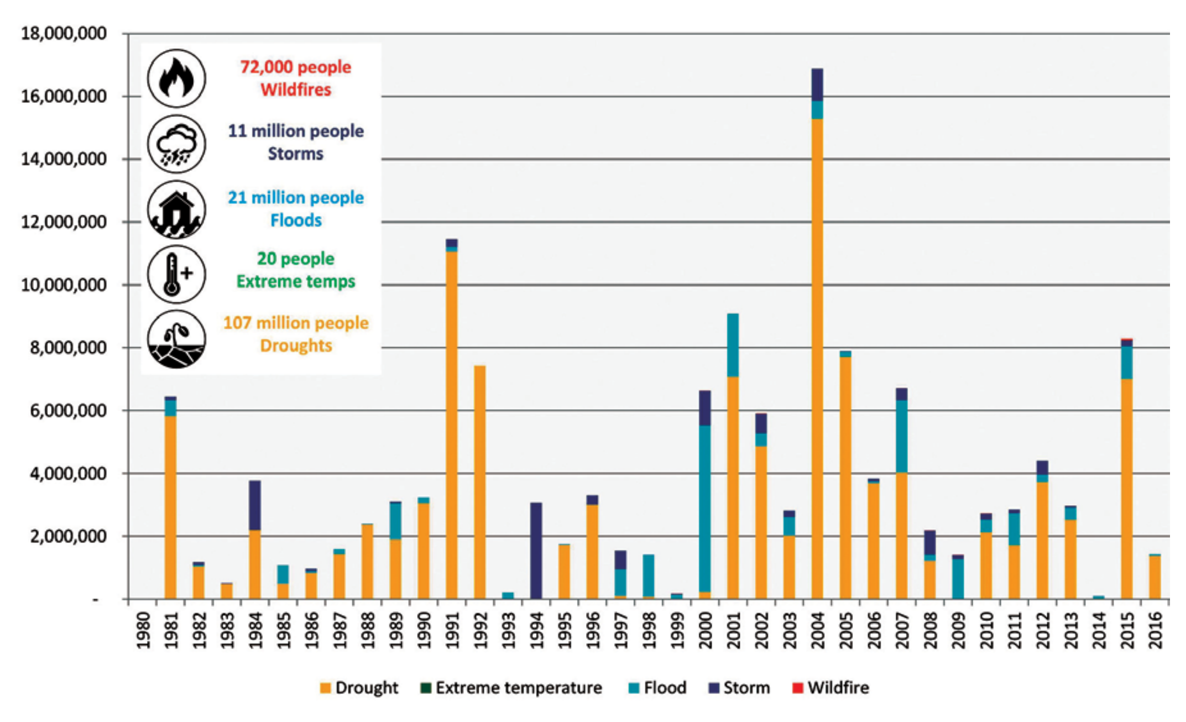


Figure 3.5: The number of people affected by each of the major categories of climate-related events – wildfires, storms, floods, extreme temperature, and droughts – in southern Africa since 1980 (Source: EM-DAT CRED, 2016).

Number of people displaced (1980-2016)

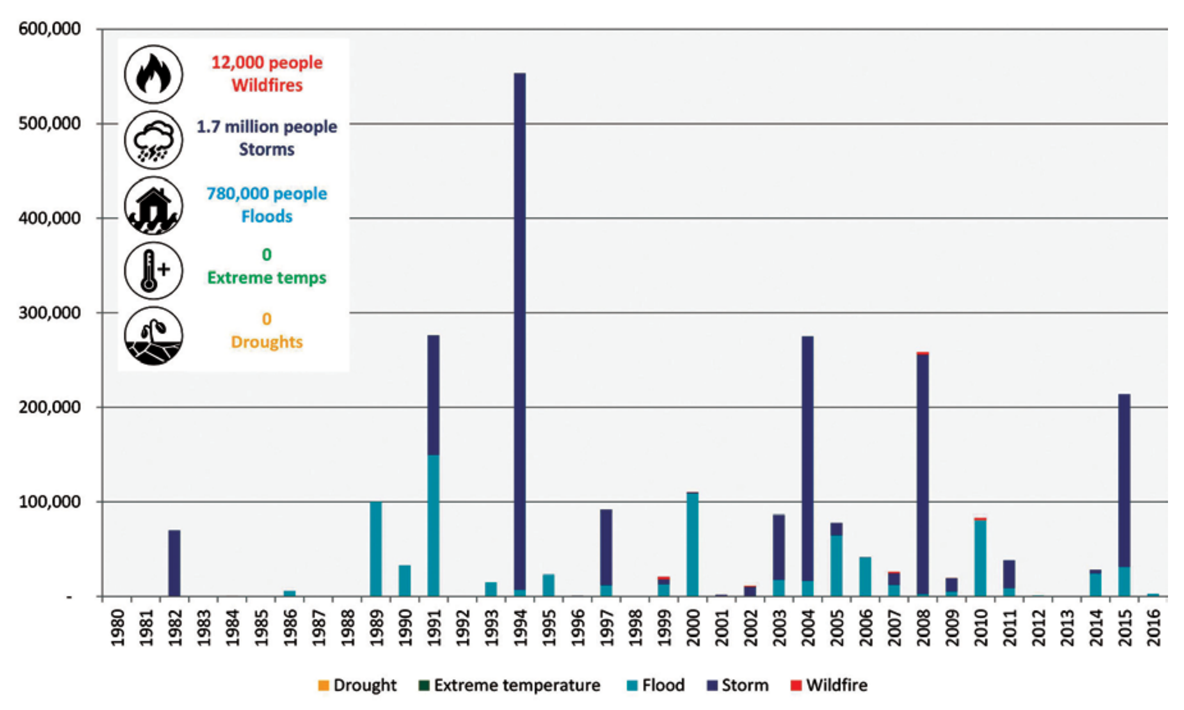


Figure 3.6: The number of people left homeless by each of the major categories of climate-related events – wildfires, storms, floods, extreme temperature, and droughts – in southern Africa since 1980 (Source: EM-DAT CRED, 2016).

Floods

Floods in southern Africa result from:

- tropical cyclones that bring widespread flooding to Mozambique and north-eastern South Africa (Figure 3.2);
- cut-off lows that cause flooding along the Cape south coast and Eastern Cape;
- thunderstorms that result in flash-flooding across the Highveld of South Africa; and
- heavy rains that cause flooding in Angola and Namibia.

Recurrent floods have a detrimental impact most noticeably in communities with less developed infrastructure and health services where floods often result in loss of life, damage to property and infrastructure as well as the spread of diseases such as malaria, diarrhoea, and cholera. Flood events are often exacerbated by dam and infrastructure failures related to inadequate design and maintenance, poor land-use planning, land degradation, deforestation and a lack of early-warning systems (Mulugeta et al., 2007). Some of the worst flood events in the region are described in Box 3.4.

Box 3.4: Examples of the worst recorded floods in southern Africa

1987

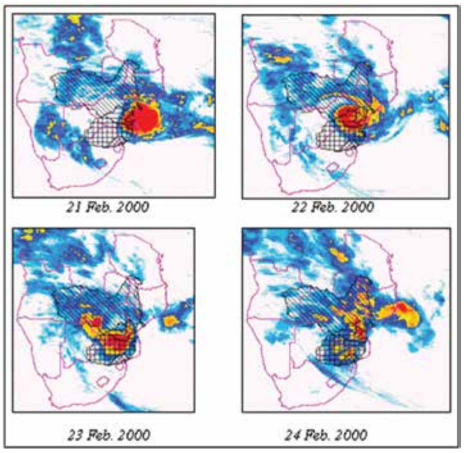
In 1987 the flooding in KwaZulu-Natal, South Africa and Lesotho caused severe damage to thousands of kilometres of roads, with 14 bridges being washed away and all entrance routes to Durban being closed. Approximately 68 000 people were left homeless and 388 people were killed (Grobler, 2003).

1991

Flash floods in southern Malawi resulted in damage to houses, agricultural crops, and infrastructure. The floods and consequent landslides resulted in 500 deaths and thousands of people displaced (ReliefWeb, 1991).

2000

Cyclone Eline resulted in severe flooding in South Africa, Mozambique, Zimbabwe and Botswana with the worst affected being Mozambique. High winds, torrential rains and high river flows caused economic losses and damage to infrastructure, livelihoods and agricultural crops. In Mozambique 700 people were reported dead and the GDP growth rate decreased from 10% to 2% (Mulugeta et al., 2007; ReliefWeb, 2000).



Picture: Satellite image showing the path of Cyclone Eline in relation to the major catchments (ReliefWeb, 2000).

2009

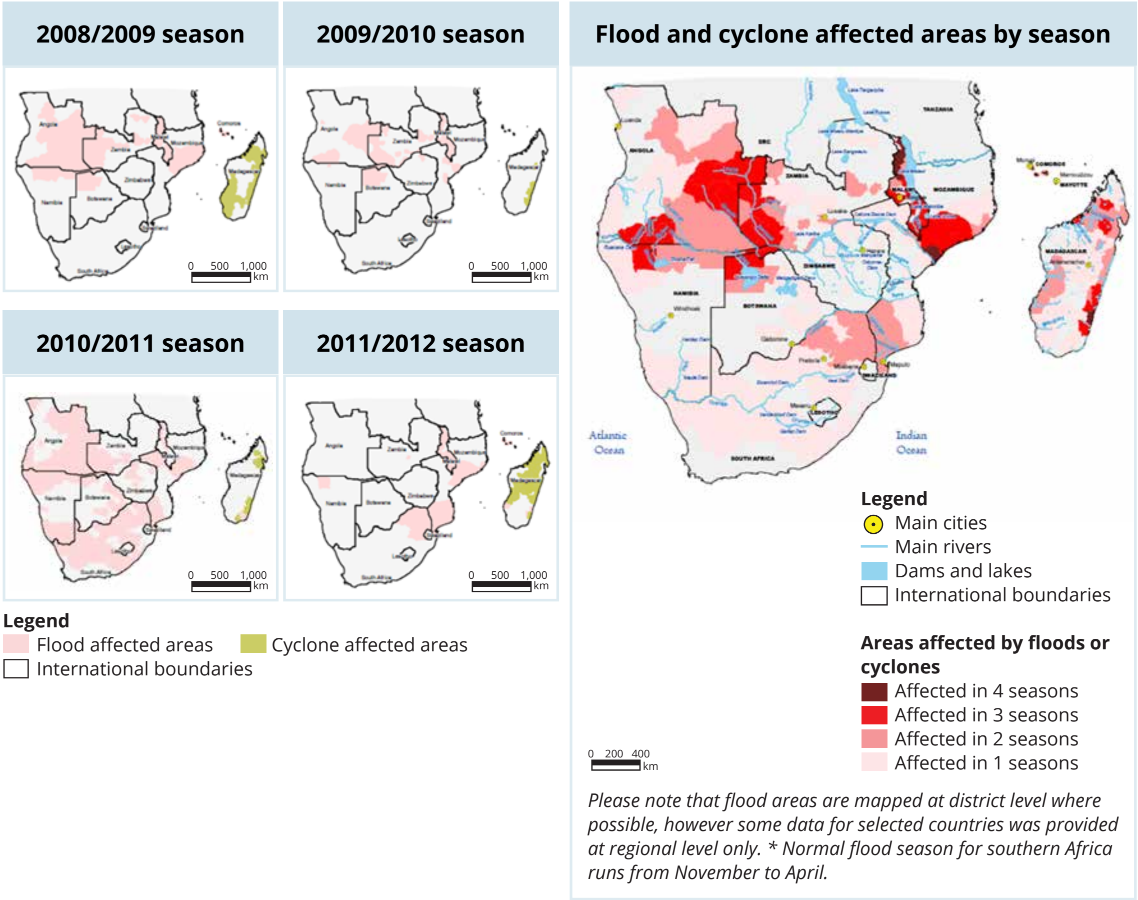
In March 2009, heavy rains caused widespread flooding in Angola and Namibia, affecting 120 000 people in Angola; leaving approximately 30 000 people isolated after roads and bridges were washed away; and leaving families homeless after 4 720 houses were destroyed. In Namibia 130 000 people were at risk. Hectares of crops were submerged and small livestock was lost. The cholera outbreak after the flood affected 143 people and killed seven people (IFRC, 2009). All countries in the region suffered major flooding events during the same period, resulting in huge losses (Mail and Guardian, 2009).

Box 3.4: Examples of the worst recorded floods in southern Africa (continued)

2008-2012

The map below highlights countries in southern Africa affected by cyclones (green) and floods (pink colour) between 2008 and 2012. The largest map in the right panel highlights countries that were affected by flooding or cyclones in each season[12], ranging from one season to four seasons.

Southern Africa: Flood and cyclone affected areas in the 2008/2009, 2009/2010, 2010/2011 and 2011/2012 rainfall seasons.



2008/2009 season

2009/2010 season

2010/2011 season

2011/2012 season

Legend

🟥 Flood affected areas 🟩 Cyclone affected areas

☐ International boundaries

Flood and cyclone affected areas by season

Legend

☉ Main cities

— Main rivers

▨ Dams and lakes

☐ International boundaries

Areas affected by floods or cyclones

🟥 Affected in 4 seasons

🟥 Affected in 3 seasons

🟥 Affected in 2 seasons

🟥 Affected in 1 seasons

*Please note that flood areas are mapped at district level where possible, however some data for selected countries was provided at regional level only. * Normal flood season for southern Africa runs from November to April.*

Source: http://reliefweb.int/map/angola/southern-africa-flood-and-cyclone-affected-areas-20082009-20092010-20102011-and-20112012

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[12] A normal season is from November to April.

Droughts

Large areas of southern Africa are susceptible to dry conditions and experience frequent droughts (Figure 3.2) (Masih et al., 2014). Severe droughts (such as those of 1982-1983, 1991-1992, 1997-1998 and 2014-2015) have been linked to the El Niño-Southern Oscillation (ENSO) phenomenon (Rojas et al., 2014; Rouault and Richard, 2005; WFP, 2016). The standardized precipitation index (SPI) – which is used to predict short-term drought – is shown in Figure 3.7 for the years 1992, 2014-2015 and 2015-2016 (McKee et al., 1993). Droughts are often exacerbated by land degradation, poor water conservation practices as well as political instability and poor economic growth. Droughts are often accompanied by high temperatures and an increase in high fire danger days. Southern African economies are dependent on rain-fed agriculture, and hence more prone to agricultural droughts. Droughts often result in decreased agricultural productivity owing to lower crop yields and loss of livestock and ultimately an increase in national and household food insecurity and rise in food prices. Droughts have additional consequences for hydropower energy generation (Lesolle, 2012). In 1992, for example, a drought in Zambia resulted in a 35% reduction in hydropower generation compared with the previous year (Beilfuss, 2012).

Box 3.5: Examples of the worst recorded droughts in southern Africa

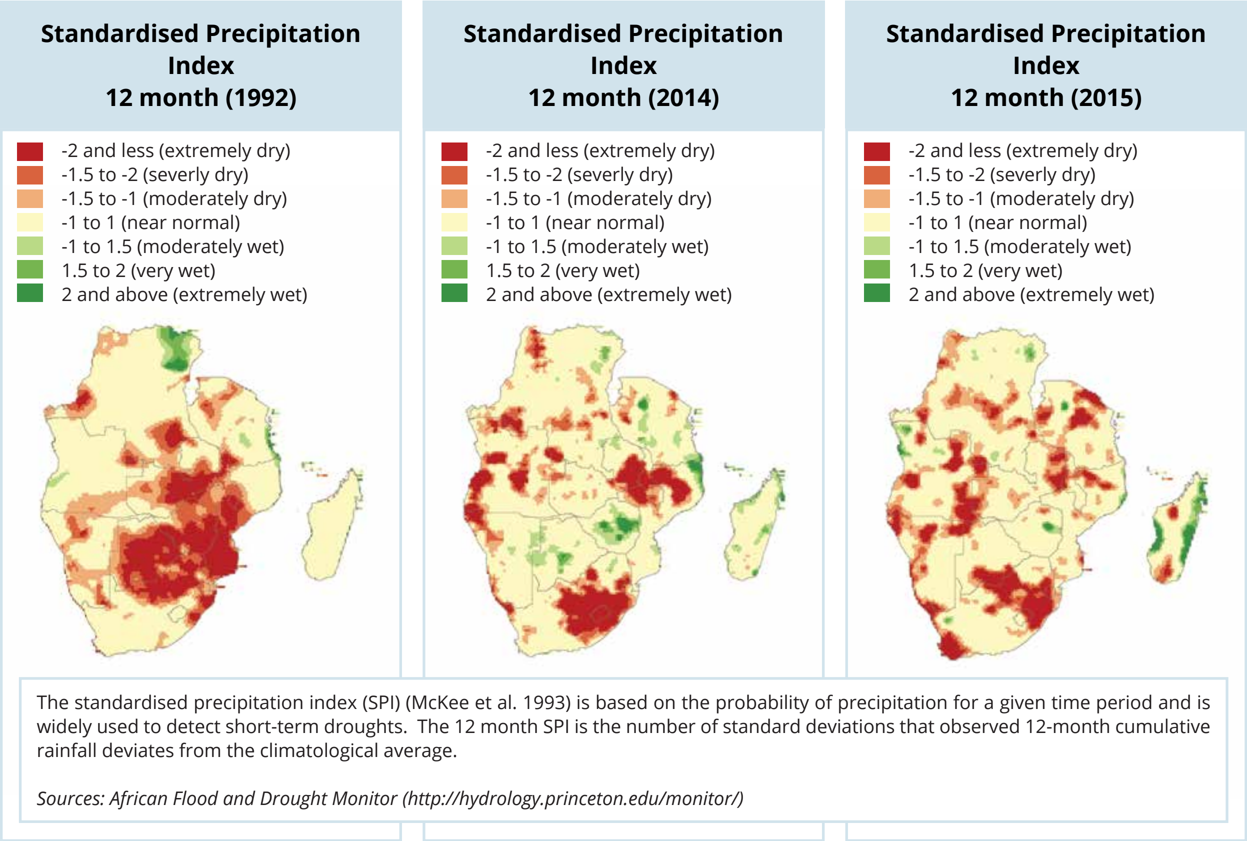
1992

The 1992 drought resulted in approximately 70% of crops failing and 11.4 million tonnes of cereal having to be imported (FAO, n.d). Large areas of southern Africa received 20-70% of normal rainfall totals, with the dry conditions amplified by excessively high temperatures. The countries most affected were Zambia, Malawi, Mozambique and South Africa.

- Zimbabwe experienced a decline in agricultural production of 45%, manufacturing output of 9.3%, and GDP of 11% (FAO, n.d).
- In Mozambique, the impacts of the drought were exacerbated by the civil war and more than 1.3 million people were affected by food insecurity. The World Food Programme (WFP) provided an estimated US$200 million in food aid relief (FAO, n.d).
- In South Africa, the loss of GDP during the 1992 drought was approximately 1.8 percent, representing US$ 500 million (Pretorius and Smal, 1992). Crop failure resulted in farm labour lay-offs, increased farm debt and farm closures, and caused knock-on effects for households that depended on the agricultural sector. It has been estimated that 50 000 jobs were lost in the agricultural sector, with a further 20 000 in related sectors, affecting about 250 000 people (Mniki, 2009).

2015

South Africa has recently experienced the worst drought since 1930, with total rainfall in 2015 of 403 mm, the lowest annual amount on record (de Jager, 2016). Temperatures over this period were of the hottest recorded over the last 10 years. The 2015 drought was the result of a strong El Niño event (WFP, 2016). The agricultural sectors that have been most severely affected are maize, wheat and sugarcane along with beef and sheep production. The majority of maize (83%), wheat (53%) and sugarcane (73%) are produced under dryland conditions, making them especially vulnerable to periods of drought (AgriSA, 2016). The Free State, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape and North-West provinces were declared drought disaster areas. Other regions in SADC (Lesotho, Swaziland, Zambia and Zimbabwe) also experienced reductions in crop yields and an associated increase in maize prices (WFP, 2016). The overall cereal deficit for the region stands at 7.90 million tonnes for the 2015-16 marketing year as compared to 3.9 million in 2014/15 (WFP, 2016).



The standardised precipitation index (SPI) (McKee et al. 1993) is based on the probability of precipitation for a given time period and is widely used to detect short-term droughts. The 12 month SPI is the number of standard deviations that observed 12-month cumulative rainfall deviates from the climatological average.

Sources: African Flood and Drought Monitor (http://hydrology.princeton.edu/monitor/)

Figure 3.7: The standardized precipitation index (SPI) for 1992, 2014-2015 and 2015-2016. SPI is based on the probability of precipitation for a given time period and is widely used to detect short-term droughts. The 12-month SPI, shown here, is the number of standard deviations that observed 12-month cumulative rainfall deviates from the climatological average (Source: African Flood and Drought Monitor accessed at http://hydrology.princeton.edu/monitor/).

Storm surges

The south-eastern coastline of southern Africa, comprising South Africa, Mozambique, Tanzania, Madagascar as well as small island states such as Mauritius, is regularly affected by cyclones and other significant weather events that result in an increase in sea level and large wave events along the coast (storm surges) (Mather and Stretch, 2012). Storm surges cause severe damage to settlements and infrastructure such as sea walls, railway lines, harbours and coastal properties. Madagascar, Mozambique and the east coast of South Africa (to a lesser extent) have been the worst affected by storm surges (Field, 2012). On the south-western coastline, Luanda in Angola is on the list of the top 20 most vulnerable cities in the world to coastal storms and sea-level rise.

Box 3.6: Examples of the worst recorded storms in southern Africa

1994

Madagascar was affected by five cyclones during the 1993-1994 season, with the worst being Cyclone Geralda, category 5, which followed Cyclone Daisy. More than 90% of the port city of Toamasina was destroyed (Longshore, 2010) and damage was estimated at US$10 million.

2004

Cyclone Gafilo, category 5, was the most intense tropical cyclone worldwide in 2004. It is estimated that approximately 773 000 people were affected (ReliefWeb, 2004).

2008

In 2008 a storm surge along the western and southern coasts of South Africa resulted in damage to coastal property and infrastructure that was estimated at R1 billion (Smith, 2013). The storm surge was caused by the combination of a mid-latitude cyclone (cold front) and secondary low pressure (Theron, 2011).

Wildfires

Fires are a frequent occurrence in southern Africa (Figure 3.2) due to a strong dry season, lasting for up to five months, combined with rapid rates of fuel accumulation. The dominant fire season is July, August and September (Archibald et al., 2010). While climatic controls (such as wind and temperature) are important in determining the size and intensity of fire, human activities (such as land clearing, inadequate land management and increased spread of invasive alien plants) have a substantial effect on fires and are a strong controlling factor on fire regimes in southern Africa (Archibald et al., 2010). The two worst recorded cases of wildfires are described in Box 3.7.

Box 3.7: Examples of the worst recorded fires in southern Africa

2008

The KwaZulu-Natal and Mpumalanga provinces in South Africa experienced fires that resulted in significant loss of revenue, estimated at US$440 million (Figure 3.4). As much as 61 700 hectares of plantation forest were burnt, equating to 2.9% and 9.5% of the total area of plantations in these two provinces, respectively. Forestry SA estimated the value of standing timber burnt to be R1.33 billion (2007 prices) and that 40% of this was unsalvageable (Forsyth et al., 2010).

2015

An estimated 57 000 people were affected by fires in Cape Town, South Africa in March 2015 (EM-DAT CRED, 2016). High temperatures of 42 °C combined with windy, dry conditions fuelled a fire that burnt approximately 4 000 hectares of vegetation (SAinfo, 2015). Fires are critical for maintaining the Fynbos ecosystem and occur every 15 years (Mucina and Rutherford, 2006). The close proximity of some developments to Table Mountain National Park resulted in a number of homes being evacuated during the fire and five being damaged by the fire (Swingler, 2015).

(Pictures: Timm Hoffman)

2016

Widespread burning was observed over the southern region of the Democratic Republic of Congo, Zambia and Angola in June 2016. The main fire season in these regions occurs from June to July and the fires in this image are attributed to agricultural burning practices.

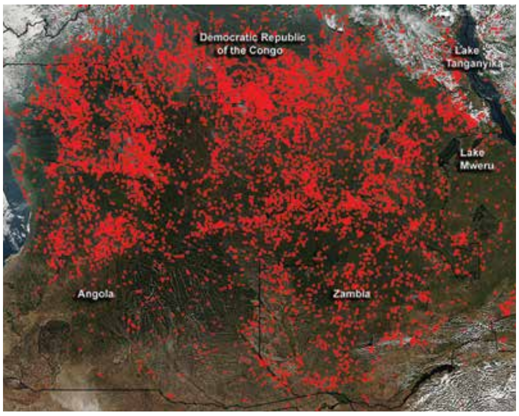


Image taken on June 3, 2016 from the Suomi NPP satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) instrument showing actively burning areas in red (Source: www.nasa.gov).

3.3. Impacts of changes in climate extremes

The socio-economic impacts of recent extreme climate events, as highlighted in Section 3.2, reveal southern Africa's significant vulnerability and exposure (see Part II of the handbook for detailed definitions) to changes in climate disasters. The expected increase in climate-related disasters due to climate change is expected to have a negative impact on food production and access to water, infrastructure, settlements, and human well-being (Stocker et al., 2013). While some sectors with closer links to climate such as tourism and agriculture are particularly at risk, the majority of sectors are exposed, either directly or indirectly, to the effects of extreme weather events. The severity of these impacts will depend on the exposure and vulnerability of communities to the climate hazard.

More frequent and intense events, combined with a growing and urbanising population and increasing value in urban and built infrastructure, imply greater exposure to such events. High exposure and vulnerability levels will transform even small-scale (slow-onset) events into disasters for some affected communities. Recurrent small or medium-scale events affecting the same communities may have cumulative effects which lead to serious erosion of the development base and livelihood options, thus increasing vulnerability (Field, 2012). The poor, in particular, will be most vulnerable because of their limited access to livelihood opportunities, infrastructure, information, technology and assets. In addition, they are often forced, through economic circumstances, to inhabit areas that are susceptible to natural disasters. This vulnerability is exacerbated by inadequate planning and insurance cover for disaster losses.

Given the increasing economic costs of extreme events, there is a great need for proactive investment in disaster risk management (DRM) activities to deal with disasters (refer to Chapter 15 for approaches to linking DRM with climate change adaptation). Currently DRM receives only a small proportion of global development assistance, and the amount allocated to proactive risk reduction, as opposed to response, is still small (Figure 3.10). Quantifying the cost effectiveness of DRM, including investments in effective climate information systems and early warning systems, remains a challenge – not only to southern Africa – owing to limited data and robust information on costs such as recovery and rehabilitation (Moench et al., 2007). Moreover, the full costs of extreme events in southern Africa are likely to be underestimated because of the lack of comprehensive studies on damage, adaptation, and residual costs (Field, 2012). Despite this, there is a large body of evidence that suggests that investment in prevention is more cost-effective than spending on relief (Hallegatte, 2012; Rogers and Tsirkunov, 2011).

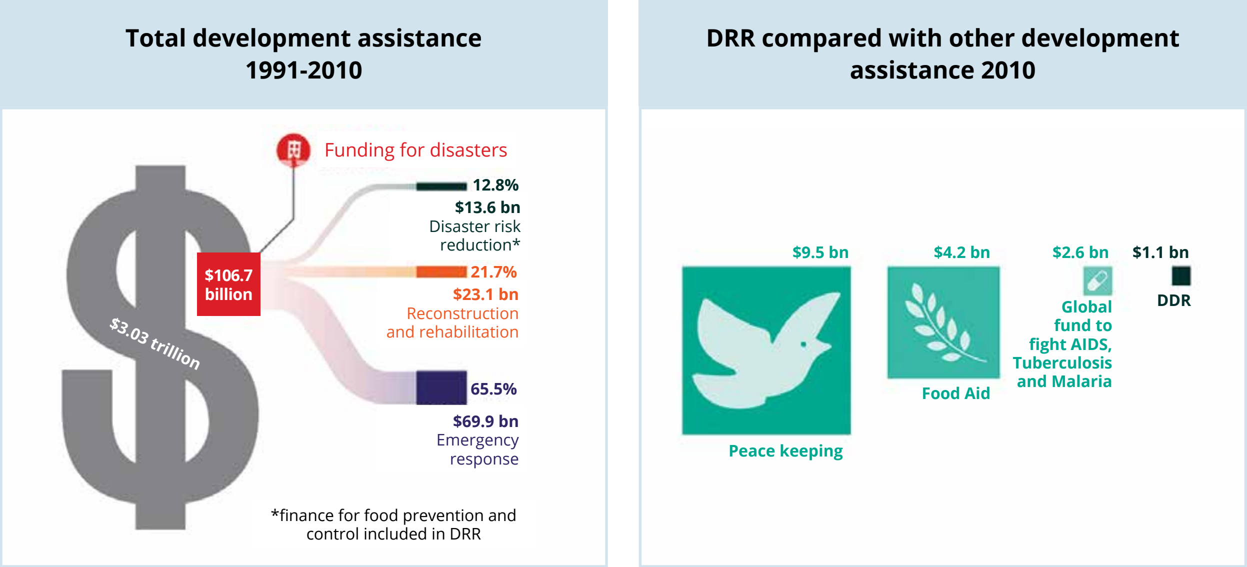


Figure 3.4: The relative cost (US$ x 1 000) of the major categories of climate-related events – wildfires, storms, floods, extreme temperature, and droughts – in southern Africa since 1980 (Source: EM-DAT CRED, 2016).

PART 2:

UNDERSTANDING THE VULNERABILITY OF SOUTHERN AFRICA TO CLIMATE CHANGE

CHAPTER 4:
ASSESSING VULNERABILITY TO CLIMATE CHANGE

AUTHORS: KATINKA WAAGSAETHER, CLAIRE DAVIS-REDDY AND NADINE METHNER

Climate-related impacts result from the interaction of climate-related hazards with the vulnerability of human and natural systems. Vulnerability-related elements include exposure, hazards, sensitivity and adaptive capacity.

4.1. Introduction[13]

Determining the impacts of climate change depends not only on the nature of climate changes (presented in Part I of this handbook), but also on the characteristics and vulnerability of the places and people that experience those changes. The following chapter presents the major theoretical and conceptual framings of risk and vulnerability, as well as common approaches that have proven successful in understanding vulnerability and risks of climate change in southern Africa. The chapter provides recommendations and practical translations of these framings and best practice guidelines for how to approach vulnerability assessments.

4.2. Understanding how exposure and vulnerability translate into climate-related risks and impacts

The risks (or opportunities) posed by climate change are dependent on the interaction of climate-related hazards with the vulnerability and exposure of both human and natural systems as well as their ability to adapt (Field et al., 2014), (Figure 4.1). Risks are considered key when there is a high probability of a hazard occurring, or high vulnerability of systems exposed (or both), and for which the ability to adapt is severely constrained. This framing takes into account that changes in the climate system and socio-economic processes, including adaptation

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[13] This chapter is based on work conducted as part of South Africa's 3rd National Communication to UNFCCC investigating the development of vulnerability indices and methodology.

and mitigation, can reduce or intensify climate change impacts. In other words, current vulnerability to an existing climate risk may not necessarily be the same as future vulnerability to climate change.

This framework (Figure 4.1) has emerged from an extensive amount of research in the last few years on vulnerability in the context of climate change and efforts in aligning with the disaster risk reduction field. It is an improvement on previous frameworks, such as that presented in the IPCC 4th Assessment Report, as it recognises vulnerability as a dynamic and multidimensional concept where risks are the result of complex interactions among societies or communities, ecosystems, and hazards arising from climate change. Climate change is not viewed as the risk, but rather the interaction of climatic changes with related hazards and evolving vulnerability and exposure of systems determine the changing level of risk (Field et al., 2014). Furthermore, vulnerability is context- and location-specific and should be framed within social, economic, political, and cultural realities of those locations (Vogel & O'Brien, 2004). Vulnerability is expressed differently at different scales from individual to household, to the surrounding community and to the broader national level scale (Cutter et al., 2003).

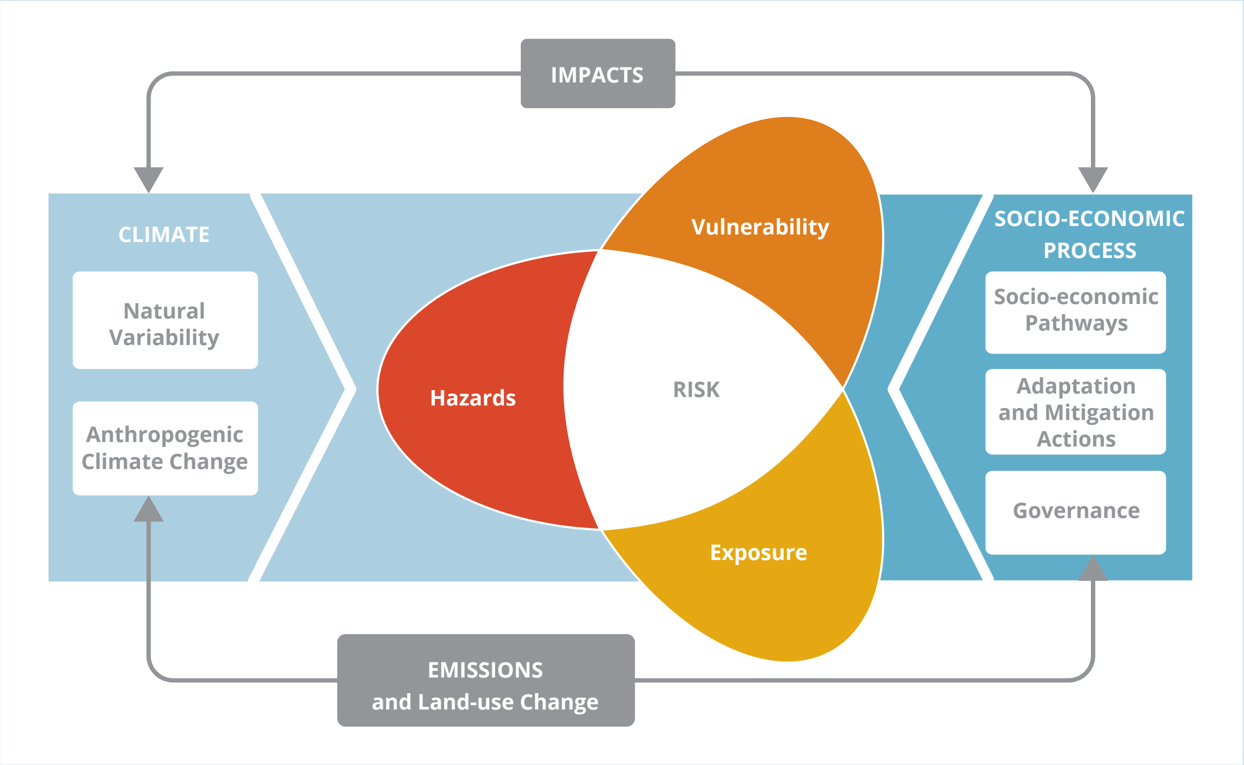


Figure 4.1: The SREX and IPCC AR5 vulnerability assessment framework where the risk of climate-related impacts results from the interaction of the climate-related hazards with vulnerability and exposure of human and natural systems (Field et al., 2014; Oppenheimer et al., 2014).

4.3. Determining the levels of risk from climate change

4.3.1. Common approaches to vulnerability assessments

Vulnerability assessments are the most commonly used tools for identifying, quantifying and prioritising key risks of a system to climate change (O'Brien et al., 2009a). Vulnerability assessments are often considered prerequisites for the construction of adaptation strategies and policies as they provide information on the circumstances that create risk and the factors which would improve the resilience of the system to respond to those risks. Defining criteria for quantifying vulnerability has thus proven difficult, but several measures of vulnerability have been developed and applied. These include proxy- or indicator-based approaches, model- and GIS-based methodologies, participatory and multi-stressor approaches, with elements of the different approaches and methods often being used in combination (Table 4.1).

Table 4.1: Strengths and weaknesses of common vulnerability assessment methodologies

Type	Description	Strengths	Weaknesses
Indicator-based	Indicator-based methodologies use a specific set or combination of proxy indicators in order to produce measurable outputs across various spatial scales. Examples of indicators include the Livelihood Vulnerability Index (LVI) (Hahn et al., 2009), Household Adaptive Capacity Index (HACI), Well-being Index (HWI), Index of Social Vulnerability to Climate Change for Africa (SVA).	• Produce measurable outputs across various spatial scales that can be easily used by policy-makers • Valuable for monitoring trends and exploring the implementation of adaptation responses	• Limited by lack of reliable data, particularly socio-economic sources, at the scale required for assessment • Challenges associated with testing and validating the metrics used, such as good governance.
Model and GIS-based	Model- and GIS-based methods incorporate biophysical and socio-economic modelling, and display vulnerability spatially through mapping. These methods commonly focus on a specific driver of change or sector and apply statistical measures and mapping techniques to display vulnerability as well as measures of adaptive capacity and resilience.	• Mapping of climate change vulnerability provides an insight into the vulnerability of place, and may have some value in identifying vulnerable places and people	• Typically, a snapshot of vulnerability, failing to encapsulate spatial and temporal drivers of structural inequalities
Participatory approaches	Participatory approaches focus on including stakeholders in the assessment process, and this can be done in a variety of ways and to various extents. A range of tools for participatory vulnerability assessments exist, including cognitive mapping, interviews, surveys, vulnerability matrices, stakeholder engagement workshops and expert-based inputs.	• Recognise the local or context-specific knowledge that exists within a system, and the fact that many aspects are best known by those individuals operating within that system	• The perception and understanding shared by participants should ideally be complemented with supporting socio-economic and biophysical data • Challenges associated with identification of the appropriate target group, and ensuring that all voices are heard and equally included in the process

4.3.2. Conducting vulnerability assessments

The choice of approach in conducting a vulnerability assessment should be directly linked to the purpose of the assessment, based on the spatial scale of assessment (national to local community) as well as the resources available, including data and budget (Patt, 2012). There is no 'one size fits all' approach, nor necessarily any 'golden' approach for any one vulnerability assessment. Often studies use a combination of bottom-up and top-down methods for a given case study (see Box 4.1). A set of best practice guidelines should be considered when undertaking vulnerability assessments (refer to Box 4.2).

Typically, vulnerability, or the probability of impact, to climate change is assessed as a function of three components: exposure, sensitivity and adaptive capacity, which are influenced by a range of biophysical and socio-economic factors (refer to Figure 4.1 and defintions included at the end of the handbook). **Exposure** can be assessed against current and/or future conditions, informed by future climate change projections (refer to Box 4.3 for guidelines on using climate models in vulnerability assessments). **Sensitivity** is often related to aspects such as the state of infrastructure, such as elements of service delivery, and the health and functioning of ecosystems, such as soil degradation. Sensitivity tends to be primarily based on current data, due to limited understanding and information on potential future sensitivity. **Adaptive capacity** is partly determined by various social factors which affect people's ability to anticipate, cope with, and respond to change but may also include other aspects; such as financial capacity, institutional capacity, and the regulatory environment. Determining or measuring adaptive capacity is scale-specific and typically more challenging to undertake as it requires primary research with communities or the application of a wide range of social data from statistical surveys.

Depending on the approach taken (Table 4.1), the output of a vulnerability assessment may be (1) quantitative and provide an overall vulnerability score based on calculations that average or weight the scores for a number of vulnerability indicators or (2) a form of scoring or rating process (high, medium and low) conducted through participatory processes or (3) a description based on qualitative information collated through groups and/or literature review. All approaches are valid and while a combination is ideal, it is often not possible.

Box 4.1: The Southern Africa Vulnerability Initiative (SAVI)

Local vulnerability is often the product of multiple stressors (Ziervogel & Calder, 2003; Casale et al., 2010; O'Brien et al., 2009b). Multiple stressors refer to a combination of biophysical and social factors that jointly determine the propensity and predisposition to be adversely affected (Field et al., 2014). The Southern Africa Vulnerability Initiative (SAVI) aimed to incorporate multiple stressors (such as climate change, HIV/AIDS, food security, access to water) into an integrated framework for understanding the vulnerability of different regions and sectors to global change in a southern African context.

The framework emphasises 'contextual vulnerability' and draws on the double exposure framework (Leichenko & O'Brien, 2008) as well as on other research on vulnerability to multiple stressors. Contextual vulnerability is based on a processual and multidimensional view of climate-society interactions. "Both climate variability and change are considered to occur in the context of political, institutional, economic and social structures and changes, which interact dynamically with contextual conditions associated with a particular 'exposure unit'." (O'Brien et al., 2011:75). The double exposure framework provides an approach for the analysis of multiple types of interactions between environmental change and globalisation (Leichenko & O'Brien, 2008). Within this framework, changing conditions affect exposure and the response to future climate change, resulting in new patterns of vulnerability and barriers to adaptation.

The SAVI does not provide a toolkit with instructions for the selection of indicators for measuring vulnerability, but does provide a set of questions that can be used in the development of an assessment. The framework was intended for use by the SADC Vulnerability Assessment Communities (VACs). The initiative used three case studies: rural livelihoods in Zambia and South Africa; trade in Durban; and HIV/AIDS in a conservation agency of Kwa-Zulu Natal Province. The studies demonstrated the contextual nature of vulnerability and how interacting stressors contribute to vulnerability.

Box 4.2: Best practice guidelines for conducting vulnerability assessments (Source: Engelbrecht et al., 2016, in press)

It is best practice when:

- The vulnerability assessment (VA) design is guided by the context in which it will be used.
- The VA takes the entire coupled system into account, considering climatic, biophysical, and social, economic and political components.
- The design of the VA process recognises that vulnerability is not static through time, and, depending on how long it will be used for, might need to allow for new information to be incorporated over time.
- The VA is based on the latest science and conceptual framing, and clearly defines the concepts as they are applied in the assessment.
- The realities of what the science can and cannot provide are accounted for.
- The VA incorporates a variety of methods, combining qualitative/quantitative, bottom-up/top-down, and thus balancing participatory input and objectivity.
- Only scale-appropriate data are included in the VA.
- The VA incorporates stakeholder participation.
- The VA process contributes to developing the capacity of relevant stakeholders.
- A VA that is conducted as a step towards developing climate change adaptation strategies and actions incorporates the stakeholders that are responsible for developing and *implementing* the actions in the process.
- The limitations of the VA method applied are acknowledged and transparent.

Box 4.3: Using climate change projections in vulnerability assessments

Choosing the single 'best' global climate model or downscaled projection for a vulnerability assessment is problematic as future scenarios are all linked to the representation of physical and dynamical processes within that specific model (refer to Chapter 2 in Part II of this handbook). The most suitable approach to be taken is to use the largest possible number of climate change projections to represent the range of possible futures as projected by models. That range can either be expressed as a set of future change narratives (e.g. wetter and hotter, wetter and warmer, drier and warmer) or as the full range of probability expressed through percentile distributions. The degree of certainty in a finding, such as change in rainfall, is based on the consistency of evidence such as data, mechanistic understanding, models, theory and expert judgement and agreement between the different models.

One approach to the use of multi-model projection envelopes is to consider the decision-making process as the starting point. If each identified climate risk is considered to be describing the context of an adaptation decision, then it is possible to explore that decision given a projected range of future climate states. For example, if a vulnerability to reduced water supply has been identified, then that would predicate a number of possible adaptation measures such as building a dam or reducing water usage. Within each of those possible measures there is a decision point or threshold where the decision to invest in an adaption measure would be taken. If such a threshold can be described, either quantitatively or even just qualitatively, then the position of the threshold within the range of projected changes can be identified.

Clearly, if the decision point doesn't fall within the range of projections, then there is little justification for a particular adaptation measure. However, if the decision point falls well within the projected envelope of changes, then that measure should be considered. For marginal cases, the decision is less clear and further exploration and risk analysis would need to be done to inform the decision.

CHAPTER 5:
AGRICULTURE AND LIVESTOCK

AUTHOR: DALEEN LÖTTER

Agriculture is impacted directly by changes in precipitation, temperature and evaporation. Increasing temperatures and more variable precipitation are likely to have a significant impact on a wide variety of crops, particularly on the yields of rain-fed crops such as maize, wheat and sorghum.

5.1. Introduction

The agricultural sector in southern Africa needs to produce enough food to feed its current population of 277 million and future predicted population of over 300 million by 2025 (United Nations ESA, 2015). All of this must happen within the many restrictions imposed on the sector by an unpredictable climate, finite natural resources and sometimes limited access to modern production technology (Kotze & Rose, 2015). Southern Africa is currently not producing enough food to adequately provide for the needs of its present population. According to the Stellenbosch Institute for Advanced Studies (STIAS, 2015), the region needs to increase overall production by at least 1 to 2 percent per annum to keep up with population increases. Figure 5.1 shows the severity of hunger in southern Africa, as it was assessed in 2013, ranging between moderate and very high. Global projections suggest that the number of people at risk of hunger will increase by 10 to 20 percent by 2050 as a result of climate change, with 65 percent of this population in sub-Saharan Africa.

Agriculture is a major social and economic sector in the SADC region, contributing between 4 and 27 percent of the region's gross domestic product (GDP). The majority of the population in the region depends on agriculture for their primary source of subsistence, employment and income (Department of Environmental Affairs, 2014a) (LTAS). This happens within various farming systems ranging from large-scale irrigation schemes to root crop farming, maize mixed farming, pastoral farming and coastal fishing (Figure 5.2). Overall, farming systems are characterised by a great level of diversity and even at the level of the individual farm unit, farmers typically cultivate 10 or more crops in diverse environments (IAC, 2004).

Maize, wheat and sorghum are the most produced cereals in the region, and the major staple foods for most of the population. Root and tuber crops, especially cassava, contribute significantly to food supply in the region and play a central role in the nutrition and economy of rural families. Overall, subsistence farming or smallholder agriculture is the most widely used method of agricultural farming in sub-Saharan Africa, and the majority of the rural poor depend on it for survival. The exception is South Africa, which has a more productive and competitive agricultural sector compared with the other countries in the region. The commercial farming sector in South Africa is highly complex and sophisticated, and plays a critical role in ensuring food security in the greater African region (DAFF, 2010). South Africa is the largest producer of milk, sugar and fresh fruit in southern Africa and also produces 17% of total maize in Africa. According to Van Rooyen and Sigwele (1998), the reasons for insufficient production in the other SADC countries include 'unfavourable climatic conditions, a complex natural resource base, inappropriate sectoral and macro-economic policies and support systems and internal strife/war'.

The SADC region is considered to be a semi-arid environment which is often plagued by droughts. The frequency of weather- and climate-related disasters has increased since the 1970s, and southern Africa has become drier during the 20th century. Significant food shortages are associated with these droughts. After the most recent drought of the 2015/2016 season, it was estimated that 32 million people would become food insecure between June 2016 and March 2017. In some African countries, agricultural yields could be reduced by as much as 50% by 2020.

Hunger severity

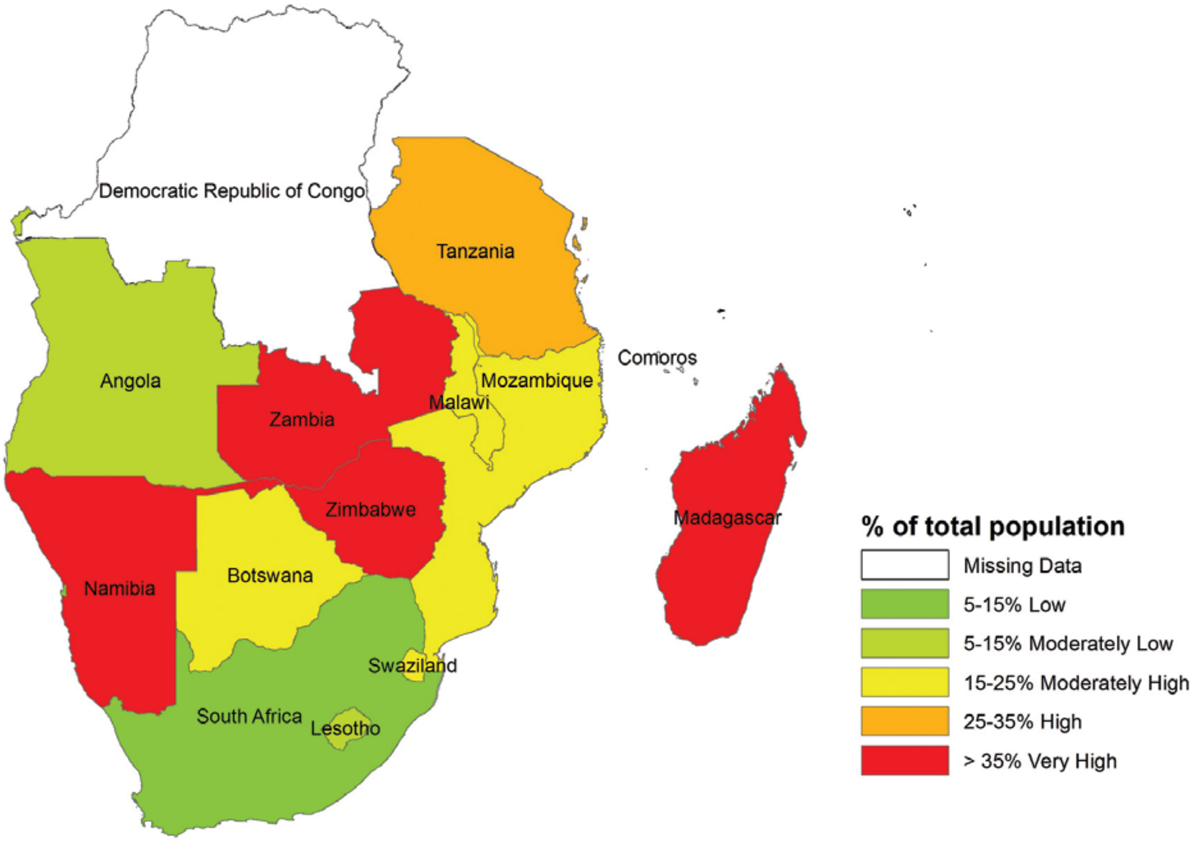


Figure 5.1: Proportion of the population in a condition of undernourishment (FAO, IFAD and WFP, 2015). The FAO defines hunger as being synonymous with chronic undernourishment. Undernourishment means that a person is not able to acquire enough food to meet the daily minimum dietary energy requirements, over a period of one year.

Farming systems

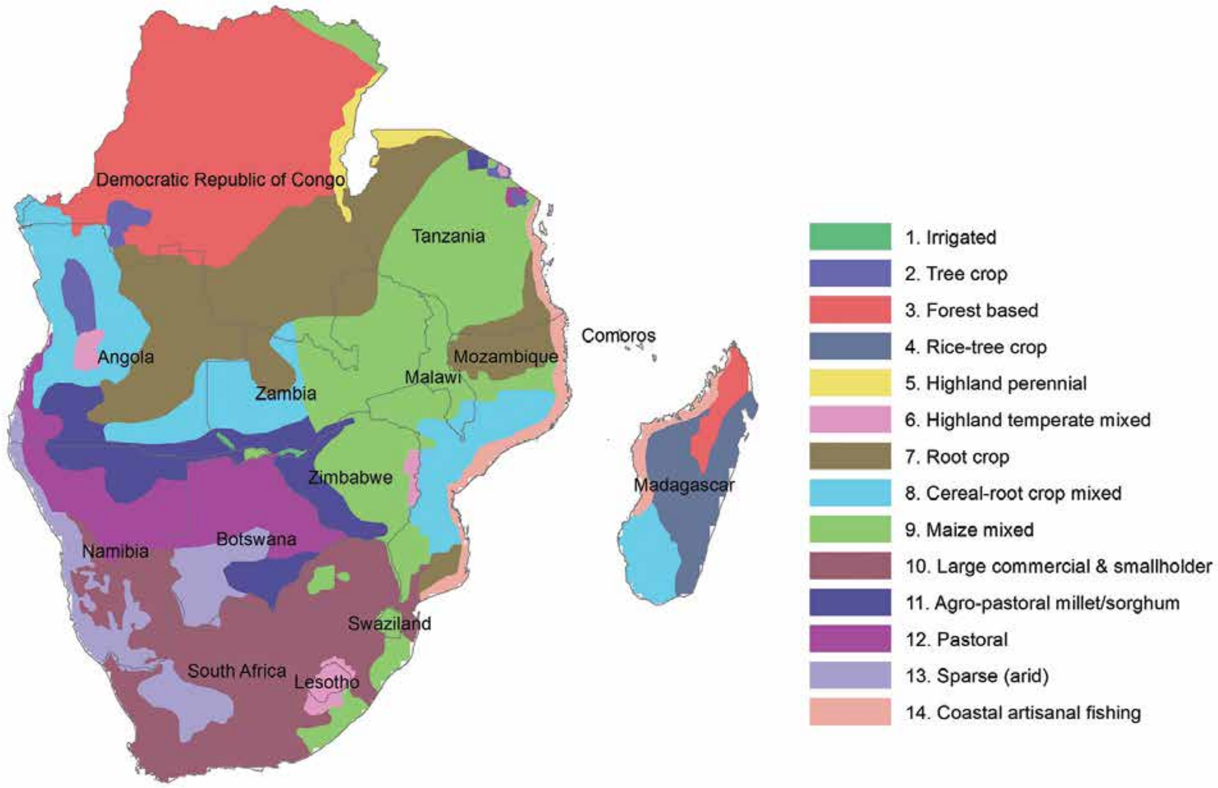


Figure 5.2: Farming systems in southern Africa (FAO, 2001).

5.2. Key drivers and processes of change within the sector

The agricultural sector in southern Africa is dictated by several important drivers and processes of change affecting its ability to guarantee food security for the region. These can roughly be divided into factors affecting the demand for food (e.g. population growth, changes in consumption patterns, urbanisation), environmental factors (e.g. climate change, environmental degradation) and external or governance factors (agricultural support and trade policies, conflicts).

5.2.1. Demand for food

Agricultural demand in southern Africa is expected to increase as population and income levels increase. New data from the United Nations laying out population growth projections to the year 2100 show that Africa is set to experience the highest population growth in the world and is the only region where the population is projected to keep increasing throughout the 21st century. Currently there are 1.2 billion people in Africa and by 2050 the population is expected to double to 2.4 billion. In southern Africa alone, the population of Angola, Democratic Republic of Congo, Malawi, United Republic of Tanzania and Zambia is projected to increase at least five-fold by 2100 (UN, 2015). Such population growth imposes profound challenges in meeting future food requirements. Along with population growth, population distribution is having a big impact on the supply of agricultural produce. According to Ziervogel and Frayne (2011), Africa will have the second largest urban population on the planet by 2030. The pace of urbanisation in sub-Saharan Africa is twice the global average, and is expected to persist for decades to come. Of the total southern African population of

277 million, at least 100 million already live in urban and peri-urban areas. By 2020, this figure is expected to rise to 150 million and to exceed 200 million by 2030. Such a change in the spatial distribution of the population will bring major changes in demand for agricultural products both from increases in urban populations and from changes in their diets, which might lead to issues of food insecurity and deepening malnutrition in southern Africa.

Not only is population growth driving food production, but major shifts in people's dietary patterns are driving the type of food being produced. There is a clear shift towards diets that are richer in meat and animal products. Sub-Saharan Africa is projected to have the greatest annual growth in the consumption of meat of any other region and the second highest growth in milk consumption. This is causing an increased demand for water and agricultural land for growing feed for livestock production, while at the same time it is further contributing to greenhouse gas emissions. Even more challenging, the necessary increases in food production will coincide with increasing changes in climate and climate variability.

5.2.2. Environmental factors

Climate change

Climate variability and change is arguably the most important driver of agricultural production. Increases in temperature and reductions in water availability will have a direct effect on agriculture through changes in soil characteristics, water availability and crop productivity as well as indirect effects through changes in farm management systems, pest and disease life cycles and competition for land and water resources. Agriculture is not only impacted by climate change, but also contributes to greenhouse gas emissions (both carbon- and nitrogen-based) primarily through land conversion, particularly deforestation, tillage and burning practices, volatility of organic and inorganic fertilisers, and methane emissions from ruminant livestock.

Availability and degradation of key natural resources

Agriculture is the largest water consumer in the region, using between 70 and 80 percent of available freshwater resources (Malzbender & Earle, 2007). Many countries in the region already face a gap in water supply versus demand (Allan, 2002). This discrepancy will impede

their ability to meet the current and future needs of the agricultural sector to produce food (Figure 5.3). According to the Food and Agriculture Organization (FAO) of the United Nations, the SADC region could face a decline in agricultural productivity of up to 50 percent over the next 10 years as a result of water scarcity and insufficient irrigation. This could severely affect many countries' prospects of greater social and economic development.

Water in the region is not only scarce, but also of exceptionally poor quality, owing to increased pollution caused by industry, urbanisation, afforestation, mining, agriculture and power generation (Ashton et al., 2008). More specifically, the pollution is a result of the progressive increase in harmful micro-organisms, nutrients, salts, metal ions, toxic chemicals, radionuclides (can emit radiation) and suspended sediments entering water courses and water supply reservoirs. The deterioration in the quality of water available for irrigation poses an increasing risk to agricultural crops and ultimately to human health. Kotze and Rose (2015) emphasise that climate change will first be felt through impacts on water resources, with far-reaching effects on water availability and quality. A rise in air temperature of 2 °C will raise water temperatures, which will alter water-gas equilibria and increase the rates of microbial processes. Higher water temperatures will lead to increased rates of evaporation, thereby reducing the volumes of water needed for dryland and irrigated agriculture (CSIR, 2010).

In sub-Saharan Africa, the most food-insecure communities live in highly degraded environments where climate change could increase degradation rates. Severe and prolonged droughts, flooding and loss of arable land as a result of desertification and soil erosion are reducing agricultural yields and causing crop failure and loss of livestock, which endanger rural and pastoralist populations. Drylands are particularly susceptible to land degradation. Unsustainable land management practices, including over-grazing, over cultivation, illegal and excessive fuelwood collection and poor irrigation technologies, among other things, have become prevalent, often due to institutional barriers.

Water risk

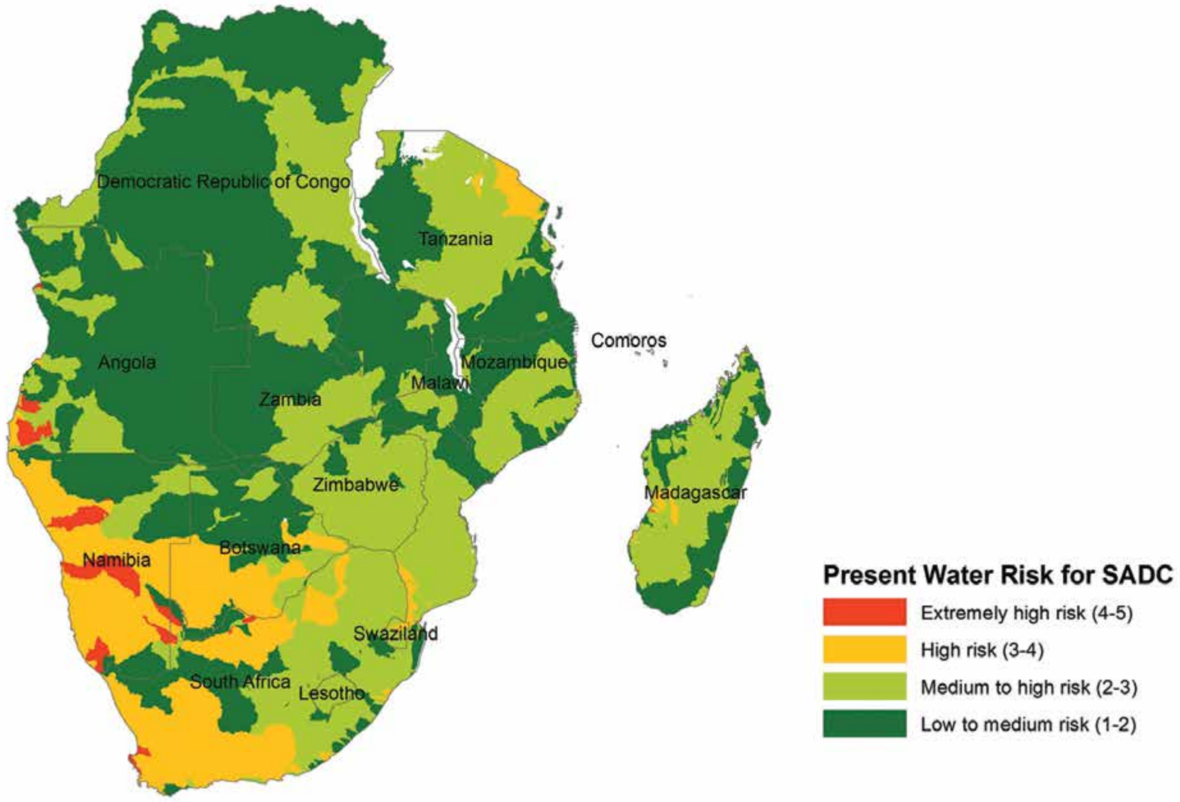


Figure 5.3: Current situation of water scarcity in southern Africa (Source: International Water Management Institute (IWMI), Web: www.iwmi.org).

5.2.3. External factors

Land reform

Land redistribution is one of the mechanisms to enable agrarian reform aimed at including marginalised farmers and communities in a country's food production system. It is widely acknowledged that land reform is absolutely necessary, but it must be implemented without compromising agricultural productivity, development, and food security. Many conflicting reports and interpretations of the manner in which the process would be applied have created concern and uncertainty for many stakeholders. In Zimbabwe, land redistribution is a bitterly contested political issue which is ultimately having a detrimental impact on the country's ability to produce food. Zimbabwe was once considered the "bread basket" of southern Africa, but is now struggling to feed its own population. Nearly 28 percent of children under age five in Zimbabwe are stunted owing to chronic malnutrition. By contrast, land reform in Namibia based on the concept of 'right of first refusal' has been very successful and roughly 28 percent of its commercial farmland has been transferred to emerging farmers. In South Africa, commercial farmers are concerned about signs that government wants to fast-track the land reform process, while local communities are concerned by the lack of progress (Pereira, 2014; Kotze & Rose, 2015). A review of land reform in 2009 indicated that 90 percent of land reform projects had failed. Close to R30 billion had been spent by that time to transfer seven million hectares of commercial farmland, which was now operating sub-optimally or was no longer in productive use.

Lack of enabling environments and political unrest

In the SADC region, many countries lack appropriate government policies to support an enabling environment for the development of their agricultural sector. This includes low funding of the national agricultural research and extension institutions, leading to ineffective technology development. Infrastructure deficiencies of roads, ports, telecommunications, irrigation, storage, cold chains, energy generation, and distribution remain a constraining feature of the agri-sector.

In recent decades, the Southern African region has also been subjected to several types of political unrest, civil war and armed conflict. Conflict and wars can disrupt agriculture in a variety of ways, depending on the characteristics of the country's agriculture. In a broad sense, conflict prevents farmers from producing food, they displace populations, destroy infrastructure and litter the countryside with land-mines.

5.3. Vulnerability of sector to climate change

Agricultural activities in southern Africa are subject to many hazards and uncertainties such as climate variability, economic and price-related issues, environmental degradation, water scarcity, and pests and diseases. The region's low adaptive capacities arising from endemic poverty, limited access to capital, infrastructure and technology; and exposure to disasters and conflicts (Parry, 2007) greatly enhance its vulnerability. When climate change issues are superimposed upon the existing vulnerabilities, the effects are exacerbated. These changes are having a dramatic impact on food and nutrition security in sub-Saharan Africa (NOAA, 2007).

5.3.1. Specific vulnerable sectors

Dryland production

75% of the SADC region is classified as arid to semi-arid. The region's climate varies from desert, through temperate, savanna and equatorial climates. Most of the region's population rely on agriculture as their main source of livelihood, either directly or indirectly. For the most part, this is derived from rain-fed production systems susceptible to droughts and floods. The projected increase in rainfall variability and extreme events for the region will exacerbate the vulnerability of these rain-fed systems. It is estimated that rain-fed farming covers around 97% of total cropland in sub-Saharan Africa.

Regardless of the approach used, most studies show a negative impact of climate change on rain-fed crop production over southern Africa. In a meta-analysis and systematic review of the projected impacts of climate change on the yield of eight major crops in Africa, Knox et al. (2012) have shown mean yield changes of -17% (wheat), -5% (maize), -15% (sorghum) and -10% (millet) across Africa by the 2050s. In terms of climatic suitability, Dinesh et al. (2015) indicate that the area suitable for maize could decline by 20 to 40% relative to the period 1970 to 2000.

Parts of southeastern Africa might experience some gains in maize yield as a result of the fertilisation effect associated with higher atmospheric concentrations of CO_2 as well as anticipated increases in rainfall in the near future (Lotsch, 2007). These benefits will, however, be negated by some losses as aridity increases towards the end of the century. Cassava appears to be more resistant to high temperatures and variable precipitation than cereal crops, with some opportunities to expand cropping areas in certain countries and regions (Dinesh et al., 2015, Niang et al., 2014). Another crop which contributes substantially to the food security and nutrition of many people in the region is the common bean (*Phaselous vulgaris L.*). This crop is projected to experience significant yield losses in most of sub-Saharan Africa (Lobell et al., 2008; Thornton et al., 2009, 2011).

Apart from rainfall anomalies, crop sensitivity to temperature thresholds is another important factor to consider in assessing future crop yield changes. Engelbrect et al. (2015) project increases of 4 to 6 °C over southern Africa by the end of the century relative to present-day climate under the A2 (a low mitigation) scenario. In addition, extreme events such as heat-wave days are consistently projected to increase drastically in their frequency of occurrence. This will lead to general decreases in soil-moisture availability, even for regions where increases in rainfall are plausible, due to enhanced levels of evaporation. Maize has been found to have a particularly high sensitivity to temperatures above 30 °C, with a yield reduction of 1% for each growing day spent at a temperature above 30 °C (Lobell et al., 2011). Wheat has an even lower optimal temperature range than maize and in many areas it is already close to threshold values for maximum temperature (Adhikari et al., 2015).

Livestock-based systems

Livestock are an integral part of the livelihood strategy of many people, especially the poor in the region. It is an important source of food (such as meat, milk and other dairy products) and provides cash to supplement income (IAC, 2004; Seo and Mendelsohn, 2007). Climate change is expected to affect livestock productivity indirectly through forage availability and quality as well as directly through heat stress. Heat stress relates to the animal's inability to dissipate environmental heat and is affected by temperature, humidity and wind speed. An increase in air temperature, as associated with climate change, will have a direct effect on animal performance through alterations in the heat balance. According to a report by the CGIAR (Dinesh et al., 2015), most domesticated species perform best at temperatures between 10 and 30 °C and will eat around 3 to 5% less for each 1 °C increase above those levels. These temperatures are already exceeded in a number of regions.

Indirectly, climate change can affect the availability of feed resources for livestock through changes in the primary productivity of crops, forages and rangelands. Changes in species composition in rangelands and some managed grasslands will also have a significant impact on the types of animal species that can graze them (Thornton et al., 2007).

Other

Given the strong linkages between agriculture and other sectors of the economy, climate change will have many secondary implications for other industries. According to Haywood (2015), the biophysical impacts of climate change can have a ripple effect along the whole agricultural value chain which spans input companies, farmers, distributors, agro-processing companies, and retailers. In the Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape (Western Cape Department of Agriculture, 2014), a case study is provided of climate change impacts on the wine value chain in terms of role players along the value chain and their exposure to climate change impacts. Specific risks relate to the increased risk of spoilage during cold chain distribution caused by increased temperatures.

5.4. Response measures

Potential climate change responses in the agriculture sector cover a broad range of options on different levels – from national level strategies such as investment in research and innovation, development of infrastructure and consideration of water resource allocation, to local level responses, which may be specific to agriculture production methods and local conditions. Providing food for the region in future will require an interlinked approach of producing food in the most economical yet most environmentally responsible manner, continued research on new crop varieties and technology, minimising of food waste, climate and environmental education and increasing the production of small-scale farmers.

There is an urgent requirement to intensify agriculture and enhance food production systems in order to achieve food security. Reducing the environmental impact of agricultural production is an important overall adaptation strategy. According to the Department of Agriculture (2008), land degradation, water scarcity and pest control are the most significant environmental issues facing agriculture in southern Africa. By following an environmentally sustainable approach to soil, water and natural veld management, the agriculture sector will be able to sustain the natural resource base while ensuring greater productivity and food security. Specific measures include more efficient use of irrigation water, minimum disturbance of the soil, crop rotation, crop diversification, crop residue management and incorporation of organic matter, best grazing systems, and erosion prevention practices. All these measures are inherent to the principles of initiatives such as conservation agriculture, climate-smart agriculture and agroecology. These environment-centred approaches have the advantage that they can achieve the same, or greater, productivity compared with conventional agriculture, but with greatly reduced production inputs. This will have the effect of making producers more competitive by lowering input costs, while reversing the trend of agriculture`s negative contribution to the trade balance.

Looking at specific examples of response measures such as those required during the most recent drought season, the sector needs interventions from government and related institutions to ensure the financial survival of farmers during the disaster, but also to facilitate drought recovery in the aftermath of the drought. This might entail subsidising feed and fodder for six months after the drought and helping farmers retain farm workers by means of a wages cash grant. National crop and/or disaster insurance would also become a priority as more extreme conditions are expected. Emerging producers are especially vulnerable.

In terms of infrastructure, less than 5% of cultivated land in the SADC region is equipped for irrigation. Development of irrigation infrastructure may allow the region to grow crops all year round and not only depend on climatic conditions.

Communicating agro-climatic information in an appropriate format to government, agri-business (e.g. seed companies), extension services and farmers is essential to enhance decision support. This could relate to the onset of rains, number of rain days, persistence of rain days, enhanced rainfall variability, droughts and long- and short-cycle crops. Communication and trust should be increased between authorities and all farming sectors (commercial, small-holder and subsistence) to disseminate relevant knowledge on climate change and promote adaptation (Department of Environmental Affairs, 2013). Such communication should be augmented with processes that support vulnerable communities to interpret and respond to such messages.

Early warning systems serve an important function as mechanisms to give timely warnings of potentially damaging weather events (e.g. heavy rain, heat waves and cold weather). Such information plays a critical role in helping farmers to prepare and act sufficiently ahead of time to reduce the possibility of harm or loss. Despite the warning being issued, early warning information does not always reach the people who need it. The packaging of early warning information also needs to be improved, including translation into local languages.

Another critical response measure is continuous investment in climate change education and awareness programmes in rural areas. In collaboration with agricultural extension services, these outreach activities could enable both subsistence and commercial producers to better understand, respond and adapt to the challenges of climate change.

Case study: Modelling rooibos crop suitability and distribution under scenarios of climate change

Arguably, the economically most significant indigenous crop within the Fynbos Biome is the leguminous shrub *Aspalathus linearis* (better known as rooibos tea). Rooibos tea is an invaluable wild resource as well as a commercially cultivated plant which has significant nutritional and health benefits. Being a rain-fed crop with wild populations having a narrow geographic range within the Fynbos Biome, climate change is expected to have important consequences for future species distribution and crop suitability. Rooibos has recently been granted geographical indication (GI) protection due to the unique environment within which the plant is cultivated, its limited geographical range and strong link with local farmers' heritage.

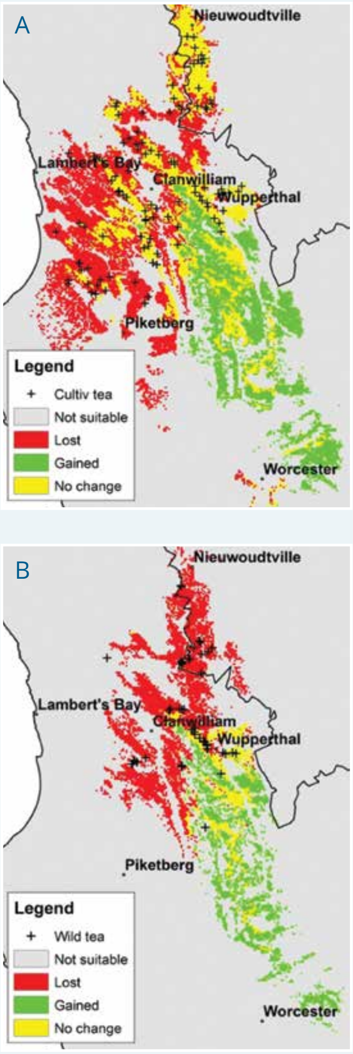
Model scenarios of rooibos crop and wild type distribution

Using a species distribution model and an ensemble of climate change scenarios, rooibos range contractions, expansions or shifts were quantitatively assessed for the time period 2041-2070 relative to 1960-1990. Using the CCAM climate change projections and Maxent species distribution modelling software, it was predicted that wild rooibos tea may lose up to 69% and cultivated tea 57% of their climatically suitable habitat range by 2070 (refer to figure below). Range contraction is most pronounced in the lowlands, while rooibos crop and wild types are likely to persist in mountain areas or expand their ranges to higher elevations.

Implications for livelihoods, conservation, and adaption planning

Unlike indigenous tea, the distribution of cultivated tea is assisted by several management interventions which make it possible to expand its indigenous range. This leads to cultivation in suboptimal locations and production in these marginal areas is likely to decrease rapidly under the influence of accelerated global climate change. Hence, lowlands along the west coast and the northern periphery of the production area are predicted to be the most vulnerable. Novel areas for future crop suitability are expected to move south-eastwards and upslope of mountain ranges. However, most of the areas where future crop suitability is indicated are located in existing conservation areas or include conservation-worthy vegetation, which may bring farmers into conflict with the biodiversity conservation sector. Current land-use legislation prevents farmers from cultivating in such areas although illegal ploughing of land does occur.

Emerging, small-scale and resource-poor farmers are often particularly vulnerable in that they do not have sufficient resources and access to timely information to deal with adverse effects of climate change. The bulk of wild tea is harvested by small-scale farmers located in near-pristine natural environments around Nieuwoudtville and Wupperthal. If species' ranges shrink or shift in the future as is predicted by the models, it is doubtful whether farmers will relocate to areas where species have colonised new sites. More pressure might be placed on harvesting the remaining populations, which may contribute to the species' decline. These findings will be critical in directing conservation efforts as well as developing strategies for farmers to cope with and adapt to climate change.



Suitability of areas for cultivated (A) and wild (B) *A. linearis* under future climate change for the period 2041-2070.

Maps show areas where range contraction, no change and range expansion occur relative to the current climate (1960-1990).

CHAPTER 6:
COMMERCIAL FORESTRY

AUTHOR: SASHA NAIDOO

Forests in southern Africa are critically important for sustainable livelihoods and ecosystems but are vulnerable to changes in climate, most important being accumulated temperature and moisture deficit, as well as to other external stressors, such as deforestation, with which climate may interact.

6.1. Introduction

Forest resources in the SADC[14] region are extensive and diverse. The total forest cover is estimated at 400 million hectares (ha)[15] in area, or more than 40 percent of the total land area of the 15 SADC member states (Figure 6.1) (FAO, 2015b). Forest cover is concentrated in a few countries in the SADC region. The Democratic Republic of Congo, Angola, Zambia and Mozambique have the largest forest areas and account for close to three-quarters of the total forest area in the SADC region. Those four countries are among the five most-forested countries in Africa; together with Sudan, they contain more than 55 percent of the continent's forest estate (FAO, 2012).

6.1.1. Indigenous forests in the SADC region

Natural forest types in the SADC countries range from tropical moist forests in Angola and the Democratic Republic of Congo to scrubland and desert ecosystems in the Kalahari and Namib deserts in western Botswana and southern Namibia (FAO, 2001). Natural forests comprise six main forest types: the miombo woodlands, the mopane woodlands, the baikiea woodlands, acacia woodlands, montane and tropical moist forests, and mangrove forests (Mubaiwa, 2004). Miombo woodlands, dry deciduous forests, constitute the most extensive vegetation type in the SADC countries covering a substantial area of Angola, Malawi, Mozambique, Zambia and Zimbabwe, extending north into the United Republic of Tanzania and the Democratic Republic of Congo (FAO, 2001).

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[14] The SADC region comprises more countries than the southern African region, notably the United Republic of Tanzania (URT) and the Democratic Republic of Congo (DRC). Established in 1980, SADC now has 15 member states: Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe.

[15] Total forest cover includes natural and planted forests

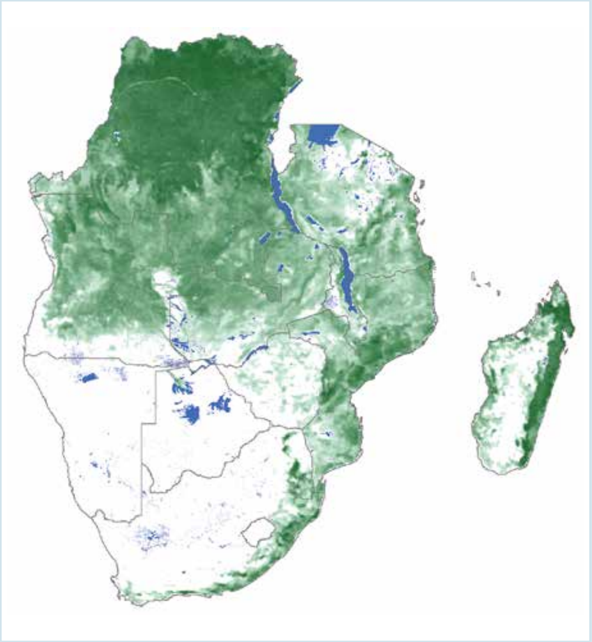
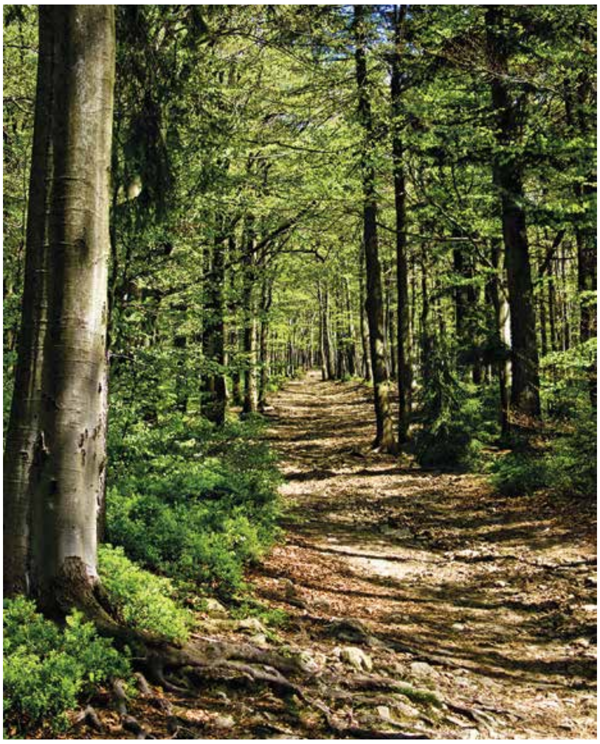


Figure 6.1: Forest cover of southern Africa of 2010 (Source: FAO 2015b).



Mopane woodlands occupy drier areas characterised by low rainfall and high temperatures in Mozambique, northern Namibia, southern Angola and large areas of Zimbabwe and Botswana. The baikiea woodlands (Zambezi teak forests) are found in the Kalahari sands of western Zimbabwe, northern Botswana, northeastern Namibia, eastern Angola and Zambia. Acacia woodlands are common in various parts of the Zambezian phytoregion where the rainfall is low and the soil suitable. Montane and tropical moist forests are found in pockets in high-altitude, high-rainfall areas in Malawi, Mozambique, Zimbabwe and Zambia and in most of Angola and the Democratic Republic of Congo. Mangroves occur in coastal areas of the tropical regions of Angola, Mauritius, Mozambique, South Africa and the United Republic of Tanzania (FAO, 2001).

6.1.2. Plantation forests in the SADC region

Plantation forests account for about 3.37 million ha of forest cover in the SADC region, approximately half of which is in South Africa (FAO, 2015a). Angola, Madagascar, Malawi, Mozambique, Swaziland, the United Republic of Tanzania and Zimbabwe have relatively small plantation forest sectors, most of which are for industrial purposes such as wood pulp and timber and are privately owned. South Africa's plantation forest area of 1.273 million ha accounts for one percent of its national land area (122.3 million ha) (DAFF, 2012). South Africa produces 70 percent of the SADC region's total roundwood and sawn timber production (FAO, 2010). In a list of major producers of industrial roundwood in 2012, consisting of 32 priority countries globally, South Africa is one of only two African countries on the list (the other being Nigeria) and produced 15 906 387 m3 of industrial roundwood in 2012 (Jürgensen et al., 2014). Commercial plantations in South Africa are certified by the Forest Stewardship Council (and the International Organization for Standardization 14001 certification scheme) as sustainably managed (DAFF, 2009). Swaziland has approximately 135 000 ha of plantation forests, Zimbabwe has 87 000 ha of commercial plantations and Mozambique has a plantation forest area of 75 000 ha (FAO, 2015a). Botswana, Lesotho and Namibia do not have commercial plantations, except for some small woodlots that were established for the provision of fuelwood and poles for general farm construction (FAO, 2003).

The expansion of plantation forests in SADC countries is limited by the availability of suitable land. Afforestation in South Africa is also limited by water legislation and permits are required to expand the area under plantations. After the introduction of the National Water Act (NWA, Act No. 36 of 1998) (Republic of South Africa (RSA) 1998), the industry lost approximately 80 000 hectares to comply with both the water and environmental legislation (FAO, 2015b). Climatic conditions in Namibia are not very conducive to tree planting, however limited tree planting aimed at implementing reforestation and afforestation at the national level does take place. Orchard development is part of Namibia's tree planting project with the purpose of increasing fruit production, reducing poverty and creating an opportunity for industrial development through agro-processing (FAO, 2015b). Major investments are currently being made by the private sector into commercial plantations in a number of countries, including Tanzania and Mozambique, as these countries offer larger tracts of suitable land, with Mozambique's proximity to the coast for exporting products to Asia also a positive factor (Jacovelli, 2014).

6.1.3. Economic, social and environmental functions

Forests are the 'green lungs' of our planet and multitask as habitats, suppliers of raw materials, a source of livelihoods, places of recreation and a means of climate protection (FAO, 2015b). Forests play a major role in the livelihoods of communities as sources of wood and non-wood products. Most countries in southern Africa have extensive rural areas with high poverty levels and the economic, social and environmental functions of forests vary greatly among countries. In rural areas, local people rely to a large extent on forests for shelter, food, energy, construction material, employment and other products for domestic consumption as well as trade (Zaikowski, 2008). Fuelwood is probably the most important forest product in many SADC countries, especially among rural communities. The miombo woodlands, for example, are important for livelihoods, with 75 million people inhabiting miombo regions and an additional 25 million urban dwellers relying on miombo wood or charcoal as a source of energy (cited in Dewees et al., 2010).

Planted forests play an important role in global and regional economies to secure industrial roundwood and wood fuel and have, in many developing countries, formed the structural basis for an increasing forest-based manufacturing and export sector (Jürgensen et al., 2014). Plantations are established with a variety of objectives including production of industrial roundwood, afforestation of degraded land, protection of the environment, increasing wood supplies, and often, the purpose may be a combination of more than one of these. The commercial forestry sector is important to South Africa's GDP and employment in the country, and also in terms of the role this sector plays in either contributing to GHG emissions or reducing GHGs. Plantation forestry provides the raw materials for downstream activities such as sawmilling, woodchip exports, timber boards, furniture, mining timber, treated poles, charcoal, pulp and paper manufacture, and non-timber forest products (NTFPs). The plantation forest industry, including support industries, contributes about 1% to South Africa's GDP and employs about 166 000 people (DAFF, 2015).

6.2. Key drivers and processes of change within the sector

Deforestation in the SADC region is a major concern and has been identified as one of the priority areas for regional action through its contribution to increased concentrations of carbon dioxide in the atmosphere and to land degradation, and its negative impact on biodiversity and the balance of associated ecosystems (Lesolle, 2012). The extent of forest-cover change and the drivers of deforestation vary among countries. The main causes of deforestation, often acting in combination, are agricultural expansion, woodfuel use, hardwood timber extraction and conversion to plantations (Geist & Lambin, 2002; Wertz-Kanounnikoff & Wallenoffer, 2011). The rate of deforestation is also affected by the combined effect of factors such as development and conservation policies, reigning ecological conditions and the fragility of ecosystems and social environments (FAO, 2001).

Deforestation in the SADC region is characterised by a combination of forests cleared for agriculture or for commercial purposes, the increasing demand for biomass as an energy source, population growth and poverty, and these pressures are set to increase. Annual net forest loss in the SADC region was approximately 0.46 percent, or 1.8 million ha, in the period 2005–2010 (Figure 6.3); the SADC member states are characterised by very diverse forest cover change rates.

Of the SADC countries, Angola, Madagascar, Mozambique and Zambia have the highest timber production capacities from natural forests (FAO, 2001). The loss of natural forests of high timber potential in countries such as Malawi and Zimbabwe was the result of clearing for agriculture and infrastructure development; fuelwood and pole collection; and overstocking with domestic animals. The ecological conditions in Botswana, Lesotho, Namibia, Swaziland and South Africa do not favour timber-producing natural forests.

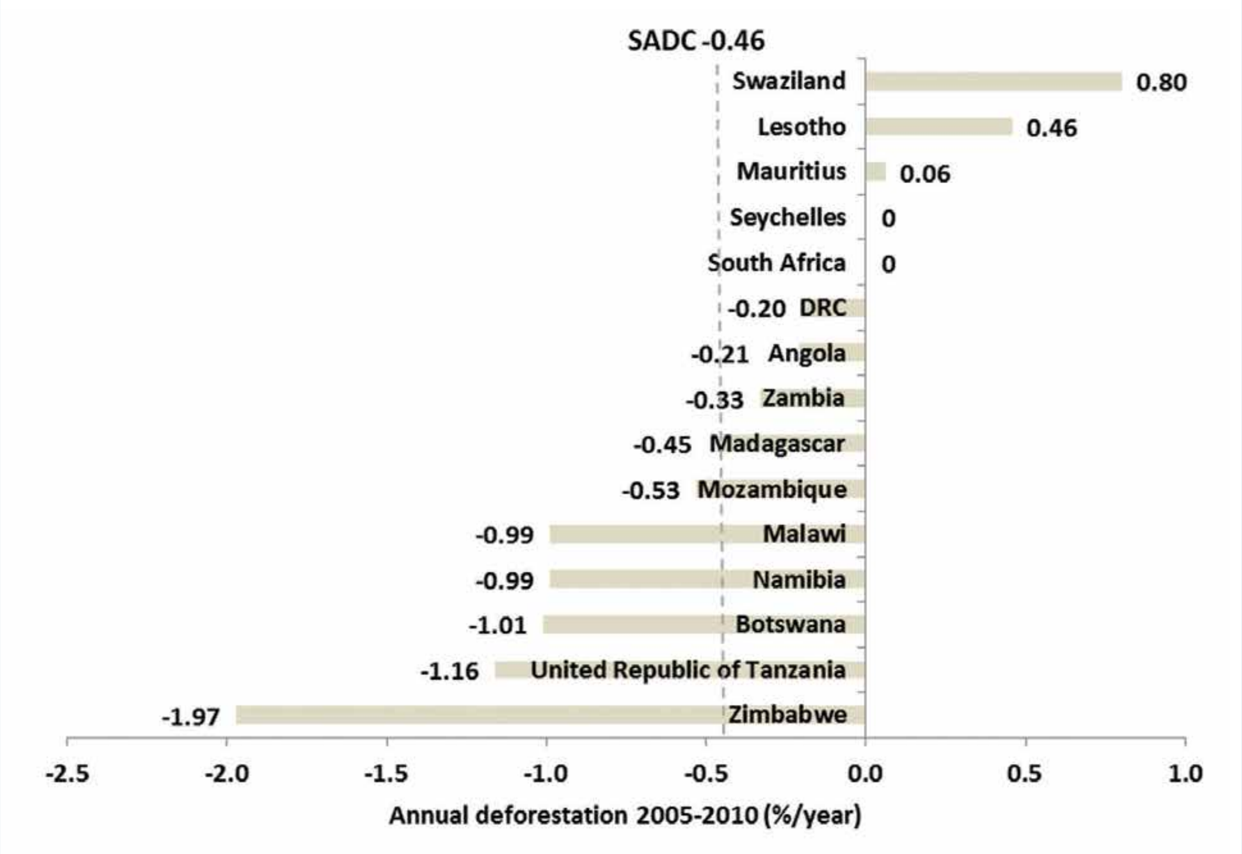


Figure 6.3: Annual rate of deforestation, SADC countries, 2005–2010 (Source: FAO, 2010).

6.3. Vulnerability of sector to climate change

Forest resources in southern Africa are vulnerable to the projected changes in climate in the region, as well as to other external stressors with which climate may interact, which, in turn, will have serious implications for local livelihoods as well as for areas and communities who may be dependent on them. Accumulated temperature and moisture deficit are important factors, but the impact of which is not always straightforward. The impact of climate change will depend on the factor which is most limiting at a site.

Climate change will alter the boundary limits of where current species are able to survive, and, in turn, this will change the consequences for the growth, survival and distribution of species. Increases in temperature in the SADC region are likely to result in changes to tree lines and phenology for certain species (Lesolle, 2012). The implications of increased temperatures on pests and pathogens affecting key species in both natural and plantation forests are also a key area of concern. Relatively minor changes in climate can increase forests' vulnerability to drought, insects and fires. Disease and insect populations and attacks may increase, leading to increased tree mortality. Forests may become increasingly vulnerable to higher background tree mortality rates and die-off in response to future warming and drought, even in environments that are not normally considered water-limited (Allen et al., 2010). Given that the vast majority of the SADC region is already water-limited, the possibility of increased tree mortality is of major concern. Some models may indicate that forest productivity may increase in certain areas, leading to increased supply of certain types of timber, however possible productivity loss through interactions with extreme events and disturbances is likely to outpace these gains (Kowero & Yemshaw, 2011).

Projections show a shift in the conditions suitable for the growth of particular trees and grasses, some of which could be more fire-tolerant than others (Department of Environmental Affairs, 2014a). Climate change has the potential to influence the number of natural and human factors that could significantly affect the fire regimes within the savanna woodlands and forests of the SADC region. The frequency and intensity of wildfires could increase due to a combination of factors such as increased ignition potential as a result of increased lightning, longer drier periods, hotter, drier and windier weather conditions which would fan the spread of fires and fire disasters, and more biomass produced during wetter rainy seasons (Department of Environmental Affairs, 2014a).

Species choice is crucially important since the current plantation forest species are based on optimum growing areas using site species matching. The different tree species and hybrids planted in commercial forests in South Africa have different climatic constraints and this determines the climatically optimum growth areas where these species can be matched for optimal growth and volume production. Changes in temperature and rainfall regimes are likely to impact the extent and location of land climatically suitable for specific genotypes (Warburton & Schulze, 2008; Department of Environmental Affairs, 2014). The forestry sector is also vulnerable to increased frequency of extreme events such as frost, snow and hail, and increased susceptibility to a wider range of pests and pathogens, as well as to changes in the patterns of disturbance by forest pests (insects, pathogens and other pests).

6.4. Response measures

Given the potential impacts of climate change on forests and commercial plantations in southern Africa, the development and implementation of adaptation policies, measures and strategies in the immediate future is crucial. Adaptation to climate change is a central priority in the Southern African Development Community (SADC)'s regional response framework and countries in the region have recognised the urgency of building resilience and facilitating adaptation to climate change in the forest sector. And while adaptation remains a priority for SADC, voluntary mitigation activities can provide benefits to promote regional integration and socio-economic development in the SADC region (Lesolle, 2012). One of the most important priorities for adaptation in forests is the need for measures to deliver benefits beyond adaptation to climate change (e.g. GIZ, 2010; Midgley et al., 2012; Lesolle, 2012; Clarke et al., 2012). A key priority will be to ensure the achievement of multiple benefits and synergies between climate change adaptation, carbon-smart land use, biodiversity conservation and the reduction of deforestation/degradation; and the improvement of livelihood options in and around forests in the SADC region.

6.4.1. Adaptation

Forests can play an important role in achieving broader climate-change adaptation goals, but may be threatened by impacts from other sectors. Strategies for adapting forests to climate change should be coordinated with those of other sectors and integrated into national and regional development programmes and strategies. Adaptation to climate change can also be construed as an extension of good development policy, like promoting growth and diversification of the economy in order to increase options for investment, employment and incomes of farmers and creating markets for environmental services (Kowero & Yemshaw, 2011).

The life cycle of a forest ranges from decades to centuries. Adaptation in the forest sector requires planned responses that are implemented well in advance of the impacts of climate change (Spittlehouse & Stewart, 2003). When developing and implementing forest-related climate change adaptation actions, policies and processes it is essential to have a good understanding of local vulnerabilities to climate change in their ecological and social contexts (Kleine et al., 2010). Climate change adaptation strategies can be viewed as a risk management component of sustainable forest management plans (Spittlehouse & Stewart, 2003). Forest managers should select adaptive practices that are locally appropriate, and they should work with stakeholders and communities to improve these practices. Examples of climate change adaptation measures are listed in Table 6.1.

Adaptation planning options for plantation forestry could focus on fire and water management in the short term; and in the longer term on pests, and on increasing drought and heat tolerance. Adaptive interventions include developing and utilising more stress-tolerant (e.g. heat- or drought-resistant, or cold-tolerant) species and hybrids; mixing species to provide some assurance against the impacts of climate change; site-species matching; and use of water harvesting methods to relieve water stress during the establishment phase (Makundi, 2014).

Table 6.1: Examples of climate change adaption measures in the forest sector (Source: Spittlehouse & Stewart, 2003; Kalame et al., 2009; Kleine et al., 2010)

Topic	Adaptation measures
Gene management	Reassess the location of conservation areas and seed banks; breed pest-resistant genotypes; determine the adaptability of genotypes and their responses to climate change
Forest protection	Manage forest fire and pests to reduce disturbance; restore destroyed forest; protect trees from disease
Forest regeneration	Use drought-tolerant genotypes; use artificial regeneration; control invasive species
Silvicultural management	Selectively remove poorly adapted trees; adjust rotation periods; manage forest density; adjust species composition and forest structure
Non-wood resources	Minimise habitat fragmentation; conserve wildlife; maintain primary forests and the diversity of functional groups
Park and wilderness area management	Conserve biodiversity; maintain connectivity between protected areas; employ adaptive management

6.4.2. Mitigation

Mitigation actions are aimed at reducing GHG emissions and thereby contributing to reducing the extent of global warming. While most SADC countries have not been major contributors to emissions to date, current patterns of development may be considered, in some areas, to be unsustainable and may add to future ecological degradation (SADC Council of Non-governmental Organisations & FES, 2011). Forests contribute to mitigation through their capacity to remove carbon from the atmosphere and store it. Approximately 20 percent of global GHG emissions are the result of deforestation and forest degradation.

REDD+, reducing emissions from deforestation and forest degradation, is a mechanism to create an incentive for developing countries to undertake forestry and related activities at the national (and in some cases subnational) level that, together, would contribute to climate change mitigation. The incentive is provided through the creation of financial value for the carbon stored in trees. REDD+ can play an important role in reducing emissions and increasing GHG removals from the atmosphere. By incentivising improved forest and land management, REDD+ can also contribute to sustainable socio-economic development and support the transformation to a green economy (refer to case study). However, a key issue for the forest sector is ensuring that there is appropriate community engagement as well as equity in the share of proceeds from forest trade, forest-generated finance, and the benefits generated by REDD+ (Lesolle, 2012).

SADC member states developed a regional REDD+ programme in 2009 aimed at addressing common problems of deforestation and degradation in the region and formulating climate change mitigation measures in the forest sector (SADC, 2013). This REDD+ programme aimed to improve the capacity of member states to manage and benefit from their national REDD+ programmes through regional cooperation and also increase the influence of SADC as a region (SADC, 2013). The priority for SADC was not to just reduce emissions, but for REDD+ to be used as a mechanism for enhancing national development and thus creating the capacity to curb emissions from land-use change and forestry.

The plantation forest sector also plays an important role in terms of mitigation and effective monitoring of the sector's emissions and current activities is needed to understand the potential and progress of this sector with respect to climate change. Introduction of REDD+ in plantations in Africa will require significant expansion of the number and location of the permanent sample plots (PSPs) to obtain estimates of the carbon-relevant plantation attributes such as below- and aboveground carbon density, detritus, products and decomposition profiles (Makundi, 2014). A study on the development of a monitoring, reporting and evaluation (M&E) system for the Agriculture, Forestry and other Land Use sector was conducted by the Department of Environmental Affairs in South Africa (DEA, 2015). The proposed M&E system aimed to ensure, facilitate and streamline data collection across all relevant sectors of Agriculture, Forestry and other Land Use (AFOLU). The study mapped current mandates in relation to the AFOLU sector and linked those mandates to both mitigation and adaptation indicators which should be measured.

6.4.3. Policy

Important policy documents for the SADC region with specific reference to the forestry sector and its functional links with climate change mitigation and adaptation include the SADC Treaty of 2005, enabled the development of the SADC protocol on Forestry 2009, which was followed by the SADC Forestry Strategy of 2010 (Kojwang & Larwanou, 2015). An overview of SADC policies, strategies and programmes related to climate change, forestry and other sectors is given in Dlamini (2014) and Kojwang and Larwanou (2015).

National adaptation priorities, as identified in national adaptation programmes of action (NAPAs) and national communications, include sustainable forest management and the sustainable use of resources; afforestation and reforestation programmes; the promotion of agroforestry, non-timber livelihoods, alternative energy sources and climate-resilient tree varieties; and capacity-building and the strengthening of institutional frameworks. Nationally appropriate mitigation actions (NAMAs) prioritised afforestation, reforestation, and promotion of energy efficiency, efficient crop and livestock production systems, efficient transport systems and waste management (Kojwang & Larwanou, 2015).

Case study: The role of REDD+ in supporting a Green Economy Transformation in Zambia (Adapted from Turpie et al., 2015)

Forests are an important part of Zambia's natural capital and provide important benefits for the rural population, urban areas, the national economy and the global community. However, Zambia has one of the highest per capita deforestation rates in Africa. Zambia's forestry sector is based on both indigenous and plantation forestry, and includes production of industrial roundwood, wood fuel and charcoal, sawn wood and wood-based panels, pulp and paper, wooden furniture, commercial production and processing of non-wood forest products and subsistence use of forest products. The main direct drivers of deforestation are charcoal production, agricultural and human-settlement expansion and illegal exploitation of timber. Mining and forest fires also play a role.

Forest ecosystems play a critical role in sustaining and supporting the stocks and flow of ecosystem services to various economic sectors and human well-being in Zambia. Forests contribute to economic growth, employment, wealth, revenue from exports, a stable supply of clean water, recreation and tourism opportunities, as well as essential building materials and energy for a wide range of economic sectors. Forests support more than 60% of rural Zambian households (which is over one million jobs). The direct and indirect values of forests were estimated to make a direct contribution of US$ 958 million, equivalent to at least 4.7% of Zambia's GDP. It is important that cost-effective ways for conserving and sustainably managing forests are implemented to support "green economy" growth in the country. Actions to reduce deforestation could be an important catalysing factor for the country's transition to a green economy, and forest ecosystems can offer opportunities to support this transition through the role of REDD+.

Actions to bring about the more sustainable use of forests and to slow the rate of forest loss in Zambia include:

- strengthening and enhancing the management and governance of forests at the local level;
- introducing measures to reduce urban demand for charcoal;
- supporting the development of livelihood and income-generating activities that support or rely upon forest conservation and maintenance; and
- increasing the sustainability and efficiency of agricultural practices.

The success of these strategies depends on the ecological, social, economic and political context in which they are implemented in Zambia. These approaches should be pursued together and can form the pillars of a National REDD+ Strategy in Zambia. The rationale for REDD+ activities and the means by which these activities can and will be undertaken may be different in each province and district of Zambia. The costs and benefits of implementing REDD+ will depend to a large extent on where implementation takes place as well as the strategies employed for reducing deforestation. In areas where forests are largely intact and where the potential for timber extraction is highest, the REDD+ priority should be to develop and enforce sustainable forestry, while ensuring that the increasing population's energy needs are met sustainably (e.g. in the North-West Province). In areas where forest cover has already been significantly reduced and degraded and the demand for charcoal is greatest, REDD+ activities must address the issue of charcoal demand (e.g. in the Central, Southern and Eastern Provinces). Ecotourism, forest conservation and sustainable rural economic development are closely interlinked and interdependent and need to be understood and included when planning to ensure the successful implementation of REDD+.

CHAPTER 7:
TERRESTRIAL ECOSYSTEMS AND BIODIVERSITY

AUTHOR: CLAIRE DAVIS-REDDY

Changes in climate, combined with land-use change and the spread of invasive species, are likely to limit the resilience of the terrestrial ecosystems of southern Africa and contribute to biodiversity loss.

7.1. Introduction

Southern Africa has a rich diversity of plants and animals and its high levels of endemism are critical to cultural heritage and support livelihoods and economic development (e.g. ecotourism). Six of the 34 internationally identified biodiversity 'hotspots' are located in southern Africa, namely the Cape Floristic Region, Succulent Karoo, Maputaland-Pondoland-Albany, Eastern Afromontane, Madagascar and the Indian Ocean Islands, and Coastal Forests of Eastern Africa. These 'hotspots' contain high concentrations of endemic plant and animal species, but these mainly occur in areas that are most threatened by human activity.

Diverse terrestrial ecosystems in the region include tropical and sub-tropical forests, deserts, savannas, grasslands, mangroves and Mediterranean shrublands (refer to map of ecoregions and biomes in Figure 7.1). The patterns of the main vegetation types reflect the primary climate zones of the region, where the highest volume of biomass occurs in the high rainfall areas and biomes are generally defined by climate. The main ecosystems (or biomes[16]) provide crucial ecosystem services such as soil production, water flow regulation, pollination, and natural fodder for dryland livestock grazing. For example, it is estimated that forests in sub-Saharan Africa account for 25% of the total global carbon stocks, with the Democratic Republic of Congo accounting for 9.8% (Saatchi et al., 2011).

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[16] A 'biome' is the highest level of ecosystem classification. This chapter has considered the biome concept to include the humans and their activities within the biome area.

Protected areas have been expanded in number and extent, with the number of formally protected areas (refer to map of protected areas in Figure 7.1) over the region steadily increasing from 8.6% in 1990, 9.4% in 2006 and 14.7% in 2014 (Juffe-Bignoli et al., 2014). All of the 15 SADC member states have National Biodiversity Strategies and Action Plans (refer to Box 1 on guiding strategies and conventions relevant to terrestrial ecosystems) and have a legal responsibility to conserve land according to commitments under the Convention on Biological Diversity. Terrestrial ecosystems are however still under threat from a range of drivers including climate change, land-use change (including deforestation and urbanisation), land and soil degradation, poaching, and invasions by alien species (refer to conservation status in Figure 7.1).

Climate change is likely to lead to significant changes across the biomes and the ecosystems services they provide through the alteration of existing habitats, seasonal rainfall, species distribution, and ecosystems. Climate change will also lead to changes in species distribution through shifting habitat, changing life cycles, and development of new physical traits[17]. The vulnerability of the terrestrial ecosystems of southern Africa to climate change is assessed in this chapter as well as the adaptation priorities required to build the resilience of the ecosystems.

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[17] This refers to species adapting to changing conditions through ‘plasticity’, which is the ability of organisms to respond to climate change, such as changes in temperature, without any genetic changes.

Case study: The Maloti-Drakensberg Park

The Maloti-Drakensberg Park is a transboundary conservation area composed of the uKhahlamba Drakensberg Park in South Africa and the Sehlabathebe National Park in Lesotho, and has been awarded World Heritage status by UNESCO. In total it is 242 813 ha in extent, extending 150 km along the uKhahlamba Drakensberg mountain range. In addition to its scenic beauty, the park’s diversity of habitats protects 250 endemic plants and threatened flora, including the endangered bearded vulture (*Gypaetus barbatus*), Cape vulture (*Gyps coprotheres*) and critically endangered Maloti minnow (*Pseudobarbus quathlambae*).

Given how wide the park’s altitudinal gradient is, it potentially forms a critical migratory pathway for grassland species to adapt to climate change. It is by far the largest block of conserved grassland in a biome that is both poorly conserved and under extreme threat from both climate change and land transformation to agriculture, mining and settlement.

Box 7.1: International conventions and regional strategies relevant to the protection of terrestrial ecosystems and biodiversity

SADC member states have ratified a number of international conventions that aim to facilitate the conservation of biodiversity:

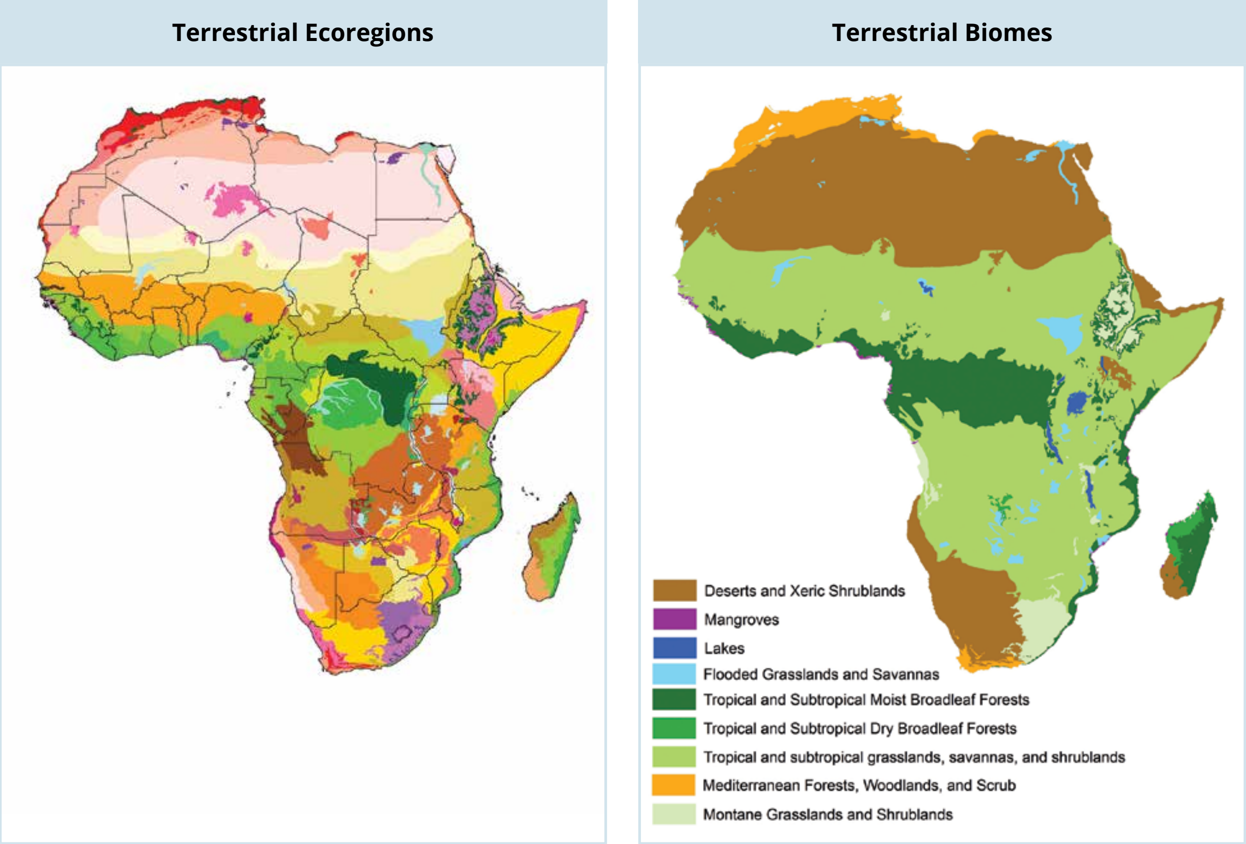
- Convention on Biological Diversity (CBD)
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)
- Convention on Migratory Species of Wild Animals (CMS)
- Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar)
- Convention concerning the Protection of the World Cultural and Natural Heritage (WHC)
- Convention to Combat Desertification (CCD)

At the regional level, the **Regional Biodiversity Action Plan** (SADC, 2006) provides a framework to ensure a coordinated response to the management of biodiversity. The strategy provides guidelines to build capacity in implementing the provisions of the CBD and aims to act as a mechanism for the cooperation and establishment of partnerships between nations on transboundary biodiversity issues.

The establishment of **transfrontier/transboundary conservation areas** aims to connect protected areas across national boundaries and is considered more effective than local or national management because environmental problems are not limited to national boundaries. Creating connections between protected areas at the transboundary scale is seen as a vital conservation tool to increase the effectiveness of conservation areas. In addition, these areas maintain the continuity of natural disturbance regimes and ecosystem services and allow for the natural range shifts in response to long-term environmental change. In SADC, there are five Type A (Established), six Type B (Emerging) and seven Type C (Conceptual) Transfrontier Conservation Areas (SADC, 2013).

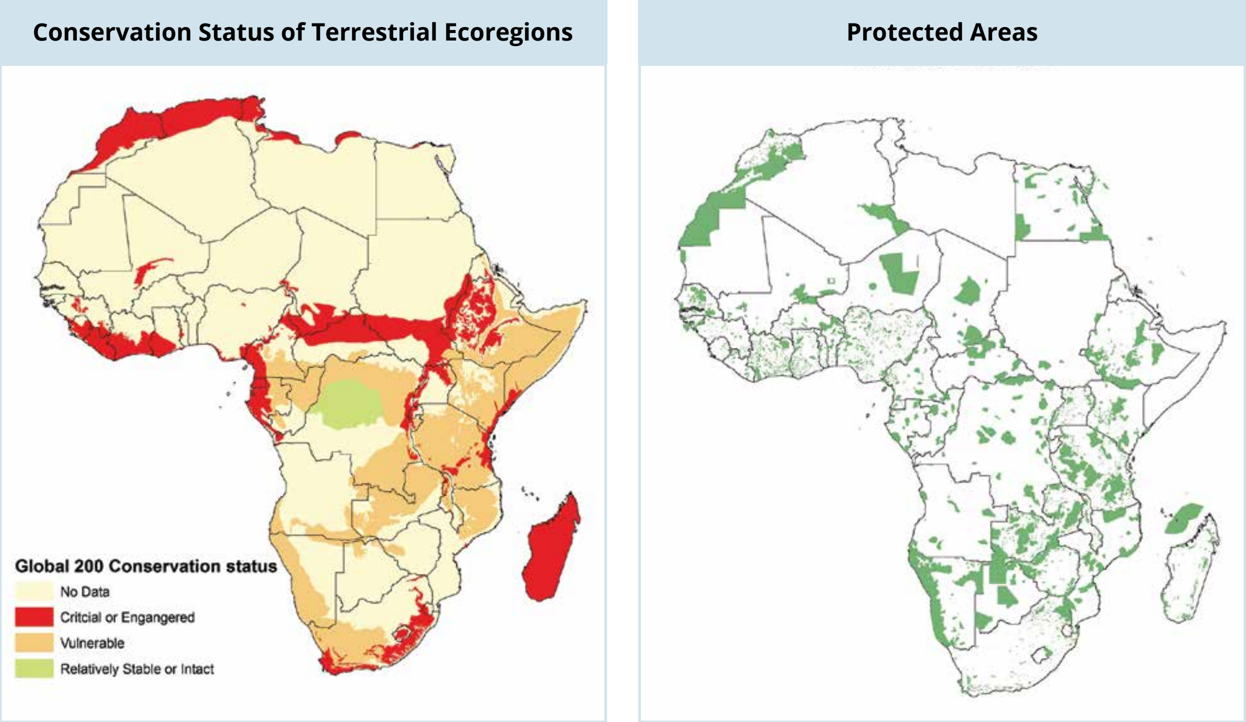
SADC Protocol on Wildlife Conservation and Law Enforcement aims to ensure that each member state facilitates community-based natural resource management (CBNRM) practices in wildlife management and wildlife law enforcement. The protocol calls for economic and social incentives for the conservation and sustainable use of wildlife (SADC, 1999).

SADC Protocol on Shared Watercourses aims to foster closer cooperation for judicious, sustainable and coordinated management, protection and utilisation of shared watercourses and regional integration and poverty alleviation (SADC, 2000).



Terrestrial Ecoregions

Terrestrial Biomes



Conservation Status of Terrestrial Ecoregions

Protected Areas

Figure 7.1: Map of the (i) terrestrial ecoregions, (ii) biomes, (iii) conservation status (Source: Olson & Dinerstein, 2002), and (iv) protected areas (IUCN and UNEP-WCMC, 2016). Ecoregions vary in their ecosystem characteristics and flora and fauna composition as well as their conservation status. The conservation status is an estimate of the current and future ability of the ecoregion to sustain ecological viability and to react to environmental change. It is based on total habitat loss, habitat fragmentation, degree of degradation, degree of protection needed, degree of urgency for conservation needs, and types of conservation practiced or required.

7.2. Non-climatic drivers of ecosystem change

7.2.1. Land-use change, habitat loss and fragmentation

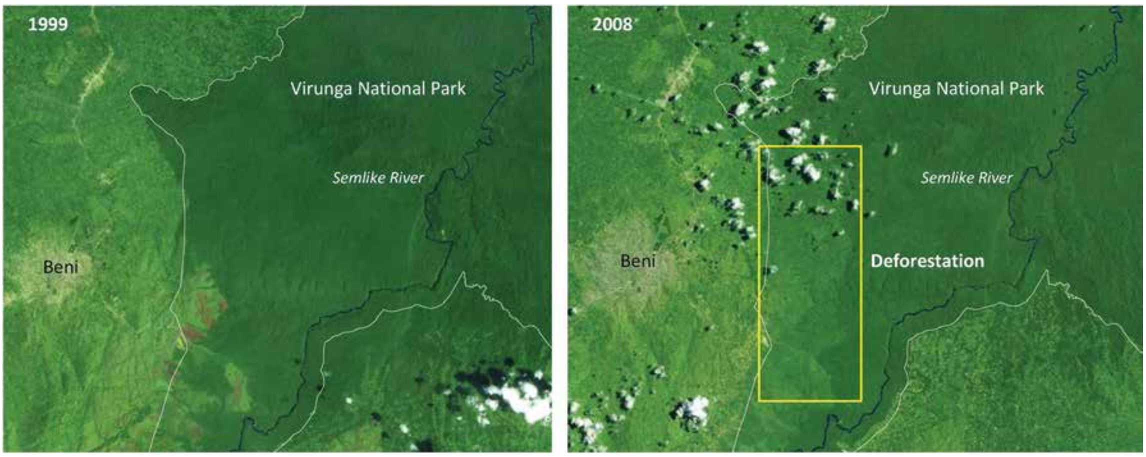
Land-use change and landscape fragmentation are important drivers of ecosystem change and the loss of biodiversity. Land-use change refers to the anthropogenic replacement of one land-use type by another, for example the conversion of natural grasslands or forests to agricultural crops, harvesting of forest resources for fuelwood, as well as shifts in the management practices of the land, for example the intensification of livestock grazing. Agriculture is seen to be the leading form of land-use change in Africa – between 1990 and 2010 African countries reported that 75 million hectares of forest land (10% of the total forest area) was converted to other land uses (FAO, 2012).

7.2.2. Invasive alien species

Invasive alien species are considered to be a major threat to the endemic biodiversity of southern Africa and affect most ecosystems. They refer to species of flora and fauna that have been introduced to an area outside of their natural origin where they are able to establish and expand their range. Declines in native species have occurred concurrently with the introduction of non-native species and it is widely accepted that invasive species are significantly altering communities and ecosystems and ultimately resulting

Case study: Forest cover loss in the Democratic Republic of Congo

The tropical humid forests of central Africa comprise the second largest continuous tropical forest in the world and about half of these are located in the Democratic Republic of Congo (DRC). Although rate and extent deforestation in the DRC is considered to be moderate compared with other countries such as Brazil and Indonesia, a study utilising Landsat Enhanced Thematic Mapper Plus (ETM+) has shown that forest cover loss is increasing (Potapov et al., 2012). Between 2000 and 2010, an estimated 2.3% of the total forest area was lost, with the greatest loss occurring between 2005 and 2010. Of particular concern is the Virunga National Park, which has the highest rate of forest loss compared with other protected areas in the DRC. The deforestation has been attributed to clearing of land for cattle grazing and agriculture and, to a lesser extent, to unregulated logging and mining. The population density in the area surrounding the national park is one of the highest in the region at 600 individuals per km².



Landsat 5 satellite images from February 13, 1999 (left) and September 1, 2008 (right) showing deforestation along the western border of the Virunga National Park (obtained from http://earthobservatory.nasa.gov/IOTD/view.php?id=79276) in the extinction of native species (Gurevitch & Padilla, 2004). Other drivers of ecosystem change, such as land-use change, act synergistically with the negative impacts of alien species on indigenous communities. To date, there is no comprehensive and coordinated regional strategy on the prevention, eradication and control of invasive species (SADC, 2006). Some countries, such as South Africa, have regulations and supporting programmes (Working for Water) that are dedicated to the prevention, control and mitigation of the spread and impact of invasive plant species.

7.3. Vulnerability to climate change

Changes in rainfall, temperature and carbon dioxide are likely to drive changes in the distribution, condition and functioning of the terrestrial ecosystems of southern Africa as well as alterations in plant phenology, increased wildfire, and exacerbated pest outbreaks (Gonzalez, 2010; Field et al., 2014). Dynamic Global Vegetation Models (DGVMs) project a variety of biome shifts (Figure 7.2), (Scheiter & Higgins, 2009; Higgins & Scheiter, 2012). An increase in woody vegetation is expected over much of southern Africa, which is supported by numerous observation studies in the region (Bond & Midgley, 2000; Wigley et al., 2009; Ward et al., 2012; Mitchard & Flintrop, 2013). Improvements in the representation of disturbance processes, such as fire and grazing, will assist in reducing the uncertainties associated with model projections.

In terms of individual species response, climate change is likely to alter the boundary of limits where species are able to survive, impacting the growth, survival and distribution of the species. There is evidence, mostly in the northern Hemisphere, that many species have already shifted their geographical ranges, seasonal activities and migrational patterns in response to changes in temperature. In a study of 329 plant and animal species, 84% had shown a poleward and altitudinal shift in their ranges (Hickling et al., 2006). In southern Africa, temperature is not the only factor limiting species range. Water availability, fire and grazing are equally important in shaping the ranges of species. As a result, a multiple stressor approach is essential for understanding the risks of climate change to terrestrial ecosystems. Taking this approach, Table 7.1 attempts to identify the most important ecosystem services and the most significant potential climate change risks for each of the nine primary biomes of southern Africa.

Table 7.1: Ecosystem services and climate risks for each of the main biomes of southern Africa

Biome	Ecosystem Services	Climate risk
Grassland	• Major area for crops, especially maize and forestry plantations • Major catchment areas for water provision • Provision of medicinal plants • Important for cattle (both beef and dairy) and sheep • Irrigated horticulture • Carbon storage – especially as soil carbon	• Increased temperature and CO_2 will result in invasion of savanna-like condition and major shrinkage of the spatial area of the biome • Increased fire intensity and likely mega fires • Increased temperature may limit livestock, and in particular dairy cattle • More intense rainfall, especially if coupled with overgrazing, will intensify erosion
Savanna	• Nature-based tourism • Livestock production, especially beef cattle farming • Carbon storage • Fuelwood, timber	• Extremely high temperatures will make domestic livestock farming challenging and may lead to a sudden switch to other nature-based ventures • Increased rainfall and rising CO_2 will lead to an increase in bush encroachment and expansion of the savanna into grasslands and other biomes • Rising CO_2 levels will lead to a high risk of alien woody plant invasion, particularly in highly degraded areas
Forests	• Nature-based tourism • Biodiversity • Fuelwood, timber, traditional medicines • Carbon storage • Water resources	• Extreme high temperatures may increase destructive fires • Drought/heat-intolerant Afrotemperate forests most at risk from increased frequency of drought and increased temperatures • All forest types vulnerable to decreasing rainfall, with swamp forest systems being vulnerable to changes in groundwater recharge
Mediterranean: Fynbos	• Water flow and water quality regulation • Soil stabilisation • Nature-based tourism, non-consumptive use • Production of wildflowers, herbal and medicinal products and for the horticultural trade • Biodiversity resources	• Increased intensity and frequency of fires and more “out-of-season” fires • Alien invasive species, especially grasses in lowland ecosystems • Habitat transformation/fragmentation, particularly on the lowlands through agriculture and urbanisation
Deserts	• Ecotourism, including a range of wildlife management operations • Commercial and emerging agriculture, large and small stock • Niche agriculture (e.g. organic, small-scale agriculture)	• Extreme high temperatures will place constraints on livestock productivity • High temperatures coupled with certain rainfall thresholds linked to increased pests and pathogens in particular areas • Higher temperatures could result in the range contraction of succulent plant species • Reduced rainfall and increased drought frequency could result in a reduction in forage quality and quantity • More intense rainfall will cause soil capping, flash flooding, erosion and poor recharge
Mangroves	• Coastal erosion protection and storm buffering • Groundwater recharge • Breeding, spawning and nursery habitat for fish species • Cultural services (e.g. recreation, aesthetic)	• Saltwater intrusion and increased sedimentation as a result of sea-level rise • Increased storm surges and coastal storms will cause erosion • Decreased rainfall and increased evaporation will increase salinity, resulting a decline in the productivity of mangroves

7.4. Response measures

The primary focus of adaptation in the biodiversity sector has been on conservation strategies, biodiversity planning, community-based natural resource management and, more recently, ecosystem-based adaptation. It has been argued that traditional conservation strategies that focus on, for example, increasing connectivity between patches of protected land, although invaluable, are likely to be insufficient to curb the impacts of climate change and more strategic approaches are required (Gillson et al., 2013). Evidence-based information at the local scale on the impacts of climate change is essential to guide land-use management and policy decisions.

The challenge is to develop adaptation options that are sensitive to the spatial heterogeneity of local social and environmental conditions and that account for major environmental and climatic feedbacks. Adaptation options should thus seek multiple benefits, which include achieving synergies between biodiversity/ecosystem conservation, sustainable livelihoods, and co-benefits for other sectors such as agriculture and health (Davis et al., 2015). Considering these guidelines, Table 7.2 provides a list of the potential adaptation responses to climate change.

7.4.1. Ecosystem-based adaptation (EbA)

Ecosystem-based adaptation (EbA) is defined by the Convention on Biological Diversity (2009) as the "use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change". EbA uses well-functioning natural systems to buffer human systems from the adverse impacts of climate change and to build resilience and adaptive capacity. EbA is implemented through the protection and restoration of ecosystem services and the sustainable management of natural resources (Field et al., 2014). EbA is considered from a range of angles, including recommendations for actions around protection of movement corridors, adjustment of burning regimes, clearing of alien vegetation and restoration of degraded areas. The best practices that must be undertaken in ecosystem-based adaptation that are critical in guiding adaptation planning are detailed in Midgley et al. (2012); and include, for example, the involvement of key stakeholders in planning and implementation, and the development of monitoring and evaluation frameworks.

Table 7.2: Potential adaptation options (Davis et al., 2015)

Land-use planning	• Abandon unviable land • Create new, viable land uses • Adjust land-use proportions/locations • Optimise protected area network
Land management	• Adjust stocking rate • Change cultivars/species • Increase irrigation efficiency • Maintain wetlands • Water management
Ecosystem-based adaptation	• Restore degraded land (including afforestation) • Protect movement corridors • Adjust burning regime • Clear alien vegetation • Catchment rehabilitation
Community-based natural resource management	• Payment for ecosystem services • Education, outreach, extension • Incorporation of indigenous knowledge

Case study: The Ankeniheny-Mantadia-Zahamena Corridor Restoration and Conservation Carbon Project

The Ankeniheny-Mantadia-Zahamena Corridor (CAZ) is REDD+ innovative aimed at conserving and restoring the threatened forests of Madagascar as well as enhancing community well-being and reducing carbon emissions (Harvey et al., 2010). The corridor is a newly-designed protected area in the eastern region of Madagascar and covers an area between the Analamazoatra Special Reserve and Andasibe-Mantadia National Park (Lopoukhine et al., 2012). The region is home to over two thousand species of plants, many endemic to the region, as well as a large number of species of mammals, amphibians and birds. CAZ also supports nearly 350 000 people, who depend on subsistence agriculture and cash crop production for their livelihoods.

Portions are zoned into strict protection areas and other areas under the management of the community. Working with Conservation International, a partnership has been set up in the region between NGOs, government organisations (Ministry of Environment and Forests), other donor-funded projects, the private sector, and community associations. Working with multiple stakeholders ensures that the provision of incentives to local communities is driven by local development needs such as health and clean water resources.

Ankeniheny-Mantadia-Zahamena Corridor (Onofri et al., 2017)

7.4.2. Community-based natural resource management (CBNRM)

Community-based natural resource management is an incentive-based strategy for promoting both conservation and local economic development. It is an approach that offers multiple benefits; securing rural livelihoods, ensuring careful conservation and management of biodiversity and other resources, and empowering communities to manage these resources sustainably (Fabricius et al., 2013). In this model, communities are given rights of access to resources and legal entitlements to benefits that accrue from using the resources, such as eco-tourism and conservation-based agricultural programmes (SADC, 2006).

CBNRM is a vehicle for improving links between ecosystem services and poverty reduction so that these practices can serve as proactive, low-regret adaptation strategies (Niang et al., 2014). CBNRM programmes in many countries in southern Africa are driven and often initiated by a combination of government, non-governmental organisations (NGOs), community-based organisations (CBOs) and, in some cases the private sector (Fabricius et al., 2013). Operationally, CBNRM involves (SADC, 2006):

- The devolution of control and management responsibilities on natural resources from the State to the local people;
- Building the technical, organisational and institutional capacity of local communities to assume management responsibilities over natural resources.

Case study: Sustainable natural resource management in Namibia

The community-based natural resource management programme in Namibia has been ongoing since the passing of the Nature Conservation Act in 1996. By the end of 2013 a total of 79 conservancies covering 19.4% of the country had been registered (Riehl et al., 2015). The three primary goals of the CBNRM programme are natural resource management and conservation, rural development, and empowerment and capacity building. Between 1991 and 2013 the programme contributed approximately US$392 million to Namibia's net national income, generated 6 472 jobs, and contributed to increases in wildlife numbers and ranges, for example the lion populations in the northwest region of the country (Namibia Association of CBNRM Support Organizations, 2013).

Key lessons from the programme so far include the importance of (Brown & Bird, 2011):

- Linking economic incentives with environmental management;
- Establishing a legal framework that allows communities to access economic benefits directly, through better management of wildlife as well as other natural resources on the communal land.

CHAPTER 8:
WATER RESOURCES

AUTHORS: SAMUEL KUSANGAYA, MUNYARADZI D. SHEKEDE AND IDAH MBENGO

The potential wide-ranging impacts of climate change on water resources (availability, accessibility and demand) make a compelling case for the need to strengthen integrated water resource management institutions in the respective SADC countries.

8.1. Introduction

Within the climate change matrix, water resources are at the epicentre of projected climate change impacts. Given the observed large spatial and temporal variability of climatic factors in southern Africa (refer to Chapter 2), climate change impacts on water resources are likely to be more pronounced in the near future than previously foreseen (Field et al., 2014). Climate change impacts on water resources have a direct and indirect effect on the socio-economic and the biophysical environments (Arnell, 1999; Schulze, 2005; Kundzewicz et al., 2008).

The key characteristics of water resources in the SADC region are summarised as follows (Schulze & Perks, 2000; Mazvimavi, 2003; Mkhandi et al., 2005):

- About 70% of the available freshwater resources are from shared water resources.
- Water is unevenly distributed both spatially and temporally, with abundant amounts of water found in the northern and eastern areas, while limited to no water is found in the dry south-western area.
- High flows in the watercourses are observed during the wet season, while low flows are observed during the dry season.
- Surface water sources are sensitive to changes in climatic characteristics, with droughts having a substantial impact on water availability.
- The distribution of water resources is unrelated to population spread and economic development. For example, countries such as Angola, Mozambique and Zambia have low population numbers compared with South Africa, but more abundant water. Furthermore, the economies of Botswana, Namibia and South Africa are more developed than those of Angola, Mozambique and Zambia, but their water resources are less abundant.

Recent studies have shown that southern Africa is currently experiencing moderate to severe water scarcity (Mekonnen & Hoekstra, 2016). In addition, supply and demand pressures as a result of land degradation, pollution and population growth, as well as urban growth, are affecting water resources in the region (McMullen & Jabbour, 2009; UN-DESA, 2011).

It is against this background that climate change has the potential to aggravate the water situation in the region. It is interesting to note that while there is unequivocal evidence that our climate is changing and that these changes are likely to impact water resources in southern Africa, there are few studies that have examined the hydrological responses to climate change in Africa (Niang et al., 2014) and particularly in southern Africa (Manase, 2009). Yet studies examining the sensitivity of the hydrological system are critical for determining the future availability of water resources for planning and management purposes. This chapter reviews the impacts of climate change on water resources as well as the associated adaptation options in southern Africa.

8.2. Key drivers and processes of change within the water resources sector

At the global level, freshwater scarcity has largely been driven by an increasing world population, improving living standards, changing consumption patterns, and expansion of irrigated agriculture (Nicol & Kaur, 2009). The main cause for increasing water stress will be growing water demand as a consequence of the increasing population and improving economic conditions, rather than decreasing availability of water (Aerts & Droogers, 2009; Kaur et al., 2010). A number of drivers are already changing the patterns of water demand and supply. These include increases in global carbon dioxide concentrations, population growth, land-use change, economic growth and technological developments (Kaur et al., 2010). In addition, the low economic and technological development of the region affects the development of relevant water infrastructure such as big dams, canals and efficient irrigation systems (SADC, 2012).

8.2.1. Water demand

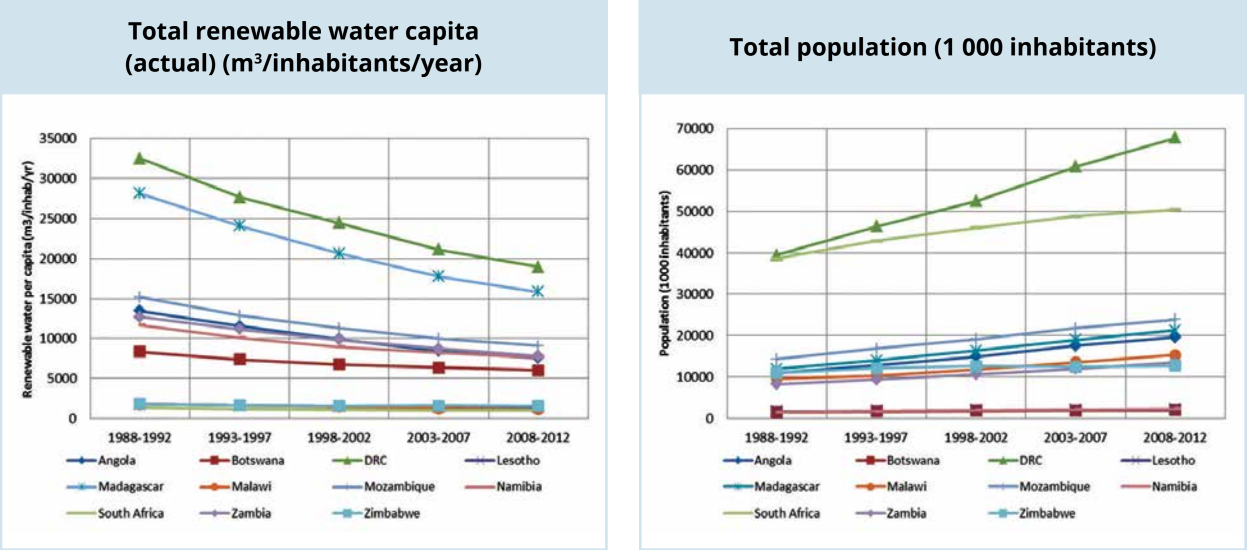
The population of SADC is expected to double from 250 million to approximately 500 million by 2040; in just 25 years (UN-DESA, 2011). In southern Africa, 14 countries are currently experiencing water stress, while 11 countries are expected to enter the water-stress category by 2025 (Rutashobya, 2008). By 2020, an additional 75-250 million people in Africa are projected to be exposed to increased water stress caused by climate change (Field et al., 2014). Water stress is estimated to be high for 25% of Africa's population. In SADC, using the Falkenmark indicator of water stress, it can be observed that Lesotho, Malawi, South Africa and Zimbabwe (Table 8.1 and Figure 8.1) are already water stressed.

Mazvimavi (2010) used the projected population for 2010 to 2050 to indicate that Tanzania will fall within the moderate water-stress category by 2020 without climate change. In addition, the study indicated that Malawi, South Africa, Tanzania and Zimbabwe will be in the high-stress category by the year 2050 even without climate change. Climate change will therefore increase pressure on water resources which are already stressed.

Table 8.1: The Falkenmark Index showing water stress in SADC countries

	SADC water resources: Total renewable water per capita (actual) (m³/inhab/yr)					Falkenmark indicator (measure of water stress) (Falkenmark, 1989)				
	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
Angola	13 451	11 570	9 940	8 445	7 544	No Stress	No Stress	No Stress	No Stress	No Stress
Botswana	8 355	7 369	6 770	6 349	6 027	No Stress	No Stress	No Stress	No Stress	No Stress
DRC	32 527	27 669	24 442	21 112	18 935	No Stress	No Stress	No Stress	No Stress	No Stress
Madagascar	28 142	24 102	20 625	17 756	15 810	No Stress	No Stress	No Stress	No Stress	No Stress
Mozambique	15 163	12 875	11 307	9 954	9 072	No Stress	No Stress	No Stress	No Stress	No Stress
Namibia	11 712	10 114	8 981	8 208	7 625	No Stress	No Stress	No Stress	No Stress	No Stress
Swaziland	4 967	4 479	4 164	3 981	3 749	No Stress	No Stress	No Stress	No Stress	No Stress
Zambia	12 718	11 170	9 838	8 727	7 807	No Stress	No Stress	No Stress	No Stress	No Stress
Lesotho	1 779	1 620	1 503	1 435	1 377	No Stress	Stress	Stress	Stress	Stress
Malawi	1 785	1 675	1 460	1 272	1 123	No Stress	Stress	Stress	Stress	Stress
South Africa	1 330	1 199	1 117	1 052	1 019	Stress	Stress	Stress	Stress	Stress
Zimbabwe	1 817	1 655	1 586	1 602	1 568	No Stress	Stress	Stress	Stress	Stress

Falkenmark (1989): Index (m3 per capita) [Condition]): (a) >1,700 [No Stress]; (b) 1,000-1,700 [Stress]; (c) 500-1,000 [Scarcity]; (d) <500 [Absolute Scarcity] Data source: FAO, 2012. AQUASTAT database – [accessed 19/11/2012], www.fao.org/nr/water/aquastat/data/query/index.html?lang=en



Total renewable water capita (actual) (m³/inhabitants/year)

Total population (1 000 inhabitants)

Figure 8.1: Total renewable water and respective population changes for SADC[6].

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18 Data source: FAO, 2012. AQUASTAT database – http://www.fao.org/nr/water/aquastat/data/: accessed 19/11/2012

8.2.2. Land-use change

Land-use change in southern Africa is likely to affect water resources in two main ways: (a) increased urbanisation and, (b) agricultural intensification, especially increase in irrigated land. Nicol and Kaur (2009) project an increase in irrigation demand by 0.4% to 0.6% a year up to 2030 and 2080 respectively, without climate change. When climate change is factored in, the projected irrigation demand will lead to an increase of between 5-20% by 2080. Consequently, increased water use on agricultural lands through irrigation will reduce the availability of blue water resources (surface and groundwater), especially for downstream water users and aquatic systems (Falkenmark et al., 2007).

On the other hand, water demand is likely to increase as a result of changes in human settlements, particularly urbanisation. The proportion of people living in urban areas increased from around 16% in 1960 to 49% by 1990 and 61% by 2014, and is projected to reach 74% by 2050 (UN-DESA, 2014). The fastest urbanising countries are Botswana, Mozambique and Tanzania. Although the urban population in sub-Saharan Africa has doubled since 1990, access to water resources has remained constant at 17% for drinking and 57% for sanitation (UN, 2012). The rapid urbanisation in sub-Saharan Africa is making it difficult for urban authorities to provide adequate infrastructure and services, principally water and sanitation. There is a need to increase investment in water and sanitation infrastructure to cater for the increased water scarcity in view of increased urbanisation and climate change.

8.3. Vulnerability of the water resources sector to climate change

Countries in the SADC region are prone to climate change impacts on water resources on account of several factors, including their geographical location, low incomes, low technological and institutional capacity to adapt to rapid changes, as well as their greater reliance on climate-sensitive sectors such as agriculture that is predominantly rain-fed (refer to Chapter 5 on the Agriculture and Livestock sector).

Most assessments of climate change impacts have been primarily undertaken at macro and regional scales, masking the complex hydrological interactions at the local, catchment scale (Schulze, 2000). Reported streamflow responses to climate change are varied, both spatially and temporally. Although most studies have been confined to modelling hydrological responses to climate only, land use and land cover play a significant role in controlling hydrological responses (Warburton et al., 2012). Additionally, streamflow is influenced not only by climate, but by other human activities such as catchment land-use changes, inter-basin water transfers, water abstractions, return flows or reservoir construction (Warburton & Schulze, 2005). Despite the above challenges, several scholars have studied the hydrological responses to climate change in the SADC region using mostly rainfall-runoff hydrological models. Rainfall-runoff models are invaluable tools in simulating information for use in making decisions for water resources planning and management, including evaluating impacts of climate change on water resources (Schulze, 2005).

Box 8.1: Data gaps as a limit to hydrological modelling

One of the biggest challenges to water resources planning and management in southern Africa is the “un”-availability of good quality data for water resources assessment. This has been aggravated by the fact that hydro-meteorological data collection and analysis are not keeping pace with actual water development and management needs (Kundzewicz et al., 2008), despite the increasing demand for water. Dube (2006) also cited constraints in funding for data collection and maintenance of hydro-meteorological services as extra restraints to water resources planning and management. As a response to the above limitations, rainfall-runoff models are invaluable tools in simulating information for use in decision-making for water resources planning and management (Schulze, 2005), including impacts of climate change. However, it has to be noted that rainfall-runoff models are a simple representation of reality, which makes their results uncertain (Schulze, 2005; Saunyama, 2008). Despite the above limitations, rainfall-runoff modelling, under the current conditions, offers the only hope in the evaluation of potential impacts of climate change to water resources. What might be required, however, is a framework not only for incorporating climate change into the current modelling scenarios, but also a framework for incorporating the respective uncertainty in model outputs.

8.3.1. *Water availability*

The 'average' river runoff and water availability are projected to decrease by 10 to 30 percent in the dry tropics (Table S1). Arnell (1999) forecasts a reduction in runoff of 26 to 40 percent in the Zambezi river system as a result of reduced rainfall and increased evaporation. Evaporative increases of 40 percent, for example, could result in reduced outflows from reservoirs. Lake Malawi, for example, has been reported to have no outflow for more than a decade in the earlier part of the 20th century (Calder et al., 1995). Moreover, the projected increased frequency of droughts will most likely increase the frequency of low-storage episodes (Field et al., 2014), which will inevitably affect future hydro-power generation from such dams as the Kariba and Cahora Bassa.

8.3.2. *Water quality*

Currently, a large part of the SADC region's population still lacks access to clean and safe water. Climate change adds pressure to existing threats facing freshwater resources and water management systems (SADC, 2012). Surface water is expected to decrease in areas of projected decreases in rainfall and increased evaporation from the ground. This will leave the soils more salty, limiting plant growth (Gordon et al., 2013). The eastern regions are likely to be affected by sea-water intrusion caused by reduced runoff and rising sea levels. Sea-level rise will cause increasing salinisation of groundwater and estuaries, leaving less freshwater for humans, agriculture and ecosystems.

8.4. Response measures

Benioff et al. (2012) identified several adaptation strategies that can be implemented in the face of climate change. For southern Africa, these include (a) river-basin planning and coordination, (b) contingency planning for droughts, (c) contingency planning for floods, (d) making changes in the construction of infrastructure, (e) using inter-basin water transfers, (f) maintaining options to develop new dam sites, (g) water conservation, (h) allocating water supplies by using market-based systems, and (i) pollution control. The following sections detail how these adaptation strategies have been implemented in southern Africa.

Box 8.2: Climate Change Adaptation (CCA) Strategy for the water sector

The main goal of the strategy is to lessen the impacts of climate change through adaptive water resources development and management in the southern African region. SADC intends to achieve this goal through the development of all aspects of the water sector as a means for decreasing climate vulnerability and ensuring that water management practices cope with increased climate variability. An Integrated Water Resources Management (IWRM) approach is important here as it offers a goal-oriented system of controlling use of water as a means of slowing the effects of climate change in the region.

Case study: The Pangani River Basin Management Project in Tanzania

Climate change is expected to exacerbate water scarcity in the Pangani River Basin in Tanzania, where water demand is already exceeding supply. Reduced basin flows have already been observed. In the basin 80% of people are dependent on agricultural livelihoods and the water scarcity is leading to tension between water users (farmers, hydropower, fishers, and residents).

In response, the Pangani River Basin Management Project was initiated in order to reduce conflict and prepare users and managers for future reductions in water availability. Key activities included:

- Environmental flow assessment (EFA)
- Multi-stakeholder consultation and legal reviews
- Establishing catchment forums
- Climate change vulnerability assessments
- Implementation of climate adaptation strategies
- Integrated water resources management planning

"Water is at the centre of many climate change impacts, and is therefore key to many adaptation policies, planning and action. The allocation of water to sustain natural infrastructure, such as wetlands and estuary habitats, and the adoption of adaptive governance build adaptive capacity to respond to an uncertain future climate."

Source: The Water and Nature Initiative:
www.iucn.org/about/work/programmes/water
www.panganibasin.com/project/index.htm

River-basin planning and coordination

River basins in southern Africa play a prominent role in regional cooperation to alleviate the pressure of water scarcity induced by climate change (refer to the SADC Protocol on Shared Watercourses detailed in Box 7.1). These basins therefore represent some of the best test cases for the practical application of the science associated with managing the water resources of southern Africa.

Apart from the shared river basins, six southern African countries also share nine aquifer systems. The groundwater system constitutes an important element that is being taken into the transboundary water management in the region (Turton et al., 2006).

Groundwater resources form the foundation of rural water supplies, which sustain livelihoods for the mostly poor rural communities. While SADC is characterised by a relatively sophisticated set of surface water agreements, it still conspicuously lacks agreements dealing specifically with groundwater. The region needs to map transboundary groundwater resources more accurately; classify such resources in terms of hydrogeological characteristics and future demands; and generate management regimes that are capable of dealing with the problems associated with the resources' specific hydrogeological characteristics (Turton et al., 2006).

Case study: Orange River Basin

To date, successful river basin coordination is exemplified by the Orange River Basin shared between South Africa, Namibia, Botswana and Lesotho. The river system originates in the Highlands of Lesotho formed by the Drakensberg and Maloti mountain ranges and flows in a westerly direction to the Atlantic Ocean. The Orange-Senqu River Basin is the second largest river basin in southern Africa after the Zambezi River and has a catchment area of approximately one million square kilometres (DWA, 2011) and an estimated natural runoff of 12 000 km3 (Jacobs 2012). However, very little of this total runoff reaches the mouth, due to excessive evapotranspiration, construction of large dams, and inter-basin transfer schemes that deliver and divert water to neighbouring river basins (Mare, 2007).

The Orange-Senqu River Commission (ORSECOM) has successfully jointly planned and managed the transboundary Orange River Basin in the different states (Ashton & Turton, 2005; Jacobs, 2012). This has involved development of water-supply infrastructures in Lesotho, the source of Orange River, to diverting water to South Africa's economic nerve – the Pretoria-Witwatersrand-Vereeniging (PWV) triangle. Lesotho benefits from the employment of its nationals in PWV, while Namibia, a downstream country, has assured water supply for its diamond mines, grape farms and domestic use (de Wet et al., 2011). Additionally, benefits also arise through stimulation of tourism growth in the Gemsbok National Park in Botswana and Kalahari Gemsbok National Park in South Africa, which is currently jointly managed as the Kgalagadi Transfrontier National Park. Kranz et al. (2010) attributed the successful transboundary water management to flexibility mechanisms embedded in the various treaties that allow managing institutions to adjust advice and adapt accordingly as basin states need changes over time.

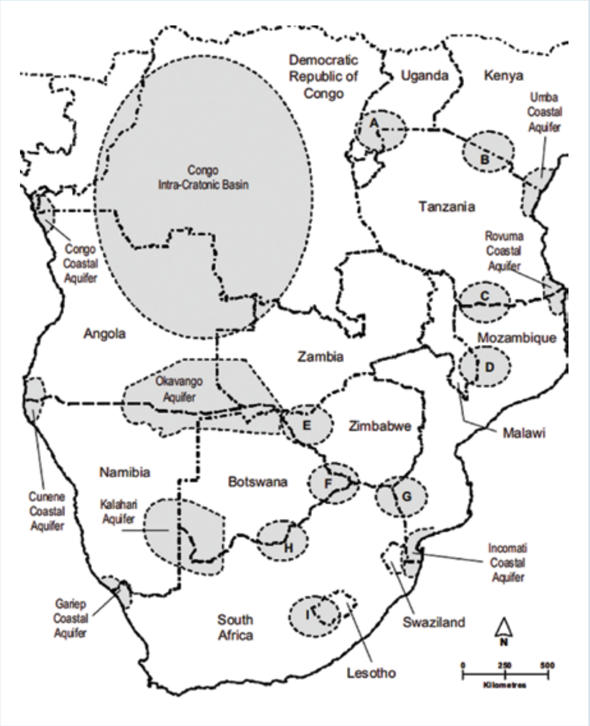

Figure 8.2: Location of major aquifer systems in southern Africa (Source: Ashton & Turton, 2009)

Contingency planning for droughts and floods

Coordinated regional contingency planning for droughts and floods requires action plans to manage the drought or flood event and coordinate emergency assistance. In southern Africa, contingency planning has mainly been characterised by governments and international donors (Dilley, 2000; Wilhite, 2000). However, in most cases, NGOs working at lower administrative scales tend to develop their own plans, which, as a rule, are rarely informed by the national plans. The ideal situation is that lower-level contingency plans should dovetail with national plans providing the guiding framework. The other major handicap pertains to resource allocation for contingency planning. In most cases financial resources are inadequate not only for preparedness activities, but also for response activities (e.g. procurement of relief materials). Improved monitoring systems and risk mapping are essential in order to cope with impacts.

Making changes in the construction of infrastructure

The SADC Infrastructure Master Plan was conceived with the aim of establishing a strategic framework to guide the development of seamless, cost-effective transboundary infrastructure. The southern Africa Regional Infrastructure Development Master Plan (RIDMP) study revealed that the region faces challenges in the provision of adequate regional infrastructure (SADC, 2012), including for water resources management. Water resources management and planning for southern Africa requires changes in the construction of infrastructure, since the poorly maintained water infrastructure currently results in water losses of between 35-50%, with an estimated annual cost of US$ one billion (PwC, 2014). Furthermore, the PwC 2014 survey revealed that African infrastructure lags behind the rest of the world, manifested by 30% dilapidated condition, with massive service backlogs across all infrastructure in almost every country, and with losses impacting on financial viability and water security. In response, the SADC Water Chapter identified 34 water infrastructure projects that could be implemented between 2013 and 2021.

The infrastructural development would increase the area under irrigation from 3.4 to 10 million hectares (13% of the potential), thus mitigating the food shortages resulting from droughts (SADC, 2012). Schulze and Perks (2000), however cautioned that once infrastructure is developed there should be marginal increases in the size of dams and changes in the construction of canals, pipelines, pumping plants and storm drains, all of which entail increased financial resource requirements, which southern Africa does not have. Notably, the PwC (2014) report indicated a financial gap between mega infrastructural developments and the need to motivate and unlock the funding process. Identified challenges included access to funding, project bankability, regulatory and legal uncertainties, political risk/interference, corruption and critical skills shortages.

Use of inter-basin water transfers

SADC countries share nineteen rivers flowing through or between countries and nine transboundary basins. Inter-basin water transfer (IBT) presents a viable option for river-basin manipulation to solve water distribution within southern Africa. IBTs in southern Africa are increasingly being used to reconcile the problems of water distribution within the region. Examples of successful IBT implementation for southern Africa include transfer from the Tugela River in KwaZulu-Natal to the Vaal River (a tributary of the Orange River) (Snaddon et al., 1998; Muller, 2002) and the Lesotho Highlands Water Project transferring water to the Vaal River, which, in turn, supplies water to the South African industrial centre of Gauteng (Hitchcock et al., 2006; Haas et al., 2010).

Maintaining options to develop new dam sites

According to the SADC Regional Infrastructure Development Master Plan, the argument for southern Africa is that the region retains only 14% of available renewable water resources, of which 10% is held in the Kariba and Cahora lakes on the Zambezi River. The remaining 86% of the renewable water resources flow to the sea (SADC, 2012). Across the SADC region there are sufficient water resources to justify more dams. To date, up to 34 water infrastructure projects have been identified as ready for immediate implementation between 2013 and 2021, with a potential to increase (a) annual renewable water resources storage from 14% to 25%; (b) the area under irrigation from 3.4 million hectares to 10 million hectares; (c) hydropower generation from 12 GW to 75 GW; (d) access to water supply from 61% to 75% of the population; and (e) access to sanitation services from 39% to 75% of the population (SADC, 2012). Dams have negative effects on the environment and on flora and fauna near the dams, however, including direct impacts on the biological, chemical and physical properties of rivers and riparian environments. Additionally, the construction of dams and associated pipelines requires substantial preplanning, engineering and funding. These limitations still constitute the major bottlenecks to the development of new dams in the SADC region.

Water conservation

Due to Africa's dependence on agriculture, climate change adaptation options through water conservation have mainly been targeted at reducing the impacts of agricultural droughts. These have been aimed at boosting water conservation, water harvesting, irrigation and soil conservation (Gandure et al., 2013; Bulcock et al., 2013).

Overall, the major constraints to adaptation include water distribution problems, labour shortage, water-logging during periods of high rainfall and risk of injury to people and livestock as a result of some of the water conservation technologies (e.g. in rainwater harvesting) (Mutekwa & Kusangaya, 2006). Although progress has been made, there are still gaps in knowledge, particularly with regard to effective water conservation adaptation and mitigation measures. Knowledge of the costs and benefits of adaptation is still not only scarce, but also unsystematic and unevenly distributed across sectors and countries. It is also still problematic to reconcile the bottom-up nature of adaptation with the top-down strategic nature of policy-making on adaptation.

Allocating water supplies by using market-based systems

Investment in the development of new water sources as well as the need for efficient, equitable and sustainable management of water resources is required. As a response, several studies have advocated for water to be treated and allocated as an economic good (Hearne & Easter, 1995; World Bank, 2005). Likewise, most policy papers in southern Africa recognise the need for economic instruments and market mechanisms for the efficient utilisation and allocation of water (Mukheibir & Sparks, 2003).

The provision of water at below true economic cost prices is regarded as the main reason for inefficient water use and allocation (Mukheibir & Sparks, 2003). In response, several southern African countries have embarked on legislative and policy reforms aimed, to a greater extent, at aligning water allocation using market-based systems. For example, Zimbabwe enacted a new water act in 1998, South Africa in 1998, Mozambique in 1991, Swaziland in 1998, Namibia in 2004, and Botswana in 2005. As noted by Hassan et al. (1996), market-based allocation leads to a rapid response to changing conditions, lowers water demand and increases water conservation. Market-based systems thus allow water to be diverted to its most efficient use, are able to respond more rapidly to changing conditions (e.g. climate change), and tend to lower demand. Overall, as market-based systems are more effective in ensuring sustainable and efficient water use, as well as increasing the resilience and efficiency of the water-supply system (Benioff et al., 2012), they represent an effective adaptation measure to climate change.

Pollution control

Efforts at regional level are under way to curb water pollution. The SADC Regional Water Policy of 2005 clearly articulates that water quality management is a significant consideration at regional level. The SADC regional water policy is aimed at, among other things: (a) ensuring harmonisation and upholding of common minimum standards of water quality in shared watercourses; (b) adoption of necessary measures to prevent and control point and non-point pollution of ground and surface waters; (c) non-disposal of exotic pollutants that can affect SADC watercourses; and (d) making environmental assessments mandatory for any development initiatives in the watercourses (SADC, 2005).

CHAPTER 9:
COASTAL ZONE

AUTHORS: CHRISTO RAUTENBACH, ANDRE K. THERON, WARREN JOUBERT AND LARA VAN NIEKERK

Coastal areas of southern Africa are vulnerable to extreme inshore water levels and flooding as a result of sea-level rise (SLR), changes in winds and local wave regime, coastal erosion and under-scoring, as well as a combination of extreme events such as sea storms during high tides plus SLR.

9.1. Introduction

The primary hazards to (physical) southern African coastal infrastructure related to the sea[19] are direct wave impacts, coastal flooding and inundation, and erosion and under-scouring (Theron et al., 2010). Focusing on the abiotic hazards to infrastructure and developments in the coastal zone of southern Africa, one finds that the main metocean drivers are waves, seawater levels, winds (to a lesser extent in most of the region) and currents (in much fewer instances).

The degree to which a specific site is exposed to prevailing ocean swells determines the wave energy impacting on the shoreline. This is largely dependent on the site location, coast configuration, topography and bathymetry. To quantify the hazard or assess the vulnerability to coastal flooding/inundation, direct wave impacts, extreme water levels and wave run-up, it is necessary to determine the maximum point that storm waves can reach (wave run-up), in other words the height to which a wave would run up the beach slope. Primary components of this are the following:

1. Determining extreme offshore wave climate (present and future);
2. Deriving resultant inshore wave conditions;
3. Calculating extreme seawater levels (e.g. components); and
4. Modelling wave run-up levels.

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[19] Note that other abiotic coastal/marine hazards to consider are low-probability hazards such as tsunamis and undersea slope failures. There are also biotic hazards/vulnerability, for example harmful algal blooms and pollution (e.g. oil spills, outfalls, etc.)

Together with a few other coastal parameters (e.g. erosion/accretion, climate change scenarios, etc.), this is a critical step in determining vulnerable coastal locations (a component of integrated coastal management strategy, mainly for safety and to protect property from abiotic physical coastal/marine processes/ impacts). In conjunction with other integrated coastal management considerations (wind sediment transport, public access, environmental criteria, heritage, etc.), this also determines the coastal setback line (as required by the Integrated Coastal Management Act). Adequate information on the inshore wave climate (1 and 2 above) and coastal flooding elevations (3 and 4 above) will have much wider integrated coastal management use (e.g. planning and response), leading to, for example, appropriate coastal adaptation measures (for e.g. protection, resilience and sustainability of goods and services) (Theron et al., 2013).

9.2. Vulnerability to climate change

Shoreline stability or the probability of erosion (and/or under-scouring of structures) is affected by many drivers, processes and activities, some of which are natural and some of which are caused by anthropogenic actions. Most of these variables are listed and typed/classified in the diagram depicted in Figure 9.1.

Understanding the potential risk to both human and natural elements of the coastal zone facilitates the mapping of vulnerable areas. There is therefore a need to determine areas of high risk (or vulnerability) which, in turn, requires prediction of future vulnerability under future climate change scenarios. Studying the hazards associated with coastal processes and dynamics, in particular related to waves and coastal flooding, will aid the planning and low-risk location of new development areas and infrastructure. Such knowledge will also assist in the identification of appropriate climate change adaptation options for existing developments that are assessed to be at risk (refer to Box 9.1).

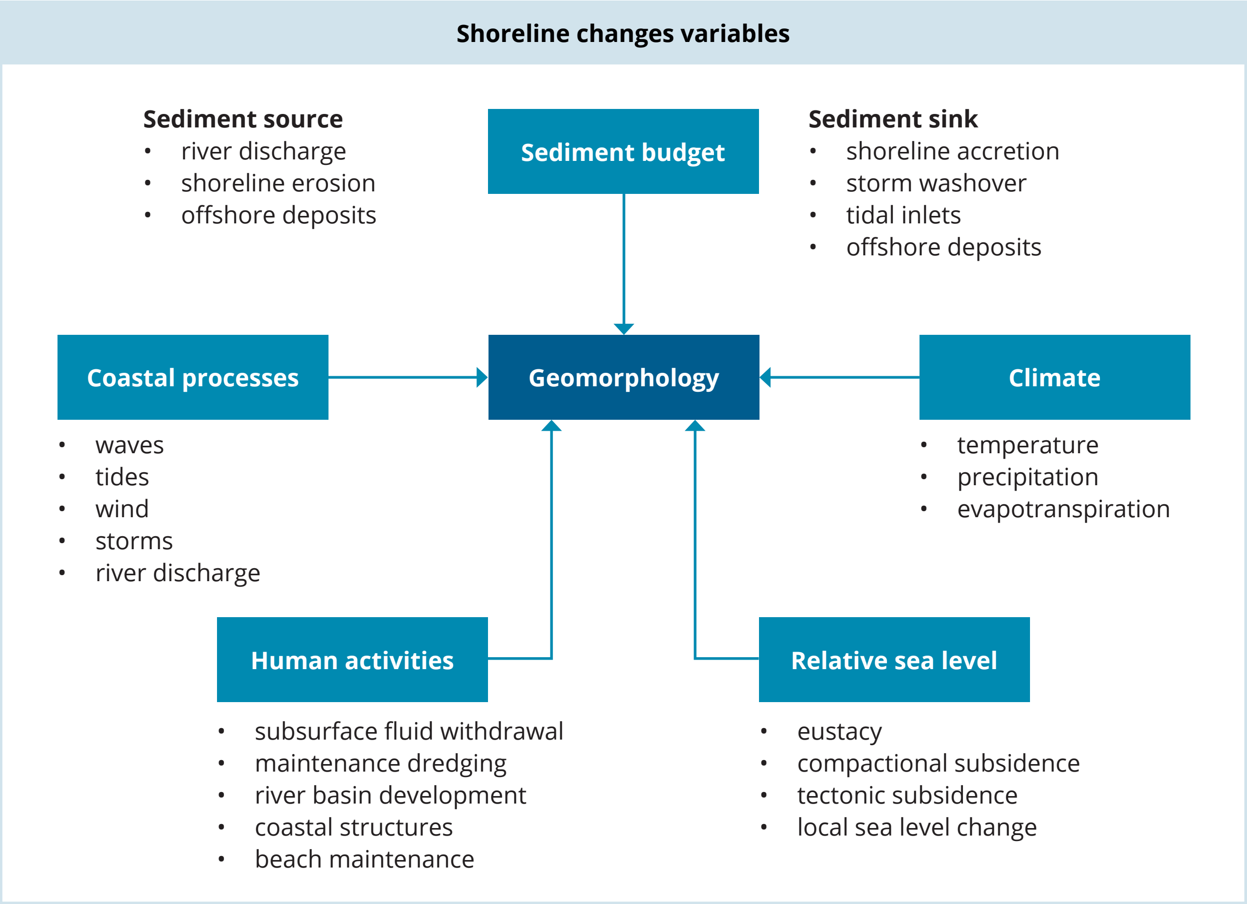


Figure 9.1: Drivers, processes and activities affecting shoreline "stability" or erosion.

9.2.1. Changes in storm tracks, frequencies and intensities

The problem with SLR is not just the vertical change in sea-level, but also its interaction with changing storm intensities and wind fields to produce sea conditions that will progressively overwhelm existing infrastructure. This is a particularly important risk in the case of the highly exposed South African coastline and a subject that has received little attention (Theron, 2007). Even though we are presently unable to reliably estimate changes in storm patterns, windiness and wave energy or direction, the increase in storm activity and severity will probably be the most visible impact and the first to be noticed. For example, higher sea levels will require smaller storm events to overtop existing storm protection measures.

Generally wave climate and conditions are determined by ocean winds (velocity, duration, fetch, occurrence, decay, etc.). The wave climate around the southern African coast shows a clear seasonal pattern and varies in intensity and directionality around the coast. During winter, the wave height increases along the coasts as the frontal systems travel along a more northerly trajectory. During summer, the high-pressure systems along the west coast force the low-pressure systems further south, resulting in a general decrease in wave height along the coast.

Predicted values for potential changes in oceanic wind regimes off southern African are lacking. Figure 9.2 presents the preliminary results of projections of changing wind patterns over southern Africa and surrounding oceans under low mitigation scenarios. The legend can be summarised into zonal or meridional components. For the zonal components, red in the legend refers to the westerly components of the wind (the wind blowing from west to east is becoming stronger).

For the meridional components, the red implies the southern component (that blows from south to north becomes stronger). These figures still have to be distilled into the actual influence of the changing atmospherics on the wave climate around the southern African ocean and then possible predictions of changes in the wave climate can be made. In view of this shortcoming and to enable an assessment of the potential impacts of stronger winds, a relatively modest increase of 10% could be assumed. Thus, a modest 10% increase in wind speed implies a 12% increase in wind stress, a 26% increase in wave height, and as much as an 80% increase in wave power (Theron, 2007). This means that a modest 10% increase in wind speed could also result in a potentially significant increase in coastal sediment transport rates and consequently impact on estuarine mouth regimes. The dynamic processes in the ocean, and especially on the coast, are thus mostly a non-linear system and small changes in the atmospherics could have a drastic effect on our coast.

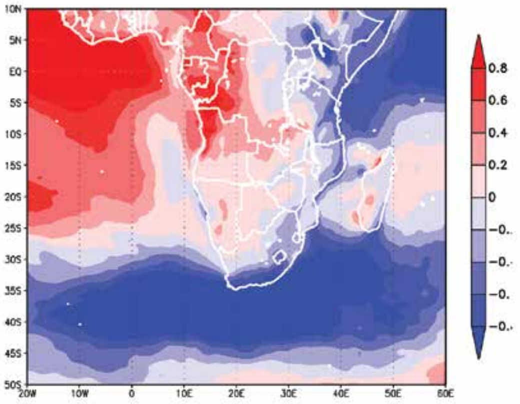


Figure 9.2: CCAM projected changes in the average winter (June-August) zonal wind component over southern Africa for 2071-2100 relative to 1961-1990.

In conclusion, the primary hazards to physical (abiotic) coastal infrastructure related to sea storms (and climate change) are the following:

- Extreme inshore seawater levels resulting in flooding and inundation of low-lying areas;
- Changes in metocean climate (weather systems and winds), waves and local wave regime, resulting in direct wave impacts;
- Coastal erosion and under-scouring of, for example, foundations and structures;
- A combination of extreme events, such as sea storms during high tides plus SLR, will have the greatest impacts and will increasingly overwhelm existing infrastructure as climate change-related factors set in time.

The main metocean drivers related to the above are waves and seawater levels (and, to a lesser extent, winds and currents).

Box 9.1: Mapping the vulnerability of South African coastal cities to SLR

Each coastal city in South African is faced with a variety of vulnerabilities. The table below attempts to illustrate each of the major South African coastal cities' vulnerability to SRL based on its topography. According to the Integrated Coastal Management (ICM) Act, the 100-metre distance from the coastline represents the urban coastline and the 1 000-metre distance represents the rural line. The table below gives the percentage of the population for each of the listed coastal cities with regards to the ICM Act's coastal lines. The population percentages do not reveal any clear threats, but when the topography is taken into account, e.g. through the 20-m contour line, the vulnerability of the various cities becomes clear. Lower-lying cities such as Saldanha and Cape Town are much more threatened by SLR than elevated cities such as East London and Durban. It should be noted that this table only serves as an example of topography-influenced vulnerability to SLR – the true vulnerability of each city has to take into account all the drivers of relative coastal sea-level change and coastline types.

Relative vulnerability of South African coastal cities to SLR

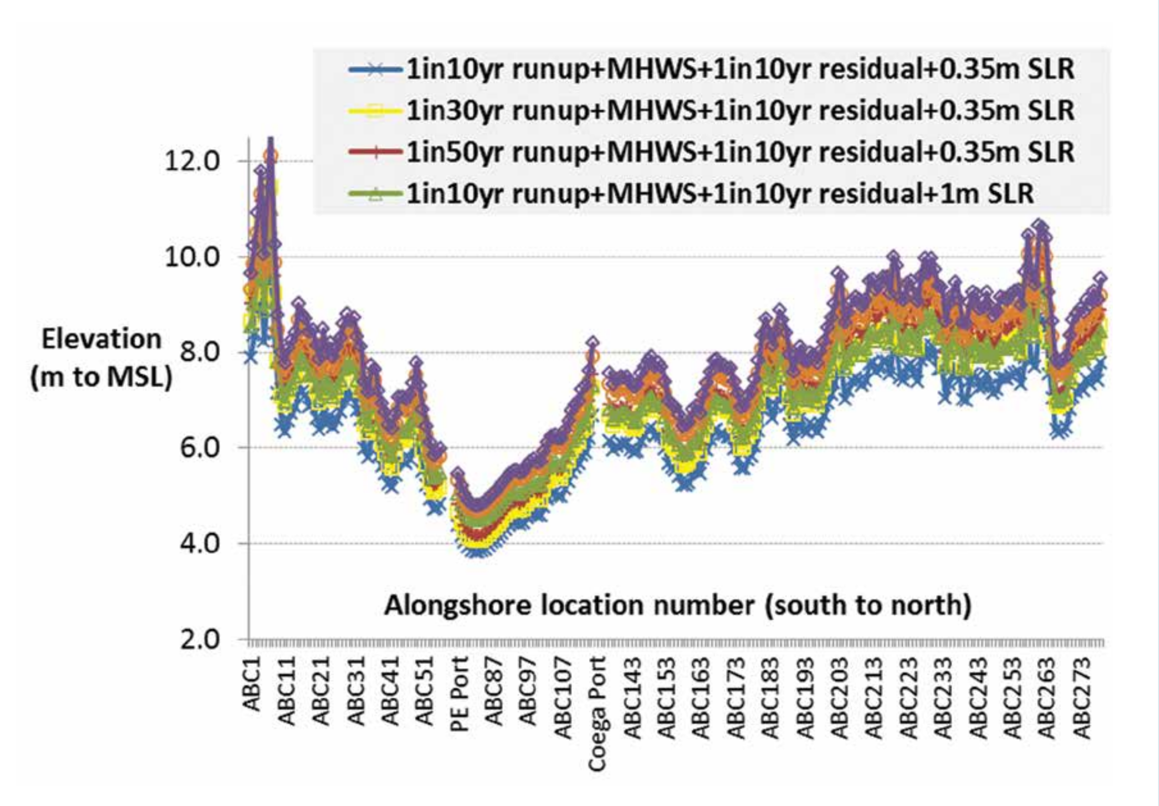
City	100-m buffer line population percentage	1 000-m buffer line population number percentage	20-m contour line population percentage
Saldanha	8.29%	38.07%	43.25%
Cape Town	0.43%	4.62%	27.59%
Port Elizabeth	0.02%	2.61%	12.12%
East London	0.04%	4.48%	1.28%
Durban	0.32%	6.86%	6.35%
Richards Bay	0%	0.55%	16.44%

During 2014, a collaborative study between the Council of Scientific and Industrial Research (CSIR) and the South African Department of Environmental Affairs (DEA) determined the coastal flooding elevations for approximately two-thirds of the South African coastline. This was achieved by creating 22 wave models in the numerical wave generation and refraction package Simulation WAves in the Nearshore (SWAN). This tool was utilised to transform the wind and wave conditions from the offshore to the nearshore (Theron et al., 2013; Theron et al., 2014). The offshore data were defined by a numerical forecast, an offshore data set, covering a period about of 15 years. This data set is based on the daily forecasts from the National Centre for Environmental Prediction (NCEP), a subdivision of the USA-based National Oceanic Atmospheric Administration group. The NCEP data cover the entire offshore region of the South African coastline.

The wave transformation results in the nearshore was then analysed through Extreme Value Analysis (EVA) on a 500-m resolution around the coastline. This EVA analysis could then indicate what the expected return period of extreme wave events were, which could then, in turn, be used in the extreme coastal flooding elevation scenarios for every 500 m around the coast. The study proposed six likely scenarios of future coastal flooding elevations, including climate change effects like projected sea-level rise. Each scenario produced wave run-up values (via mathematical models) and using as input extreme wave heights, nearshore profile slopes, extreme seawater levels excluding tides (wind and hydrostatic setup at locations where data were available), tides, and sea-level rise projections by the year 2100.

Box 9.1: Mapping the vulnerability of South African coastal cities to SLR (continued)

The procedure depicted in the graph below was followed all around the greater part of the South African coast at a 500-m resolution.



Predicted coastal flooding levels for Algoa Bay, South Africa, with the Mather wave run-up model (Mather et al., 2011). Here the Mean High Water Spring (MHWS) tide was used as the tidal contribution. The six flooding scenarios are plotted against shoreline locations, named AB in this example. The gaps in the data are where the shoreline was rocky and for which the Mather model (used in this study) was not the appropriate model.

The coastal flooding elevations can now be used for coastal management purposes and for estimating the particular coastal location's abiotic vulnerability to abiotic climate change associated with SLR and wave run-up. One example might be the estimation of the coastal setback or management lines. A coastal development setback line should be a line landward of which fixed structures (e.g. houses, roads, etc.) may be built with reasonable safety against the physical impacts of the coastal processes (e.g. sea storms, wave erosion and run-up). Factors that co-determine the location of setback lines are storm wave run-up elevations and how far the shoreline will retreat due to erosion, which, in turn, are affected by the amount of SLR that is expected and the projected increases in storminess. To interpret the coastal flooding elevations to management lines, terrestrial topography information will be required, e.g. LiDAR data.

9.2.2. Coastal ocean acidification

The oceans have absorbed approximately 30% of the total anthropogenic carbon dioxide emissions from the atmosphere (Canadell et al., 2007). When seawater absorbs anthropogenic CO_2 from the atmosphere, chemical reactions occur that reduce the pH of seawater, and affects the partial pressure of CO_2, dissolved inorganic carbon, total alkalinity, the concentration of carbonate ion, and the saturation states of the biominerals aragonite (Ωarag) and calcite (Ωcal) in a process called "ocean acidification" (Feely et al., 2010). These changes in the carbonate system in turn affect the marine living organisms, particularly calcifying organisms which use calcium carbonate to produce shells or skeletons. In fact, the saturation state of calcium carbonate, rather than the pH of the carbonate system, is the key driver of calcification rates of shell-forming organisms (Fabry et al., 2008). A value of $\Omega = 1$ indicates saturation, and $\Omega > 1$ is favourable for calcification, whereas dissolution is favoured when $\Omega < 1$, and provides a useful indicator of a chemical threshold. This threshold is not a strict criterion for biomineralisation (calcification) or dissolution, as some organisms require supersaturated conditions while others have adapted strategies to maintain calcified structures at undersatured conditions at a bioenergetics cost (Feely et al., 2009). Global models used to estimate long-term changes in (NCAR, CCSM3) have shown a decrease of 0.5 units of Ωarag from the pre-industrial era to the decade ending 2013 (Feely et al., 2009).

Typical of upwelling systems, the Benguela Current System along South Africa's west coast has a naturally lower pH, currently ranging between 7.60 and 8.25, depending on the season (Gregor, 2012). This system is predicted to have a pH of between 7.8 and 7.5 by the year 2100 (Caldeira & Wickett, 2003). As a result of climate-driven speeding up the South Atlantic subtropical gyre (Roemmich, 2007; Saenko et al., 2005), upwelling in the Benguela Current System is going to become more intense (Bakun et al., 2015), which may extend the persistence of lower pH and Ωarag in this region. On the Agulhas Current System along the east coast, although upwelling is less intense and less frequent than in the Benguela, the impact of ocean acidification along the south and east coast will have similar consequences.

A marked difference in Ωarag states between the surface and subsurface (300 m) is observed in Figure 9.3. Under the anticipated increasing upwelling conditions in the future, surface waters around South Africa are expected to experience more frequent occurrence of low pH waters undersaturated with respect to aragonite. Predicting the responses of individual organisms to high CO_2 and associated low pH in data-sparse regions

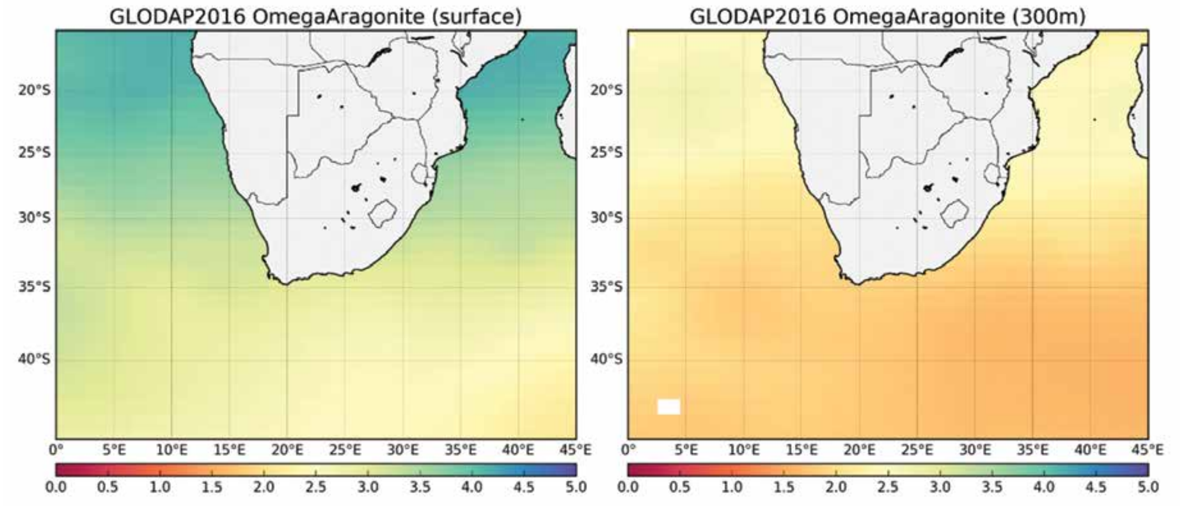


Figure 9.3: Regional climatology of saturation states of aragonite in the surface (left) and at 300 m depth (right) mapped from 1°x1° GLODAPv2 dataset using the Data-Interpolating Variational Analysis mapping method (Lauvset et al., 2016).

of southern Africa is complicated. In the sub-tropical Atlantic Ocean (15 ^{o}S – 50 ^{o}S), the water column becomes undersaturated with respect to aragonite between 400 m and 1 000 m. This aragonite saturation horizon in all ocean basins has shoaled by varying amounts between 50 to 200 m over the previous 250 m due to anthropogenic addition of CO_2 to the ocean (Feely et al., 2004; Orr et al., 2005). Over the next 20 to 30 years, the aragonite saturation state will decrease below the present envelope of variability, causing near-permanent under-saturation in subsurface waters (Hauri et al., 2013). Going forward, the impact of this shoaling of the saturation horizon remains poorly understood.

9.3. Adaptation response measures

When it comes to mitigating the climate change effects associated with SLR, there are a few generally agreed-upon strategies. To protect a particular coastline, the coastal processes have to be well understood. If the incorrect protection measure is enforced addressing the wrong driver of the coastal problem experienced, the problem will only get worse. Generally two types of coastal erosion can be distinguished:

- *Episodic* erosion and
- *Structural* erosion.

Episodic erosion is generally associated with coastal erosion occurring during a severe storm. This type of erosion occurs over the time span of hours and in large volumes. The sediments removed from the coastline are usually not lost to the littoral system and can be returned to the coastline under calmer wave conditions (usually in summer). If a particular coastline has an intact dune system, the brunt of the erosion occurs on the fore dunes.

Structural erosion, on the other hand, is the long-term, steady erosion of a particular coastline. The main driver of this type of erosion is usually a longshore current that traverses up and down the coastline. If the net amount of sediment entering a particular stretch of coastline is less than the amount exiting the section, structural erosion will occur. Utilising protection measures that do not alter or inhibit the longshore transport of sediments will therefore not solve the erosion problems caused by structural erosion.

In Figure 9.4 a schematic example is given that illustrates the various coastal mitigation strategies. The first option is to accommodate the changing sea levels by elevating the coastal infrastructure. Hard-engineered protection measures are also an option where, for example, sea walls or revetments are built to protect infrastructure. Natural protection measures (or soft-engineering interventions) may be obtained by beach sand nourishments or the proper rehabilitation of dune systems. In a presently undeveloped area the best form of defence is prevention by building new infrastructure outside of the coastal vulnerable area (setback-line). Given all these strategies understanding the coastal processes and time scales involved is critical for implementing the correct solution for the correct problem. Examples of coastal management and mitigation interventions for Mozambique, Tanzania and Kenya can be found in Shaghude et al. (2015) and Theron et al. (2012).

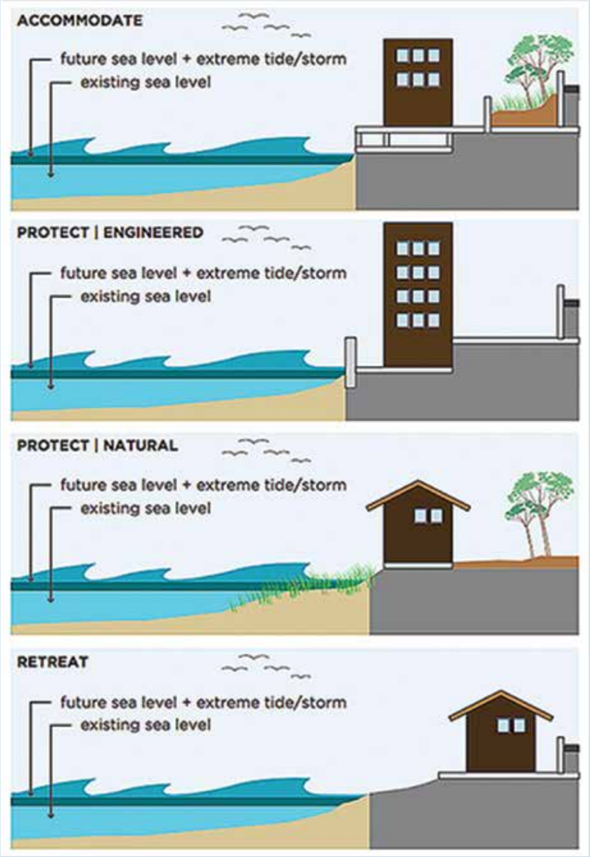


Figure 9.4: Schematic illustration of mitigation and adaptation measures in response to SLR (Campbell & Wilson, 2016).

In Table 9.1 a summary is provided of various types of interventions that can be considered for a variety of natural coastal systems. Within Table 9.1 the protection measures should be subdivided into soft (natural) and hard (engineered) protection. Generally soft interventions are preferred above hard interventions (depending on the problem faced). A successful example of a soft protection measure can be found in the Dutch 'sand engine' where an entire new peninsula was created from dredged sediments. This sand engine provided much needed sand to the surrounding beaches by utilising the naturally occurring longshore currents. The closest southern African example of a soft engineering intervention is the beach nourishment scheme at Durban, on the east coast of South Africa. Here sand is accumulated in a sand trap at the southern end of a large breakwater. The northwards moving longshore current feeds sediments into the sand trap. The sand trap is then dredged and fed into a pumping system that fluidises and pumps the sediments to the beaches located northwards of the breakwaters and the harbour entrance. The longshore current then transports the sediment further northwards. In this example anthropogenic intervention is repeatedly required, while in the Dutch sand engine example only one large intervention was needed. Due to the fact that only one large intervention was made and that frequent maintenance is not required, local wildlife is now returning to this stretch of coastline close to Den Hague in the Netherlands.

Table 9.2: Rising sea levels impact differently on coastal areas and their inhabitants. The measures are classified as: [P] - Protective, [A] - Adaptive, and [R] - Retreat measures. Adapted from Bollmann et al. (2010).

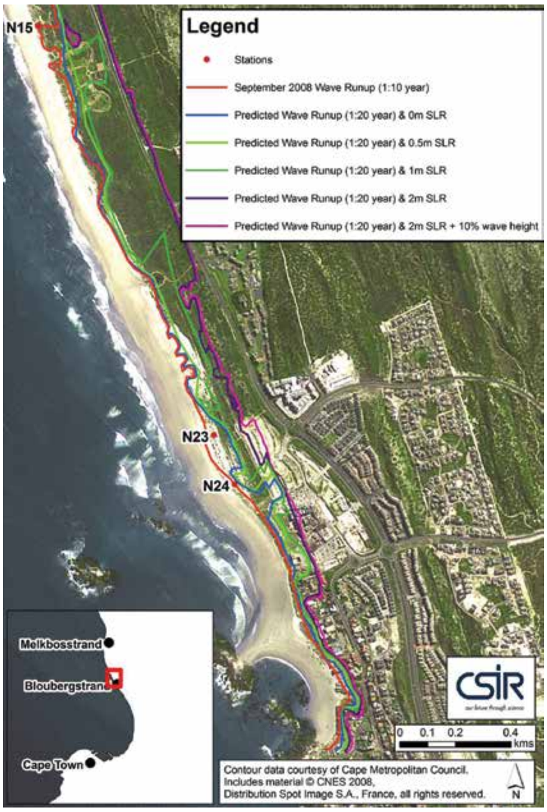
Effects of sea-level rise on natural coastal systems		**Possible protective/adaptive measures**	**Relative costs**
1. Flooding of low-lying areas and resultant damage	a) Storm tides b) Backwater in estuaries	1. Dykes and flood barriers [P] 2. Artificial dwelling mounds, flood-proof building (standards) [A] 3. Identification of risk zones [A/R] 4. Adapted land-use and landscape planning [A/R]	1. Very high (construction, maintenance) 2. Medium to high 3. Very low (one-off) 4. Medium (recurrent)
2. Loss of or changes to coastal wetlands		5. Adapted land development planning [A/R] 6. Dyke relocation [A/R] 7. Foreshore reclamation [P/A] 8. Beach nourishment, sediment protection [P]	5. Low to medium (ongoing) 6. Very high (one-off) 7. High (recurrent) 8. Medium/low (ongoing)
3. Direct and indirect morphological changes, particularly erosion of beaches and bluffs		9. Construction of groynes, bank protection, sea walls [P] 10. Beach nourishment, dune protection [P] 11. Underwater reefs, breakwaters [P] 12. Development-free zones [R]	9. Medium to high (construction) 10. Medium/low (ongoing) 11. Medium to high (construction) 12. Low to high (one-off)
4. Intrusion of saltwater	a) into surface water b) into ground water	13. Dams and tide gates to prevent influx of saltwater [P] 14. Adapted/reduced withdrawal of water [A/R] 15. Pumping in of freshwater [P] 16. Adapted withdrawal of water [A/R]	13. High (construction, maintenance) 14. Low (ongoing) 15. Medium (recurrent) 16. Low (permanent)
5. Higher (ground) water levels and limited soil drainage		17. Soil/land drainage improvement [P] 18. Construction of pumping stations [P] 19. Altered land use [A] 20. Designation of flood areas/high-risk areas [A/R]	17. High (ongoing) 18. Very high (construction, maintenance) 19. Low (permanent) 20. Very low (recurrent)

Case study: Application of prediction methodology for extreme water levels, sea storms and wave runup in Table Bay, South Africa

Coastal areas within Table Bay (Bloubergstrand to Melkbosstrand) near Cape Town were selected to illustrate how wave run-up calculations may be used to highlight present and future vulnerable areas. The western and southern Cape, including the study areas, part of which are illustrated in the map, were subject to significant storm impacts as recently as 1 September 2008. Run-up data were collected by the CSIR following the 2008 storm. Although this storm had a return period of about 1 in 10 years, the impact on the coast was not as severe as that of the 2007 storm on the KwaZulu-Natal coast. It may be noted that the storm of March 2007 had run-up levels in the vicinity of Durban that reached higher than 8.5 m above mean sea level. One of the main reasons why the KwaZulu-Natal coast is more severely impacted by storms of a similar nature is the greater level of density in coastal development close to the high-water line in this area.

The Geographical Information System used in the mapping of areas that are susceptible to wave run-up requires coastal topographical data as input. These data were provided by the Cape Metropolitan Council, and the beach slopes that were used in the calculation of the run-up levels for the two sites were obtained from beach profiles surveyed by the CSIR. The range of appropriate SLR scenarios for 2100 is given as 0.5 m to 2 m (Theron et al., 2016). The impacts of climate change on wave run-up at this location are illustrated by calculating the run-up levels with increased sea levels of 0.5 m, 1 m and 2 m. As is to be expected, the most severe impact is observed when an SLR of 2 m and a 10% increase in the storm wave heights coincide.

The run-up mapped for the 2008 storm does not indicate significant impacts in this area, which came from observations during the storm. However, according to the predicted run-up mapped in the figure, even a 1-in-20-year storm (without adding any SLR effects) will start causing problems for existing developments. As progressively higher sea levels are added and the scenarios become more severe, the predicted run-up increases and the vulnerable areas become increasingly larger. Clearly, once SLR exceeds about 1 m, a mere 1-in-20-year sea storm could cause major problems in the highly built-up areas near Blouberg, including the nearby nuclear power station. In addition, major transport infrastructure (the coastal trunk road) is also at risk due to an increased sea level; all the more so were sea storm occurrence also to increase.



Contour data courtesy of Cape Metropolitan Council.
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Illustration of the predicted effects of climate change on coastal run-up lines near Blouberg, South Africa

CHAPTER 10:
HUMAN SETTLEMENTS

AUTHORS: WILLEMIEN VAN NIEKERK & ALIZE LE ROUX

Different human settlement types and locations with varying vulnerabilities and capacities will experience the hazards associated with climate change to an unequal extent. Poor communities will experience the most severe setbacks from the impacts of climate change; eroding their adaptive capacity and threatening their resilience.

10.1. Introduction

Human settlements with their high concentrations of people, economic activity and infrastructure are arguably one of the most significant stages on which climate change will play out (Smith, 2009). Settlements in southern Africa are confronted with many complex development dilemmas at various levels, some of which are legacies, but many challenges are entrenched or created by current market forces and planning practices. Settlements are not all equally vulnerable to the impacts of climate change. The vulnerability of settlements in southern Africa is impacted by various and complex socio-economic processes related to the cultural, political and institutional contexts and demographic pressure, as well as specific high-risk zones susceptible to flash floods, sinkhole formation or landslides (Oliver-Smith, 2002; Niang et al., 2014). As urbanisation challenges collide with the impacts of climate change, a 'strange new urban world' (McClean 2010, p.8) develops in which settlements are becoming progressively more vulnerable but less able to deal with the risks (ICLEI, 2010).

Resilient cities are able to sustain themselves by coping with, or adapting to climate change threats, whereas cities vulnerable to climate change are to varying degrees unable to cope with the adverse effects of climate change, and experience some form of harm when a hazard occurs (UNFCCC, 2010). Vulnerability precedes disasters, contributes to their severity, and persists afterwards. The multidimensional impacts of climate change on human settlements in this region compound the challenges, going far beyond cities' experience and capacity to adapt and respond to climate change, causing major setbacks in hard-won economic and social development that increasingly hinder efforts towards sustainable development. Ultimately, poor and vulnerable communities experience the most severe setbacks from the impacts of climate change, eroding their adaptive capacity and threatening their resilience (Parnell et al., 2007; Faling, 2010; Roberts et al., 2012; Niang et al., 2014).

This chapter describes some of the key drivers and processes of vulnerability and risks in human settlements in southern Africa that pose considerable challenges, but also opportunities, for climate change adaptation. Data for the whole of southern Africa (excluding Mauritius and Seychelles) are provided for two of these key processes, namely urbanisation and informality. The potential climate risks and their consequences for settlements in the SADC region are discussed. The chapter concludes with a number of response measures that address both hard and soft adaptation options for cities, but, more importantly, the underlying key processes that drive risk and vulnerability.

10.2. Key drivers and processes of vulnerability and risks within settlements

"The vulnerability of human settlements to climate change is understood as an outcome of their exposure to environmental risks and changes resulting from climate change, and the extent to which the adaptive capacity of affected communities and households is reduced by social vulnerability. These factors are location specific, related to particular local climate, topology and human settlement patterns." (Department of Environmental Affairs 2014b, p.6).

Urban settlements across Africa are experiencing immense changes at a swift rate. Much of this change is causing urban populations to become and remain vulnerable to numerous risks such as the impacts of climate change. The key drivers and processes causing these changes include urbanisation, natural population growth within cities, informalisation of the city, growing inequality, increasingly youthful

urban populations, smaller household formations, industrialisation, and growth and decline in the economy and employment opportunities (Todes et al., 2010; African Development Bank Group, 2012; Freire et al., 2014; UN Economic Commission for Africa, 2014). Two of these key processes and their associated challenges are discussed below, with reference to the situation in SADC countries.

10.2.1. Urbanisation

Urbanisation is a necessary catalyst for economic prosperity. Cities and towns generate the majority of national GDP, and urbanisation, if managed well, can be a powerful process for leveraging transformation and economic growth (UN-Habitat, 2014). As colonial and apartheid regimes in Africa started to break down, urbanisation rapidly increased. It is estimated that the urban population in Africa has grown from 15% in 1960 to 40% in 2010 and is expected to continue growing to more than 60% by 2050 (UN-Habitat, 2015). The main drivers of this urbanisation are natural population growth, rural-urban migration (including climate change refugees), circular and seasonal labour migration, international migration, conflict and war, changing and decaying rural landscapes, land reform, and a perception of plentiful economic opportunities, housing and services in the cities (Todes et al., 2010; Niang et al., 2014; UN-Habitat, 2014; United Nations ESA, 2014). However, urbanisation in most of Africa occurred with little change in the economic structure and insufficient investment in the built environment and human capital to harness the process for sustainable and inclusive growth (Todes et al., 2010; Freire et al., 2014). The United Nations calls this "urbanisation without development" (UN Economic Commission for Africa, 2014).

Figure 10.1 shows the level of urbanisation for the SADC countries. South Africa is the most urbanised at an estimated 64%, followed by Botswana (57%) and Namibia (46%). The least urbanised countries are Malawi (16%), Swaziland (21%) and Lesotho (27%). Figure 10.1 also illustrates the population density per square kilometre, as well as the urban agglomerations with more than one million people and their expected populations in 2025 (projections sourced from UN ESA, 2014 and UN-Habitat, 2014). Currently, of the estimated 311 million[20] people who live in SADC countries, 126 million live in urban agglomerations. The largest urban agglomerations are the Gauteng city region in South Africa, Kinshasa in the DRC, Luanda in Angola and Dar es Salaam in Tanzania. Urban agglomerations in the SADC region provide housing and livelihoods to 41%[21] of the SADC population and are expected to continue to grow as African cities have among the fastest growing populations (UN-Habitat, 2015).

The main challenges associated with urbanisation in Africa are low economic growth and growing poverty that contribute to the "urbanisation of poverty", inadequate infrastructure and lack of services, degradation of the environment, the absence of clear policies on land ownership, unsustainable consumption of resources, a laissez-faire approach to urban management, and limited capacities at local government level (UN Economic Commission for Africa, 2014; UN-Habitat, 2014). The result is that much of the urbanisation is unplanned and informal, located in undesirable spaces that are exposed to multiple and complex hazards. Many settlements in the SADC countries are consequently becoming home to an increasingly vulnerable urban population, to climate change in particular (Pelling et al., 2009; Roberts et al., 2012; Niang et al., 2014).

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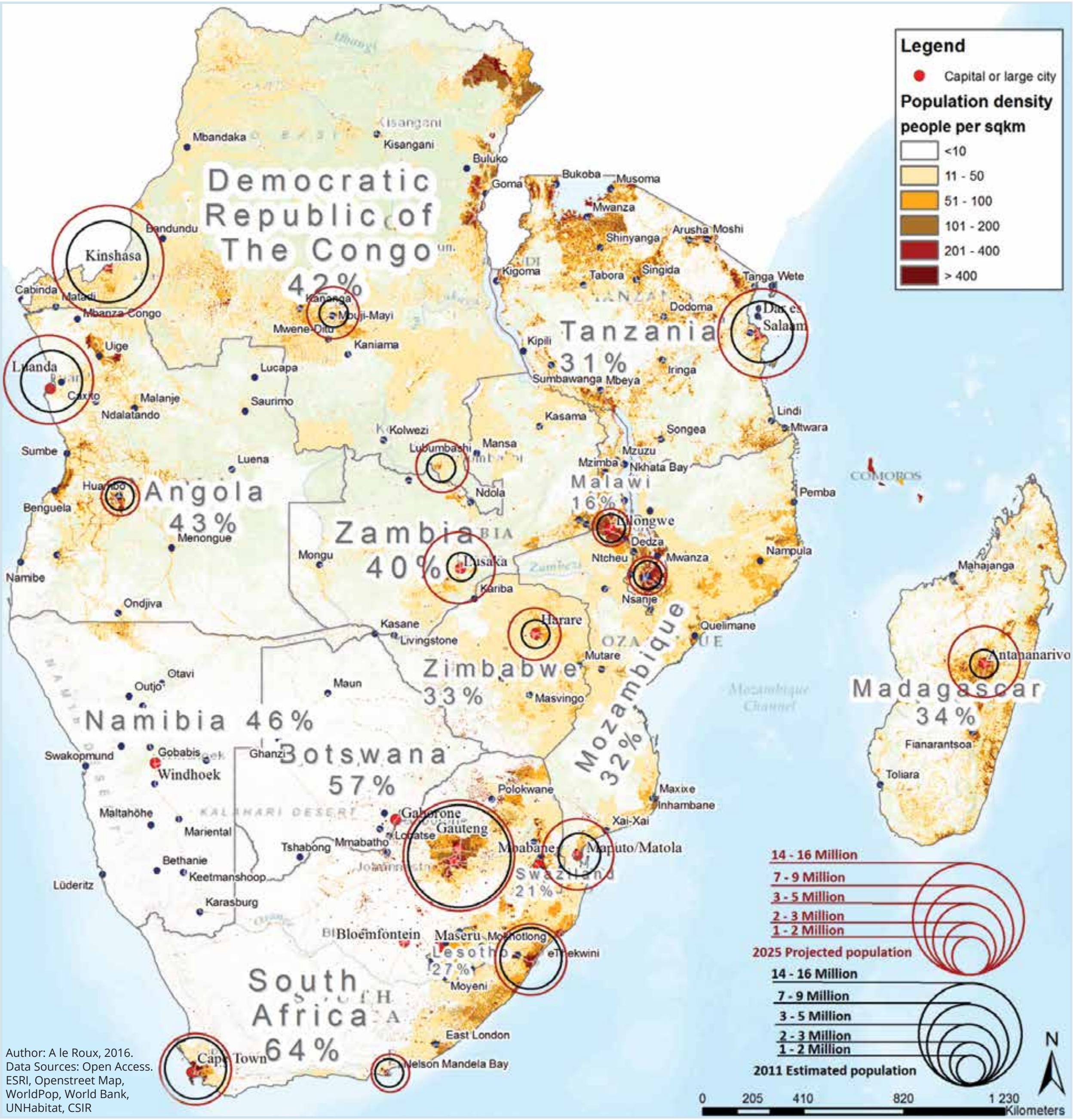
[20] Figures exclude Mauritius and Seychelles.

[21] CSIR calculations based on latest census figures of each SADC country (projected figures used in case of missing census data, e.g. Angola). Urbanisation rates used as reported by UN ESA (2014). Calculations exclude Mauritius and Seychelles.



Author: A le Roux, 2016.
Data Sources: Open Access.
ESRI, Openstreet Map,
WorldPop, World Bank,
UNHabitat, CSIR

Figure 10.1: SADC population distribution and density, proportion of urban population and projected growth of cities.

10.2.2. Informality and inequality

The proliferation of informality, particularly urban slums, is one of the most prominent phenomena of SADC settlements, and potentially one of the most pressing future challenges. Factors contributing to the development and growth of urban slums are the sheer number of people that need to be housed and provided with services and a lack of formal employment, but also mainstream urban policy that fails to address issues of informality or appreciate the cumulative consequences of poverty. Urbanisation has mostly failed to bring about inclusive growth. Rising inequality is thus another prominent characteristic of cities in the SADC region. With an average Gini coefficient[22] of 0.58 (well above the 0.4 average), African cities are the second highest unequal cities in the world. The way settlements develop generates exclusion and segregation by reflecting and reinforcing a pattern of wealth accumulation that only benefits a few. Informal settlements self-locate on the periphery of settlements at distances far from economic opportunities, with low or no potential to make a living. Informal employment and youth unemployment have become everyday features of African cities that cause a lot of distress to households (African Development Bank Group, 2012; Van Niekerk, 2013; UN Economic Commission for Africa, 2014; Rajab, 2015).

Table 10.1 shows the current estimated percentage of urban slum dwellers (UN-Habitat, 2013) in cities. The highest prevalence of urban slum dwellers (as a percentage of total urban dwellers) is found in Madagascar at 76%. Second is Malawi at 69%, followed by Angola (66%), Tanzania (64%) and the DRC (62%). Zimbabwe (24%) and South Africa (23%) have the lowest percentage of urban slum dwellers.

The inhabitants of informal settlements in SADC countries often live in life-threatening conditions and face extensive risks on a daily basis that make them vulnerable to various hazards. Inadequate access to basic municipal services such as water, sanitation, electricity and waste removal creates unhygienic environments and increased pollution that can cause serious health threats. It is also a major cause of increasing service delivery riots. The lack of affordable and effective public transport places an undue economic burden on the poor. Where people live in high densities close to the city centre, there are conflicting interests and actions competing for scarce land and opportunities, and infrastructure is overwhelmed by the demand. Other challenges include tenure insecurity, a lack of land-use management and building regulations, lack of access to safe drinking water, and the use of highly flammable material to construct dwellings combined with the use of flammable sources of energy (Van Niekerk, 2013; UN Economic Commission for Africa, 2014; Rajab, 2015). These trends place enormous pressure on the ability of governments to respond effectively to, and mitigate risks associated with climate change (Le Roux et al., 2016 – in press).

Table 10.1: Percentage of urban slum dwellers in southern Africa

SADC country	% urban dwellers living in slums
Madagascar	76
Malawi	69
Angola	66
Tanzania	64
DRC	62
Zambia	57
Lesotho	54
Namibia	34
Zimbabwe	24
South Africa	23

10.3. Potential climate risks and their consequences for settlements

The future climate of southern Africa is generally expected to be characterised by increased temperatures and changes in rainfall. The projected climate changes will expose people and the built environment to hazards such as severe weather events, drought, water shortages, floods, sea-level rise, heat waves, vector-borne diseases, coastal erosion, storm surges, cyclones and sinkhole formation. These events are likely to cause injury and death to many people and severe damage to the built environment, which would have knock-on effects on economic development and negatively impact service delivery and sustainable development in the areas of greatest need. Arguably the biggest threat facing many urban agglomerations would be the reduced access to fresh water and concerns around food security (UN-Habitat, 2011; UN-Habitat, 2013; Department of Environmental Affairs, 2014b). Table 10.2 expands on some of these possible threats and their consequences for human settlements.

Looking to future risks, Figure 10.2 shows population density and those SADC coastal settlements with populations above 200 000. Eleven percent[23] of people in southern Africa live in coastal settlements below

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[22] The Gini coefficient measures the deviation of the distribution of income among individuals or households within a country from a perfectly equal distribution. A value of 0 represents absolute equality, a value of 100 absolute inequality (http://hdr.undp.org/en/content/income-gini-coefficient)

100 m above sea level. Mozambique is particularly vulnerable, with 39% of its people living below 100-m elevation, followed by Madagascar (27%), Angola (15%), South Africa (12%), Tanzania (11%) and Namibia (6%).

Coastal cities in southern Africa are densely populated, have made huge investments in infrastructure such as ports, power stations and oil refineries, are home to threatened ecosystems, and play a vital role in the economies of the SADC countries. Coastal cities are, however, at great risk of severe impacts from hazards such as storm surges, flooding and sea-level rise, owing to the dense population concentrations and the accumulation of assets, for they produce the majority of the GDP on relatively small areas. Specific risks in some of these countries include:

- Mozambique is arguably the SADC country most vulnerable to climate change. Thirty-nine percent of its population live in coastal areas below 100-m elevation, and climate projections indicate potential increases in the number of cyclones, in flooding and storm surges as well as in drought events (UN-Habitat, 2013; UN-Habitat, 2014). Since agriculture is largely based on subsistence farming, droughts and shifts in rainfall patterns can lead to severe food and water insecurity. Mozambique is a country with a history of conflict and insecure land tenure and this is likely to lead to resource conflicts.
- Luanda (Angola), Dar es Salaam (Tanzania) and Kinshasa (DRC) are among the top five fastest growing cities in Africa (KPMG, 2012). Luanda and Dar es Salaam are both coastal settlements that are megacities in the making (UN-Habitat, 2013; UN-Habitat, 2014; United Nations ESA, 2014), while Kinshasa, the capital of the DRC, is already a megacity and located on the banks of the Congo River where it is vulnerable to flooding.
- The capital cities of Antananarivo (Madagascar) and Lilongwe (Malawi) suffer from inadequate and lacking infrastructure and services to cope with the effects of climate change impacts (UN-Habitat, 2014).
- Coastal cities in Angola have seen tremendous growth and in-migration (Luanda grew from 141 000 in 1950 to over five million in 2010, Benguela/Lobito grew from 8 500 in 1950 to 365 000 in 2010) and this trend is expected to continue for the next decade. Currently 15% of Angola's coastal population are located below 100-m elevation, and extreme poverty, inadequate shelter, lack of land use and disaster management are reducing people's ability to cope with current and future climate-related events. Much of the growth has been absorbed in high-risk environmentally sensitive land in river basins, coastal swamps and low-lying areas. Flooding tends to be the biggest concerns for these cities, for it displaces people (e.g. 10 000 displaced in January 2016 in Benguela/Lobito), affects service delivery of safe water, and results in continuous outbreaks of cholera (e.g. 35 000 cases in 2006 [Cain et al., 2015]).
- The DRC picture is grim, as natural resource looting, failing government structures, continued armed and social conflict, corruption and poverty will render attempts at mitigation insufficient (UN-Habitat, 2013; UN-Habitat, 2014).

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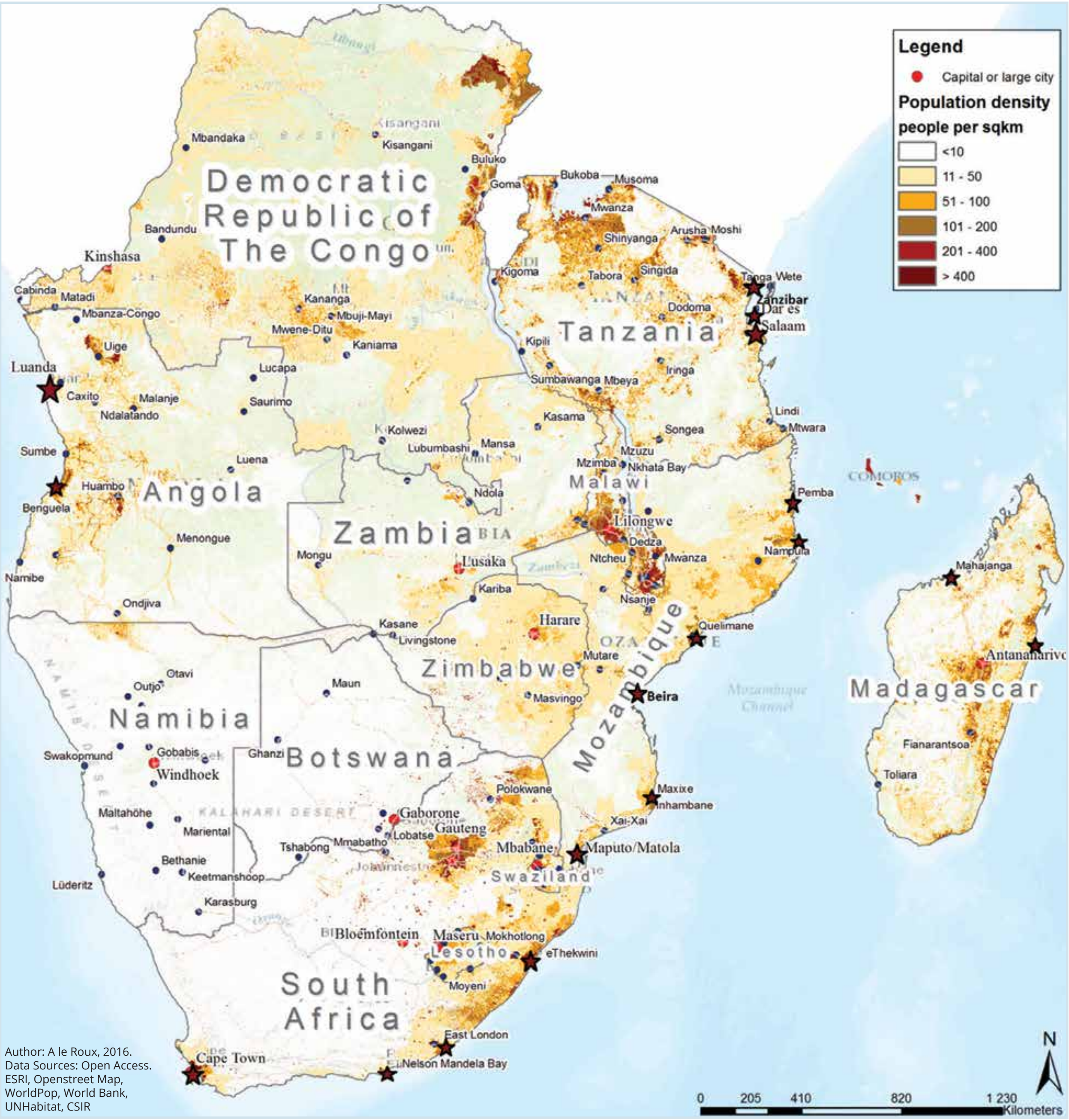
23 CSIR calculations based on Worldpop 1 sq km population grid and 30m World DEM.

Table 10.2: Possible impacts of climate change phenomena on human settlements (Niang et al. 2014; Department of Environmental Affairs, 2014b; Engelbrecht et al., 2016 – in press)

Climate change phenomenon	Consequences for human settlements
General warming – less intense and fewer cold days and nights, more frequent and intense hot days and nights	• Intensified heat island effect. • Increased energy demand for cooling. • Declining air quality in cities. • Reduced energy demand for heating. • The incidence and geographic range of vector- and water-borne diseases could change due to changes in the mean temperature.
Extreme weather – heat waves and droughts	• Increased water demand compounded by present strain from overexploitation and degradation. • Resource conflicts. • Declining water quality, water stress and pressure on water-supply systems. • Surface water evaporation. • Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and poor. • Reduction in quality of life for people without appropriate housing. • Drought stress will be exacerbated in drought-prone regions. • Susceptibility to environmental degradation for rural settlements in particular. • Reduced crop productivity, increased pests and diseases, which could have implications for local livelihoods, food-system infrastructure and urban food security. • Undernutrition could have lifelong impacts on development and health. • Increased risk of wild fires.
Extreme weather – heavy rainfall events and violent storms	• Adverse effects on quality of surface and groundwater, contamination of water supply. • Increased risk of deaths; injuries; infectious, respiratory and skin diseases; water- and food-borne diseases; and post-traumatic distress disorders. • Unplanned informal settlements are particularly susceptible to floods, offering poor accessibility for emergency services. • Disruption to commerce. • Damage to or destruction of bulk and critical infrastructure. • Disruption to transport systems and traffic. • Flash floods and mudslides could destroy or damage assets, force people from their homes, or lead to deaths. • Large displacement of people (who may return to the area), or distress migration to urban informal areas. • Pressure on urban and rural infrastructure, including power outages, disruption of public water supply and transport. • Loss of property and withdrawal of risk coverage in vulnerable areas by private insurers.
Sea-level rise and storm surges	• A threat to coastal settlement, disrupts transport systems, infrastructure and public services, especially in informal settlements. • Decreased availability of fresh water due to salt-water intrusion. • Harmful impacts to marine and estuarine environments. • Increased risk of deaths and injuries by drowning in floods and migration-related health effects. • Increased migration, which can result in human suffering, human rights violations, conflicts and political instability. • Loss of property and livelihoods, particularly in marine fisheries and tourism, and the withdrawal of risk coverage in vulnerable areas by private insurers. • Damage to real estate, decreased value of beachfront properties and decreased tourism. • Permanent erosion and submersion of land. • Costs of coastal protection versus costs of land-use relocation and damage to natural infrastructure – potential requirement for movement of populations and infrastructure.



Author: A le Roux, 2016.
Data Sources: Open Access.
ESRI, Openstreet Map,
WorldPop, World Bank,
UNHabitat, CSIR

Figure 10.2: Population density and distribution; and coastal settlements with populations above 200 000 people

The impact of climate change on cities will be complex and, based on their spatial locations, diverse (UN-Habitat, 2013). Projected climate change (see Chapter 2) will result in a growing number of vulnerable people (both socially and physically) exposed to a growing number of natural hazards, resulting in a higher number of people at risk. A rapidly growing vulnerable urban population (unmanaged growth resulting in sprawl, people settling in low-lying or environmentally sensitive areas) coupled with the expected increases in hazards (sea-level rise, greater number of cyclones, extreme temperatures, increase in intensity of rainfall, drier inlands, etc.) and inadequate infrastructure (lack of stormwater runoff, failure to adhere to building codes, inadequate infrastructure networks) will prove devastating for many cities in the SADC region. Many governments in the SADC countries are already struggling to meet the basic needs of city dwellers and a rapidly growing urban population will place enormous pressure on governments to create sustainable human settlements. The risk of injury, loss of life, damage to infrastructure and costly recovery processes, among other things, will increase as climate change will exacerbate pre-existing vulnerabilities.

Case study: The vulnerability of Luanda (Angola) to climate change impacts

The capital of Angola, Luanda, was originally designed for half a million people by colonial Portuguese planners. Luanda is now home to a population of more than five million people, and is currently one of the five fastest growing cities in Africa (UN-Habitat, 2011; UN-Habitat, 2014). Twenty-seven years of civil war saw many people flee to Luanda, which was largely spared from the conflict. With peace came economic opportunity, and even more people came to the capital from the impoverished countryside. This urbanisation has not been managed well, and the housing problem has been left unattended for half a century (UN-Habitat, 2014). The population of Luanda is projected to grow at 3.7% between 2010 and 2025 – from 4.8 million to 8.7 million people (Freire et al., 2014). To keep up with the average annual growth rate, Luanda will have to provide for almost 300 000 new inhabitants per year (UN-Habitat, 2014), posing great challenges for the provision of infrastructure and services (Eriksen et al., 2008).

Angola's post-war economic growth was quite robust for more than a decade, though its economy, based mainly on oil exports, is one of the least diverse economies in Africa. It attracted significant foreign capital investment that created wealth for Luanda, but the impact on employment has been limited. This is not only because oil revenue is fuelling corruption and political cronyism, but also because education was severely affected during the war years, to the extent that the oil industry had to import skills from other countries due to a lack of qualified personnel (UN-Habitat, 2014). At present, Luanda is one of the most unequal cities in the region, with one of the highest slum populations (66% of urban dwellers in Angola live in slums). In Luanda, 54.3% of the population live below $1.25 per day and the Human Development Index is 0.486 (UN-Habitat, 2014). The accommodation needs of the highly paid oil workers have increased residential costs, thus pushing out the urban poor to the periphery of the least desirable urban areas such as river basins, low-lying areas, coastal swamps and environmentally sensitive areas, causing huge disparities, segregation, fragmentation, inequalities and vulnerabilities. The city faces urban challenges typical of many southern African cities: urban sprawl, segregation, unemployment, slum and informal settlement proliferation, inequality and poverty, hunger, social exclusion, housing backlogs, inadequate infrastructure and a severe lack of service provision. Even when clean water is available, it may not be affordable to the poor. This lack of services renders cities more vulnerable to the impacts of climate change and disasters, as their adaptive capacity is depleted (UN-Habitat, 2014).

Case study: The vulnerability of Luanda (Angola) to climate change impacts (continued)

Projections indicate that Angola would most likely experience increases in temperature and seasonal shifts in annual rainfall in the future. A World Bank aquifer index indicates that Angola is very likely to become a water-scarce country in the future, with a projected decrease in annual runoff of between 30-50 percent (Schellnhuber et al., 2013), as well as a 30% variation in the duration of the rainy season (UN-Habitat, 2014). As a low-lying coastal city, Luanda is vulnerable to sea-level rise, salt-water intrusion and storm surges. It is already exposed to unsustainable large-scale degradation of its coastal area and is expected to increasingly experience coastal erosion, regular localised flooding, and soil degradation. Other impacts comprise heatwaves, droughts, air pollution and high night temperatures. Vulnerable sectors include biodiversity, tourism, health, infrastructure, fisheries, agriculture and food security (Eriksen et al., 2008; UN-Habitat, 2014). Fisheries and market gardening in particular are very vulnerable due to the importance of these industries to the poor and their sensitivity to climate variability (Niang et al., 2014). Furthermore, with Angola's economy being heavily dependent on fossil fuels, the global pressure for mitigation measures may affect the national economy, and specifically the economy of its cities, such as Luanda (UN-Habitat, 2011).

The aftermath of the civil war in Angola, rapid urbanisation, the lack of urban management and continuous environmental destruction have undermined the capacity of Luanda to adapt to climate change. Slum dwellers are the worst off as they often live in the most dangerous and most exposed areas, have the worst quality housing, and are constantly exposed to various hazards (UN-Habitat, 2014). Luanda needs to urgently address its many urbanisation issues, while simultaneously planning and designing the city to adapt to the impacts of climate change. This could include revising floodlines, upgrading and protecting infrastructure, establishing coastal set-back lines, relocation of vulnerable settlements, implementing early warning systems, and intervening in high-risk areas. Adaptation options should especially be pro-poor.

10.4. Response measures and conclusion

Settlements in southern Africa are highly vulnerable to climate change but have low levels of adaptive capacity. Despite numerous efforts, there is an adaptation deficit in Africa. The lack of adaptation can foremost be explained by a lack of understanding and political acceptance of urbanisation and informality in many countries. Urbanisation is complex and challenging, but should be embraced as a powerful and unavoidable process that represents an invaluable opportunity for development. "Urbanization is not a sub-plot, but rather the main policy narrative for Africa" (Freire et al., 2014), for the urban population will almost double in the next two decades (UN Economic Commission for Africa, 2014). Policy-makers should prioritise and manage urbanisation challenges by planning settlements systematically, enabling concurrent, diversified economic development, investing in infrastructure and basic services, developing institutions, increasing productivity, improving liveability, monitoring long-term risk and vulnerability factors, mobilising local and foreign investors, and by carrying every resident along with their plans (African Development Bank Group, 2012; Freire et al., 2014; Niang et al., 2014; UN Economic Commission for Africa, 2014). In this regard, the urban management and planning function in cities needs to be strengthened to help cities plan ahead for inclusive growth and avoid certain situations, such as the emergence of more urban slums (Freire et al., 2014). However, governments should accept existing informality as a response to the housing backlog, and resist a universal approach of eradication and relocation of slums. Rather, governments should provide the environment and services for informal settlements to become full-fledged, self-sustaining and dignified components integrated into the city (Rajab, 2015).

There are various barriers to local adaptation, which include institutional, cultural, political, social and gender-related aspects. However, adapting to climate change offers an opportunity not only to address the threats presented by the impacts of climate change, but also to address many of the development challenges of existing and future urbanisation. Successful urbanisation and adaptation are "primarily about coordinating various types of long-run investment" (Freire et al., 2014). A targeted, flexible, differentiated and contextual approach to climate change adaptation is required that reduces settlements' exposure to events while simultaneously addressing a broader process of poverty reduction, ecosystem stability, social justice and equality, and political and institutional change. Such an approach assumes a constantly changing, complex urban system, place-based vulnerability, and adaptation options specific to the local context, culture and tradition (Mercer, 2010; Faling et al., 2012; Niang et al., 2014).

Often significant financial resources, investment in institutional capacity and technological support are required to build adaptive capacity and implement adaptation strategies at both a national and local government level (Niang et al., 2014). Adaptation options could also be low-cost and simple low-regrets adaptation measures that reduce the current and future vulnerabilities of households and have multiple development benefits. Physical adaptation options could include to design for the efficient use of water; protect high-yield agricultural land, environmentally sensitive areas and natural landscapes from urban sprawl; plan greater interconnectivity between different land uses and transport; intensify land uses where appropriate; revise flood lines; design to cool cities through natural ventilation; retreat, accommodate or protect from sea-level rise; relocate, adapt or safeguard critical infrastructure; create rainwater storage and flood retention areas; plan to harvest water and conserve energy; comply with building codes and zoning restrictions; and structurally adapt buildings (UN-Habitat, 2011; UN-Habitat, 2014; United Nations ESA, 2014; Department of Environmental Affairs, 2014a; Department of Environmental Affairs, 2014b). Soft, pro-poor adaptation options that build resilient livelihoods include social services, safety nets and protection; better water, land tenure and governance security over land and vital assets; and strengthened civil society (Niang et al., 2014).

CHAPTER 11:
HUMAN HEALTH

AUTHORS: REBECCA M GARLAND AND HANNA-ANDREA ROTHER

Southern Africa has multiple risks that contribute to the overall burden of disease (i.e. the quadruple burden of disease), which may make people more vulnerable to the health impacts from climate change. In addition, the sector is vulnerable as the links between climate and health are not well-quantified, and thus difficult to predict the impact. This chapter provides some examples of the breadth of issues concerned in climate change and human health.

11.1. Climate and health linkages

The links between climate and human health are complex and multi-faceted. Box 11.1 highlights a variety of climate-sensitive health impacts (Patz et al., 2005). These impacts of climate on health already exist in many areas in southern Africa. A changing climate has the potential to exacerbate these issues in areas where they already exist, as well as impact factors such as the frequency and spatial distribution of their occurrence. The largest human health risk from climate variability and climate change is expected in those populations that are currently impacted the most by climate-related diseases (Woodward et al., 2014). This chapter provides some examples of the breadth of issues concerned in climate change and human health.

Box 11.1: Key impacts of climate on health (modified from Patz et al., 2005)

Direct impacts	
Heat	Heat stress, cardiovascular disease
Extreme events/severe weather	Immediate impacts (injuries, fatalities) and indirect impacts (e.g. cholera)
Indirect impacts	
Air pollution	Asthma, cardiovascular disease
Water and food supply	Malnutrition, diarrhoea, harmful algal blooms
Mental health	Anxiety, despair, depression, post-traumatic stress
Water-borne diseases	Cholera, cryptosporidiosis, campylobacter, leptospirosis
Allergies	Respiratory allergies, poison ivy
Vector-borne diseases	Malaria, dengue, Zika virus, encephalitis, hantavirus, Rift Valley fever
Extreme events/severe weather	Immediate impacts (injuries, fatalities) and indirect impacts (e.g. cholera)

As highlighted in Box 11.1, climate can impact health directly (e.g. through increasing temperatures and immediate effects from severe weather) and indirectly (e.g. changes in agriculture and food supply due to climate change can impact malnutrition). Severe weather is listed twice as there can be immediate direct impacts as well as indirect impacts (e.g. increases in cholera from flooding).

Increases in temperature can have an impact on public health and workers' health (Garland et al., 2015; Andrade-Rivas & Rother, 2015), and is the basis of three case studies here to highlight the range of potential risks and considerations for an example of the direct impact of climate variables on human health.

Temperatures are already increasing in the region. By 2100, under a business-as-usual scenario, temperatures are projected to increase by 4-6 °C in the subtropics in Africa, and 3-5 °C over the tropics in Africa (refer to Chapter 2). These increases in temperature can have direct impacts on health (e.g. heat stress and heat stroke, and increases in mortality from exposure to high temperatures). Previous studies have found that urban areas may be more vulnerable to negative health impacts from exposure to high temperatures; the increased vulnerability can be due to many reasons including the urban heat island effect and the presence of air pollution (Kovats & Hajat, 2008). Case Study A below provides projections of high temperatures and potential risks to human health in SADC under a business-as-usual (BAU) scenario. Occupational health can also be impacted by increasing temperatures, and many outdoor workers can be exposed to multiple health risks. Case Studies B and C highlight the linkages between heat, sun and pesticide exposure, and the complexities in protecting worker health from these multiple risks.

The indirect impacts of climate on health are more varied and have complex interactions. For example, malaria is a well-studied climate-sensitive disease, though the impact that climate factors have on malaria are complex and non-linear. Temperature and rainfall are the most studied climate factors in relation to malaria. In general, there are optimal ranges of climate conditions where malaria risks are highest, and some studies have found that small changes in temperature can lead to non-linear and larger increases in malaria transmissions (Pascual et al., 2006, Alonso et al., 2011). In order to fully characterise the impact of climatic variables on malaria, multiple factors with high spatial and temporal resolution are needed (Parham and Michael, 2010). The spatial range for suitable climatic conditions in Africa for malaria are projected to increase as a result of climate change, especially in regions that are currently on edges of current malaria areas (e.g. Tanser et al., 2003). However, as discussed in section 11.2 below, for all health impacts, including malaria, the drivers are complex and not just climatic variables.

Case study A: High temperatures and risks to human health in SADC

By Rebecca Garland, CSIR

Temperatures in Africa have been increasing over the past 50 years. This increase is expected to continue into the future due to climate change, with increases as great as 3-6 °C by 2100 under a business-as-usual scenario. These increases in temperature can have large impacts on human health across the continent.

The health impacts from exposure to high temperatures can range from discomfort and fatigue to heat stress, and can also lead to death. During heat waves, increases in mortalities are often recorded.

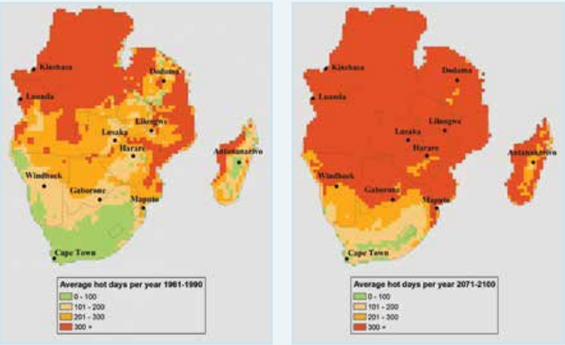
A recent study investigated the potential risk to human health from high apparent temperatures in Africa under a "business-as-usual" scenario. Apparent temperature is a temperature index that attempts to quantify "how hot it feels" by combining temperature, relative humidity and wind speed. The "business-as-usual" scenario (BAU) was the A2 scenario for the IPCC 4th Assessment, and depicts a scenario where there has been little mitigation of GHG emissions.

The study assessed the increase in "hot days", where a hot day was defined as a day where the maximum apparent temperature was above 27 °C. There were no areas in Africa that were projected to see decreases in hot days.

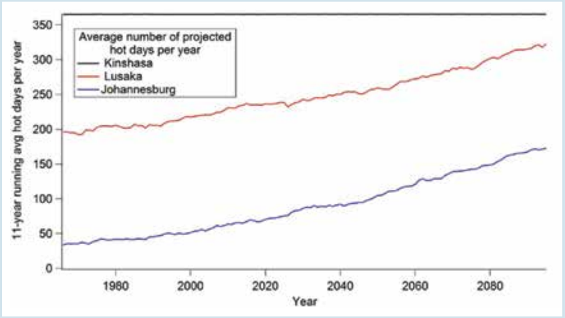
The maps highlight the modelled average number of "hot days" per year in the current climate (1961-1990) and in 2071-2100 assuming BAU. From this figure it can be seen that areas in tropical Africa already have almost every day above this threshold (in red in figure top panel). By the end of the century, under BAU, it is projected that a larger amount of the region would experience 300 plus days per year on average of "hot days".

The graph displays the 11-year running average of the number of hot days per year for Johannesburg, Lusaka and Kinshasa. Increases across the study period can be seen for Lusaka and Johannesburg, while there are no increases for Kinshasa as almost every day is already a "hot day"! However, when the temperature threshold for "extremely hot days" of maximum apparent temperatures above 39 °C was used, Kinshasa was projected to have an increase from ~10 days per year in 1970s and 1980s, to over 300 days per year by 2100.

These projections highlight the large risk to human health from high temperatures. Heat-health action plans are an effective public health measure, that when implemented can assist in decreasing the impact from high temperature events. These action plans consist of an early warning system for high temperatures together with actions and alerts that are activated when a high-temperature event is forecast by the country's meteorological agency.



Modelled average number of "hot days" per year in 1961-1990 (left) and 2071-2100 assuming BAU scenario (right).



See more on Heat-health action plans at: World Health Organization Regional Office for Europe, "Heat-health action plans", 2008 (pdf available at: http://www.euro.who.int/en/publications/abstracts/heathealth-action-plans). For more information on this study see Garland et al., Regional projections of extreme apparent temperature days in Africa and the related potential risk to human health, Int. J. Environ. Res. Public Health, 2015. (pdf available at: http://www.mdpi.com/1660-4601/12/10/12577)

Case study B: Outdoor workers in the Western Cape, South Africa

By Manshil Misra, School of Public Health & Family Medicine, University of Cape Town, South Africa

A variety of sectors integral to the South African economy utilise outdoor workers. The Working for Water (WfW) programme was launched in 1995 by the South African Department of Environmental Affairs. The main goal of this state-funded initiative is to protect biodiversity in areas that contain important water sources by controlling invasive alien vegetation. WfW workers are sourced from local residents in removal areas, as an additional objective is to provide employment and skills development to needy communities.

WfW workers are typically exposed to several hazards (e.g. herbicides, sun, heat) while removing alien vegetation. A significant concern is the effect on the health of outdoor workers in light of climate change and its effect on severe variations in weather, including exposure to extreme heat.

A recent study involving WfW workers was conducted in Citrusdal (Western Cape), where temperatures are known to frequently exceed 40 ^{o}C during summer. The study sought to identify possible approaches to augment current exposure prevention strategies by exploring perceptions and practices of WfW employees toward their heat and sun exposure, as well as their understanding of climate change.

The results show that in this vulnerable population, there was varying knowledge and understanding of the health impacts of exposure to heat and sun, and ways to prevent harmful effects from them. Workers frequently experienced themselves, or observed in others, the immediate significant adverse effects (e.g. headache and loss of consciousness) from exposure to extreme heat and sun. This was often linked to the personal protective equipment (PPE) workers are provided with to protect them from exposure to toxic herbicide but which are unsuitable for working in extreme heat. Many workers indicated that the respirator could not be worn more than a matter of minutes when temperatures were 30 degrees or more. Other factors impacting on health and exacerbated by the heat were carrying heavy backpack sprayers in the direct sun and spraying in thick vegetation that retains the heat.

These results suggest that despite the recognised risks that are faced by outdoor workers who have some knowledge of how to mitigate these, and policy (within a national organisation) in place to address occupational health, further work must still be undertaken to bolster policy and enhance its practical application. Measures also need to be put in place to review how standard operating procedures (e.g. wearing PPE when applying hazardous pesticides) put workers at risk while working outdoors. This is especially imperative in light of the future threats related to climate change, such as increases in temperature.

Case study C: Climate change and pesticide health risks for Zimbabwean small-scale cotton farmers

By Cliff Zinyemba, School of Public Health and Family Medicine, University of Cape Town, South Africa

All pesticides are toxic and can cause a range of acute and chronic health effects from vomiting, rashes, allergies, asthma, cancer and interfering with the body's hormones. A study was conducted to assess whether climate change was a key factor impacting on small-scale Zimbabwean cotton farmers' exposure to pesticides.

Fifty farmers who had been consistently growing cotton over a period of 30 years were interviewed. They were asked a range of questions, including the types of pesticide used, changes in quantities of pesticides used on their farms, use of personal protective equipment (PPE) as well as the handling of pesticides, including spraying patterns.

The study found that many of the pesticides being used by the cotton farmers are hazardous. Several of these are endocrine-disrupting chemicals (EDCs) interfering with human hormones, impacting, for example, fertility and sexual development. Examples of pesticides used include some which are classified as slightly hazardous (Class III) by the World Health Organization, such as Lambda-cyhalothrin, carbaryl and atrazine; and others which are classified as moderately hazardous (Class II) such as dimethoate and fenvalerate. Farmers use these pesticides in large quantities, often handling them without any PPE. With increasing temperatures being experienced, farmers indicated that they are becoming less concerned why PPE such as rubber boots, gloves and long-sleeved clothing should be worn and highlighted the discomfort such clothing causes, which makes application with PPE virtually impossible. With more and more hazardous pesticides being used, the use of PPE becomes crucial to reduce health risks in the short and long term. However, PPE was not considered a priority as illustrated by the farmers, who preferred to spray while wearing sandals, short trousers and short-sleeved shirts in order to withstand the heat. Even if the correct PPE is available it is unlikely that they would be worn in extremely hot conditions.

Climate change is likely to perpetuate the health risks associated with such pesticides as a result of increased exposure to pesticides, not only for farmers but also for their families and other residents. Increased exposure to hazardous and endocrine-disrupting pesticides is resulting from increased use, potential for increased vapourisation and limited use of PPE.

The use of pesticides has increased in Rushinga, with some farmers using up to four times the recommended dosage of pesticides per hectare than they did during the 1980s. The indication is that this increase is resulting from climate change and variability impacts on pest populations, cropping patterns and pest resistance. Farmers also spray more frequently, and as a result spend more time spraying than they did in the past, thus significantly increasing the risks associated with their direct exposure to pesticides, and that of their families and neighbours. This also leads to an increase in indirect exposure from contaminated air, drinking water and soil used for household crops, as well as an increase in pesticide residues in produce sold and consumed.

Climate change may, therefore, be a key factor – among others – impacting on Zimbabwean small-scale cotton farmers' exposure to pesticide. If adaption measures are not introduced in Rushinga, climate change may not only perpetuate the dependency of the farmers on pesticides, but increase pesticide usage and health risks associated with direct and indirect exposure. Adaptive strategies should focus on integrated and reduced toxicity pest management as a priority to enable farmers to adapt to climate change in a sustainable way, in which pesticide-related health risks are minimised. The health sector plays a key role in effective pesticide poisoning surveillance programmes to inform evidence-based policy-making.

11.2. Key drivers and processes of change within the sector

Figure 11.1 highlights the linkages between climate change and human health, as well as mitigation and adaptation potential. The impacts on human health from climate variability are similar, however the representation of the impact of mitigation measures is only applicable to climate change. This figure highlights both the direct and indirect impacts on health from Box 11.1.

For all health impacts listed in Box 11.1, there are non-climate factors that also influence and drive the risk to human health (highlighted as modifying factors in Figure 11.1). For example, cholera epidemics are caused by a lack of access to safe water and lack of proper sanitation. A study in Lusaka, Zambia found that cholera outbreaks occurred mostly during the rainy season, and that parts of the city with insufficient drainage had increased risk of cholera outbreaks (Sasaki et al., 2009). Thus, for water-borne diseases, service delivery can be modifying factors that can either exacerbate the health impact (i.e. from poor service delivery) or mitigate the health impact (i.e. effective service delivery even in severe weather). With respect to exposure to high temperatures and resultant impacts on public health, the built environment can play a role as the thermal comfort of buildings can impact heat stress. In addition, across all potential health impacts, the condition of the health system is a key modifying factor; an over-burdened health system may exacerbate the impact on health from a changing climate. These non-climate factors do need to be accounted for when trying to quantify the potential impacts on health from climate change. For example, it has been 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). Identifying these factors will also play an important role in developing specific adaptation options for the sector; however targeted research is needed to identify the relevant local modifying factors that can be the basis for adaptation options.

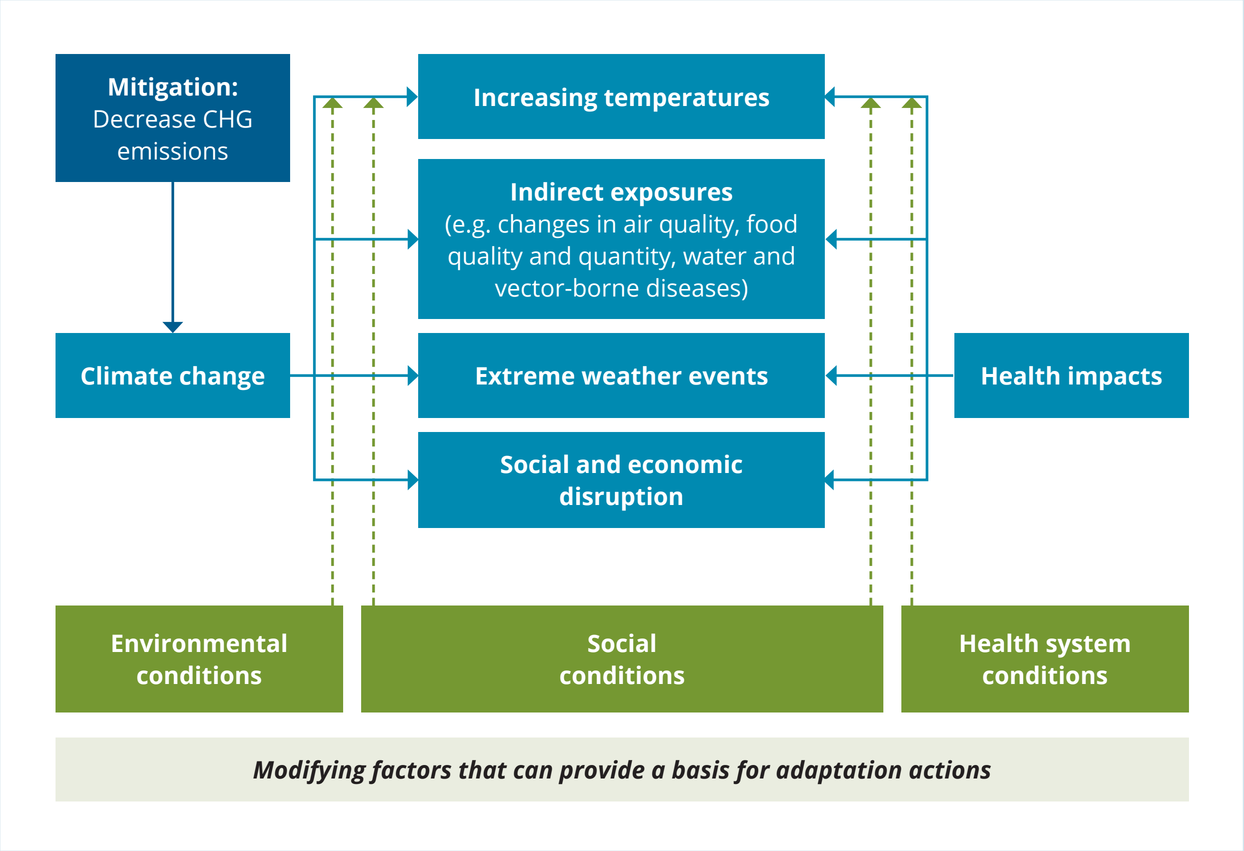


Figure 11.1: Linkages between climate change and health (adapted from Confalonieri et al., 2007; Ahdoot & Pacheco, 2015).

11.3. Health sector role in mitigation

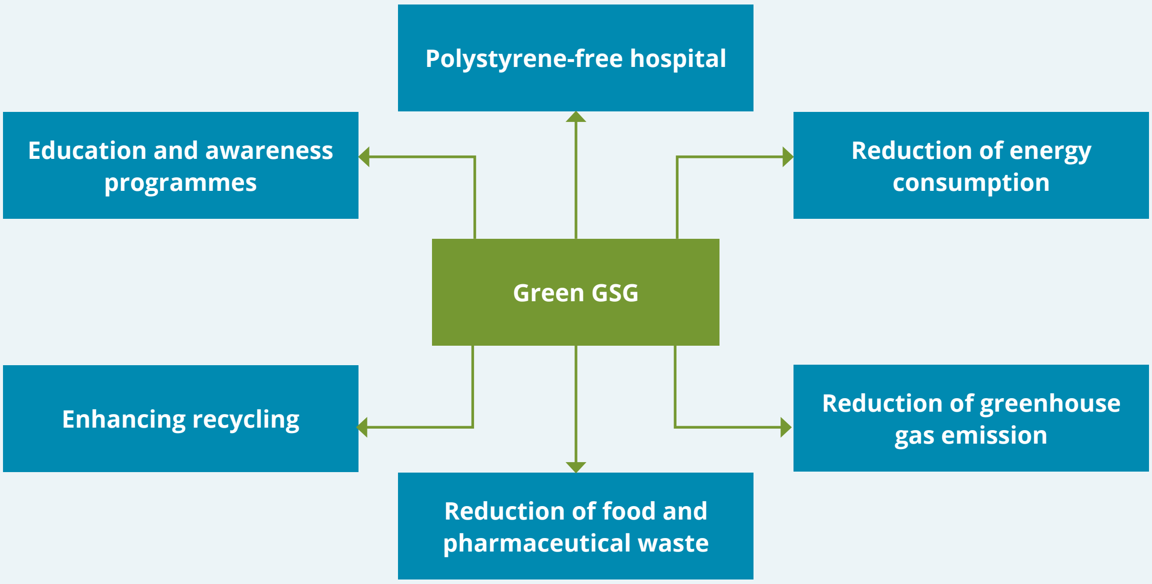
In order to mitigate climate change, decreases in greenhouse gas (GHG) emissions are necessary. The health sector can play a role in mitigating climate change; an example of such an initiative in Cape Town, South Africa is highlighted in Case Study D. Government support would be needed to implement this type of initiative in all hospitals in southern Africa.

Case study D: Green hospitals as role models to mitigate climate change

By Edda Weimann & Bhavna Patel, Groote Schuur Hospital, Cape Town

The South African health system is characterised by a stark inequality between public and private health care providers, with life expectancy significantly differing between socio-economic groups. Public healthcare facilities are under severe austerity measures, are experiencing shortages of hospital beds, have limited transport services and a lack of skills. Hence, every effort should be undertaken to minimise the impact of climate change and alleviate the burden of an already overloaded health system. In addition to the need for adaptation measures in the sector, GHG mitigation measures are needed, too. The health sector itself contributes to climate change as a major energy consumer, polluter and creator of hazardous waste. Consequently, health care providers can take action to reduce their own climate impact and perform as leaders inspiring others in reducing GHG emissions.

Groote Schuur Hospital (GSH) in Cape Town, South Africa has developed and practices the GSH Green hospital leadership framework (figure below). It comprises awareness campaigns, continuous education of staff and students, improvement of energy efficiencies, reduction of water consumption, waste and hazardous waste such as mercury and polystyrene, recycling throughout the hospital, reduction and recycling of food waste and the decrease of pharmaceutical waste. The framework can be applied to any other health care provider.



Groote Schuur Green Hospital Framework (adapted from Weimann and Patel, 2017).

11.4. Response measures

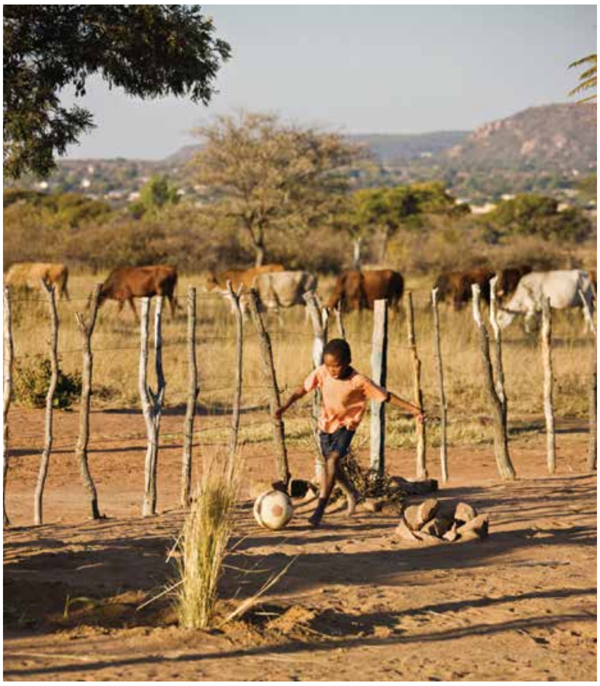
Currently, there is limited information on climate-health linkages, specifically in southern Africa. This makes it difficult to quantify the current impact of climate variables on health and estimate the potential risk from a changing climate. What is of particular concern are the uncertain risks to children – future generations – resulting in negative health outcomes from years of exposure to climate-induced health impacts (Box 11.2).

Urgent response measures are needed in the southern Africa region to reduce the impacts on the health of populations, especially children, workers and the elderly. Adaptive capacity varies, particularly at the individual level. In addition, the risk of climate variables to health will be different across regions, and a spatial assessment to identify hotspots can assist in understanding the key climate-health risks by area (such as in Case Study A).

Climate-related impacts can be modified through the listed modifying factors (purple boxes) in Figure 11.1. These modifying factors highlight areas where adaptation efforts can be placed in order to decrease the impact on human health from a changing climate. For example, for decreasing occupational health risk to high temperatures, actions such as effective early warning systems and flexible work hours can assist in decreasing the impact to human health from high temperatures.

Once health risks are identified, potential adaption options can be screened following frameworks such as that of Ebi and Burton (2008). This framework screens options using factors such as their technical feasibility, degree of effectiveness, environmental acceptability, economic efficiency, social and legal acceptability and compatibility, and the available human and financial capacity of the area. Examples of potential adapation options that can help to decrease vulnerability and mitigate negative health impacts are illustrated in Box 11.3.

A challenge for the health sector in southern Africa is to prioritise climate change in relation to other pressing health burdens, as well as secure ample funding for adaptation measures and to support research in a vulnerability context of weak health systems, fragile health care facilities in terms of service provision and infrastructure, and limited adaptation capacity within the sector.



Box 11.2: Are children the canary in the "mineshaft" of climate-linked disease outcomes?

By Hanna-Andrea Rother, Division of Environmental Health, University of Cape Town, South Africa

For children, the risk of climate-related health burdens is much higher than for adults. Children are not little adults. Their physiology (including still developing systems) and their behaviours (hand-to-mouth, spending large amounts of time outdoors, and playing close to the ground) increase their exposure risks; along with that they breathe, eat and drink more for their size compared with adults. In 2007, Zang and Hiller projected that children under the age of five from high-income and low-income countries would bear 88% of the global burden of disease resulting from climate-linked factors. Children in the poorest countries of southern Africa where the disease burden is high will be most impacted by climate variability and climate change effects. The table below illustrates the primary (i.e. direct) and secondary (i.e. coping and adaption strategies) impacts that need to be taken into account when assessing children's health risks, as well as developing appropriate risk-reduction strategies.

As research on climate-health links in southern Africa is limited and the long-term impacts on health are still widely unknown, one has to ask if African children are the "canary" to assess what the hazards really are. In order for children not to become an experimental indicator, policy-makers urgently need to devise policies based on the precautionary principle as well as ensure that climate issues are entrenched in all policies. Furthermore, health uncertainties need to be stated when managing for and communicating risks to vulnerable populations and decision-makers so as to ensure focus on impact suppression.

Primary and secondary impacts of climate on southern African children

Time frame*	Primary impacts	Secondary impacts
Short-term and immediate impacts	• Drowning and injury risks from damaged infrastructure • Vulnerability to disease (e.g. cholera & diarrhoea)	*Household level* (e.g. adapting livelihood practices such as children involved in income-generating activities; lifestyle changes)
Medium-term	• Risk of food shortages leading to child hunger and malnutrition	*Community level* (e.g. increased impacts on poverty, basic services, food provision, housing)
Long-term	• Increased incidence of malaria • Increased incidence of respiratory diseases and heat stroke	*Local/national/regional government level* (e.g. limited climate response strategies; sound planning tools and by-laws; dedicated budgets for climate and health)

* Time frame relates to the response time between a given climate event and health impact. For example, an extreme weather event can have short-term and immediate health impacts; (a) season(s) of drought can have longer impacts on child hunger that are more persistent in the medium term. Source: Adapted from UNICEF, 2011

Box 11.3: Examples of health sector policy options for adaptation to climate change [Source: Kula et al., 2013]

- Improving, modifying, or expanding health protection systems including surveillance systems for vector- and water-borne diseases, and seasonal forecasting and early warning systems for infectious diseases (e.g. epidemic malaria).
- Developing and implementing health forecasting and early warning systems (including emergency incident response plans) for extreme events such as heat- and flood-health warning measures.
- Maintaining and improving current environmental health regulatory standards (e.g. water and air quality standards).
- Improving or modifying health systems infrastructure by adapting hospitals and clinics to increased frequency of extreme weather events such as heat waves and floods.
- Increasing the capacity of health care services and human resources to cope with additional disease burden associated with extreme weather events.
- Preventing or treating the additional cases of disease due to failure in adaptation upstream.
- Improving the provision of medication to reduce the impact of potential increases in the transmission of infectious diseases.

The World Health Organization (WHO) has rightly indicated that reducing climate change impacts is a risk management issue. As highlighted by the 2015 Lancet Health and Climate Change Commision, not only do mitigation measures and relevant health policies reduce climate change impacts or assist in managing them, these can also have health benefits (Watts et al., 2015), as is the case with cycling (Case Study E). This is an apt example of the need for the health sector to work with other sectors, for instance in the planning of cycle routes and by using health benefits such as reducing obesity and heart conditions to promote cycling rather than just climate change alone.

As the WHO (2015c) has emphasised, it is critical that climate change adaptation measures are mainstreamed into existing and future health interventions to increase success and reduce the silo approach to climate management. Creating and implementing separate climate and health adaptation policies not integrated into other initiatives and policies will have limited success. Perhaps a “Climate in All Policies” approach similar to the “Health in All Policies” approach should be taken.

Case study E: Barriers to cycling mobility in Masiphumelele, Cape Town

By James Irlam, Primary Health Care Directorate, University of Cape Town, South Africa

Non-motorised transport (NMT) such as cycling and walking has multiple social, economic, environmental, climate and public health benefits and is integral to the agenda of sustainable development. There is considerable potential for more cycling mobility in South Africa, especially in low-income communities. Barriers to cycling mobility were investigated using a mixed methods study design in Masiphumelele, a low-income community in Cape Town, in October 2015.

A focus group discussion with local bicycle shop customers informed the design of a questionnaire and a Best-Worst Scaling (BWS) stated choice survey of 100 household residents. The BWS survey used 10 choice sets of four statements each to rank the relative importance to study participants of 20 potential barriers to cycling mobility on their average Best-Worse (B-W) scores.

Key findings

Taxis were the most frequently used mode of household transport (93%), followed by walking (44%), train (23%), bicycle (16%) and bus (11%). A third of households (32%) owned at least one bicycle that is used for transport. Twenty-two participants (22%) reported that they cycle fairly often (n=15 respondents) or regularly (n=7 respondents), primarily to save money (44%), keep fit and healthy (32%), and to save time (15%). The main reasons against cycling were unsafe roads (23%), unaffordable bicycles (15%), inability to cycle (15%), inadequate health and fitness (12%), long distances (10%) and no bicycle (7%).

The BWS survey identified and ranked significant perceived barriers to cycling as poor road safety (B-W score = 0.16); inability to transport loads on a bicycle (0.15); not being permitted to transport a bicycle on the train during peak commuting hours (0.13); and the risk of being late for work (0.12). Unaffordability and lack of safe storage of bicycles were significantly more important barriers for men than for women, whereas poor health was more important for women than for men.

Two-thirds (68%) of respondents supported the promotion of cycling mobility in Masiphumelele, mostly for reasons of financial savings (43%) and health benefits (28%). The main suggestions for promoting cycling were to teach cycling skills (30%), sponsor bicycles (21%), actively promote the benefits of cycling (20%), and create a safe environment for cyclists (12%).

Conclusion

There is a relatively high prevalence of bicycle ownership and use, as well as good support for promoting cycling mobility in Masiphumelele, mostly due to the perceived benefits of financial savings and health.

The health sector's role in actively promoting the benefits of cycling, educating about road safety, teaching cycling skills, making bicycles and spares more affordable, enhancing the safety of the cycling environment, and building local capacity is a key intervention for increasing cycling mobility in low-income communities like Masiphumelele, mitigating climate change while increasing health benefits.

CHAPTER 12:
ENERGY AND AIR QUALITY

AUTHORS: TIRUSHA THAMBIRAN AND YERDASHIN PADAYACHI

Energy changes, shifting to renewable, could lessen the environmental health problems associated with burning of fossil fuels and biomass fuels. Climate change is likely to have impacts on renewable energy production and distribution in southern Africa where drought conditions result in reduced hydro-electric generating capacity.

12.1. Introduction

Energy is seen as being crucial to any country's economic and social development. However, the combustion of biomass and fossil fuels for use as energy leads to a wide spectrum of air emissions such as carbon dioxide (CO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), sulphur dioxide (SO_2), total suspended particulates (TSP), carbon monoxide (CO), and polyaromatic hydrocarbons (PAH). These emissions have severe consequences for human health and the environment. In particular, the combustion of fossil fuels for electrification has received much global attention as it has been shown to contribute to many health-damaging air pollutants, and to significant amounts of global anthropogenic greenhouse gases (GHGs) that are linked to climate change.

While international policy has endeavoured to mitigate the main climate change pollutant (CO_2) resulting from energy production and consumption, the focus of many developing countries is on addressing the health impacts associated with poor air quality. These issues are particularly relevant within southern African countries. While energy production within these countries contributes least to climate change emissions globally, the energy production and consumption patterns place a large proportion of the region's population at risk of incurring air pollution-related impacts.

This section provides an overview of the key energy sources that are used in southern Africa, and reflects on the implications of these energy sources for air quality. The key drivers and responses to address these issues are also considered.

12.1.1. Overview of energy in southern Africa

The energy resources that occur within the SADC region are composed of both traditional and renewable energy resources (Mabhaudhi et al., 2016). Grid-electricity in the SADC region is secured through the Southern African Power Pool (SAPP), an alliance of 12 energy producers inter-connected through a regional grid to provide electricity across southern Africa (Conway et al., 2015). The SAPP was formed through the signing of an intergovernmental memorandum of understanding for the formation of an electricity power pool by SADC member countries (excluding Mauritius) in 1995 at the SADC summit in Johannesburg, South Africa (SAPP, 2015). The primary energy sources exploited by SAPP include hydro-electric, coal and natural gas, with only a few countries in the region exploiting distillate fuel and wind energy (Table 12.1) with electricity chiefly produced from coal resources (Conway et al., 2015).

Given the lack of electricity-generating capacity as shown in Table 12.1 and limited distribution networks (with the exception of South Africa, Botswana, Namibia and Mauritius), less than 45% of the population of most southern African countries have access to electricity (Figure 12.1). Poverty, lack of disposable income, high levels of corruption, large numbers of people in rural areas and high population densities are considered to be important factors that limit electricity access in sub-Saharan Africa (Onyeji et al., 2012). There are further variations in the energy mix at a country level, with stark differences in energy production between urban and rural areas (Ruhiiga, 2012).

The SADC region is endowed with both crude oil and natural gas reserves. The crude oil reserves in Angola are the largest in the region but most of this is exported out of the SADC region (Eleri, 1996; Zhou, 2012). The Democratic Republic of Congo and South Africa also produce crude oil, though South Africa is the home of the main oil refineries in the region (Table 12.2). Crude oil is mainly imported into the region from countries outside of the SADC. The liquidity crises that affected Zimbabwe and Tanzania have severely reduced the oil refining capacity of these countries (Mabhaudhi et al., 2016). Limited infrastructure in southern Africa to transport crude oil across the region further creates bottlenecks for the availability of the resource for road transport and industrial use. Road and rail infrastructure are the main conduits for refined petroleum and diesel products via road and rail freight transport (Mabhaudhi et al., 2016). Road transport is an important transport medium in the SADC region, with the number of motor vehicles having increased in Botswana, Mauritius, Seychelles, South Africa, Swaziland, Zambia and Zimbabwe between 2000 and 2014 (SADC, 2016).

Limited availability of modern energy sources such as kerosene, liquefied petroleum gas and grid-supplied electricity in SADC countries – with the exception of South Africa and Mauritius – has meant that households in these countries have become dependent on the use of wood biomass fuel. Tanzania, Mozambique, DRC and South Africa are the main producers of woody biomass in the region. Wood is mainly used in rural homes and charcoal in urban areas (Mwampamba et al., 2013). Charcoal, when burnt, emits less smoke and releases more energy, which makes it appealing to urban households (Cerutti et al., 2015). In most southern African countries more than 50% of the population are dependent on biomass fuel resources including firewood, charcoal and dung to meet their domestic energy needs (Figure 12.2).

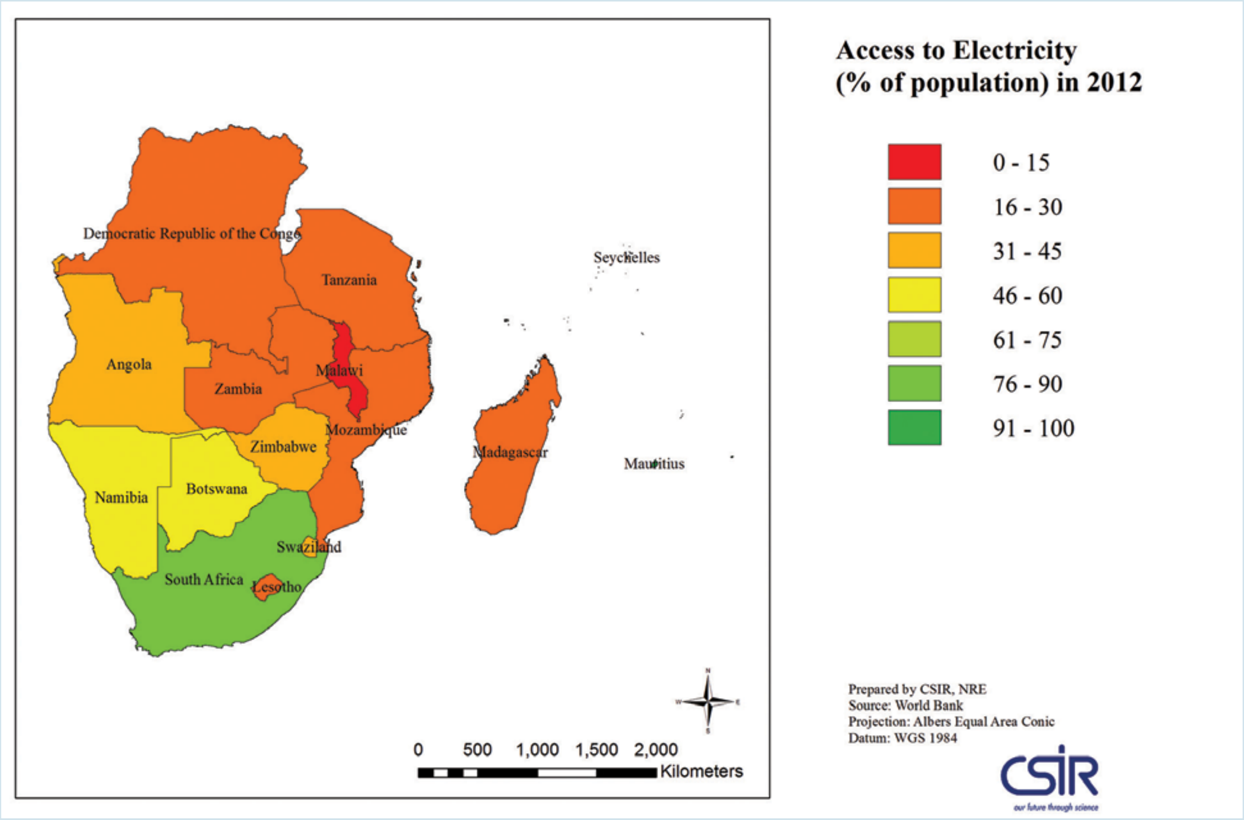
Table 12.1: Electricity generation capacity (MW) of southern African countries in the year 2014/2015, including the primary energy sources for each country [SAPP, 2015; NEWJEC in Engineering and Consulting Firms Association (EECFA), 2009].

Country	Technology				
	Hydro-electric (MW)	Coal (MW)	Gas (MW)	Distillate (MW)	Wind (MW)
Botswana	0	732	160	0	0
Mozambique	2 573	0	0	151	0
Angola	1528	492	190	0	0
Malawi	351	0	1	0	0
South Africa	2 000	35 721	0	2 409	2 492
Lesotho	74	0	0	0	0
Madagascar[1]	105	211	0	0	0
Namibia	348	132	0	21	0
Swaziland	61	9	0	0	0
Democratic Republic of Congo	2 442	0	0	0	0
Tanzania	717	0	585	78	0
Zimbabwe	750	1 295	0	0	0
Zambia	2 156	0	0	50	0
Mauritius[2]	56	389	0	0	0
Total	13 161	38 981	936	2 709	2 492

1 Electricity generation capacity for the year 2007;
2 Electricity generation capacity for the year 2013.

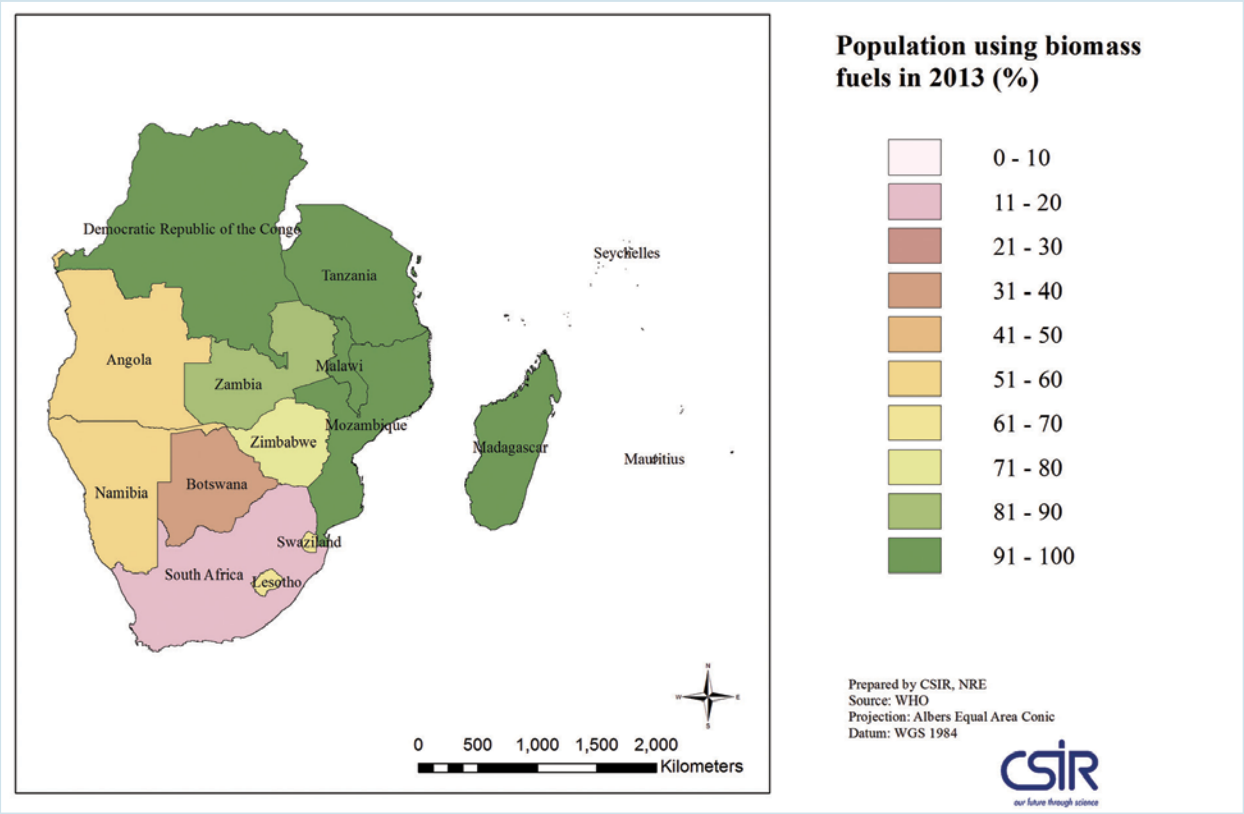
Table 12.2: Oil production and refinery capacity in the SADC region (Zhou, 2012)

Country	Crude oil (bbl/day)	Refinery capacity (bbl/day)
Angola	1250 000	39 000
DRC	20	-
Madagascar	-	15 000
South Africa	215	504 547
Tanzania	-	14 900
Zambia	-	23 750



Prepared by CSIR, NRE
Source: World Bank
Projection: Albers Equal Area Conic
Datum: WGS 1984

Figure 12.1: Percentage of the population with access to electricity in 2012 (World Bank, 2015).



Prepared by CSIR, NRE
Source: WHO
Projection: Albers Equal Area Conic
Datum: WGS 1984

Figure 12.2: Percentage of the population using biomass fuels in 2013 (WHO, 2015b).

12.2. Key drivers and processes of change within the sector

12.2.1. Energy

At the macro-scale, key drivers of energy consumption within the SADC region include economic growth, industrial development, motor vehicle transportation demand, urbanisation, and population growth (Schwela, 2012). In the context of economic growth, the SADC region is affected by a slump in the regional economy. The increase in the gross domestic product (GDP) growth rate from 2012 to 2013 was smaller than the increase in the GDP growth rate from 2009 to 2010 (Figure 12.3). Economic growth has slowed down not only for the SADC region, but also for the whole of the sub-Saharan African region. Industrial development has also been low in the region, mainly dependent upon the informal sector and concentrated in a few large cities found in each country. South Africa has been an exception due to greater global competitiveness supported by government and the prevalence of a large domestic demand for goods (Wekwete, 2014).

The greater dependence on primary resources such as biomass fuel with little to no additional processing is a common problem among both rural and urban households. At the country-scale, limited financial resources of southern African governments to fund energy projects constrain the capacity of governments to improve electricity access (Onyeji et al., 2012). Energy projects are typically expensive to start up even before production can begin. The costs of fossil fuel-based electricity remain too high for households, which opt for cheaper biomass fuels (Cerutti et al., 2015). Decentralised electricity grids and renewable energy sources are seen as the most appropriate solutions to expanding electricity access in southern African countries (Onyeji et al. 2012). However, the start-up of renewable energy projects remains affected by high associated costs (van Zyl-Bulitta et al., 2009).

Countries in southern Africa are often at a disadvantage when it comes to the development of renewable energy projects as a result of the high financing costs of the technologies for developing countries. For example, wind power generation in a developing country is 40% more expensive compared with a developed country (Figure 12.4).

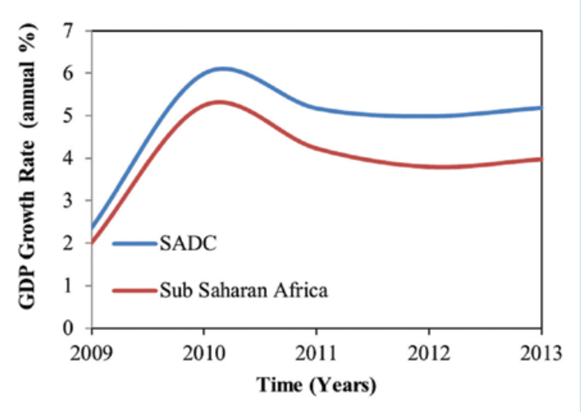


Figure 12.3: Economic growth represented by the GDP growth rate (annual %) from 2009 to 2013 (World Bank, 2015).

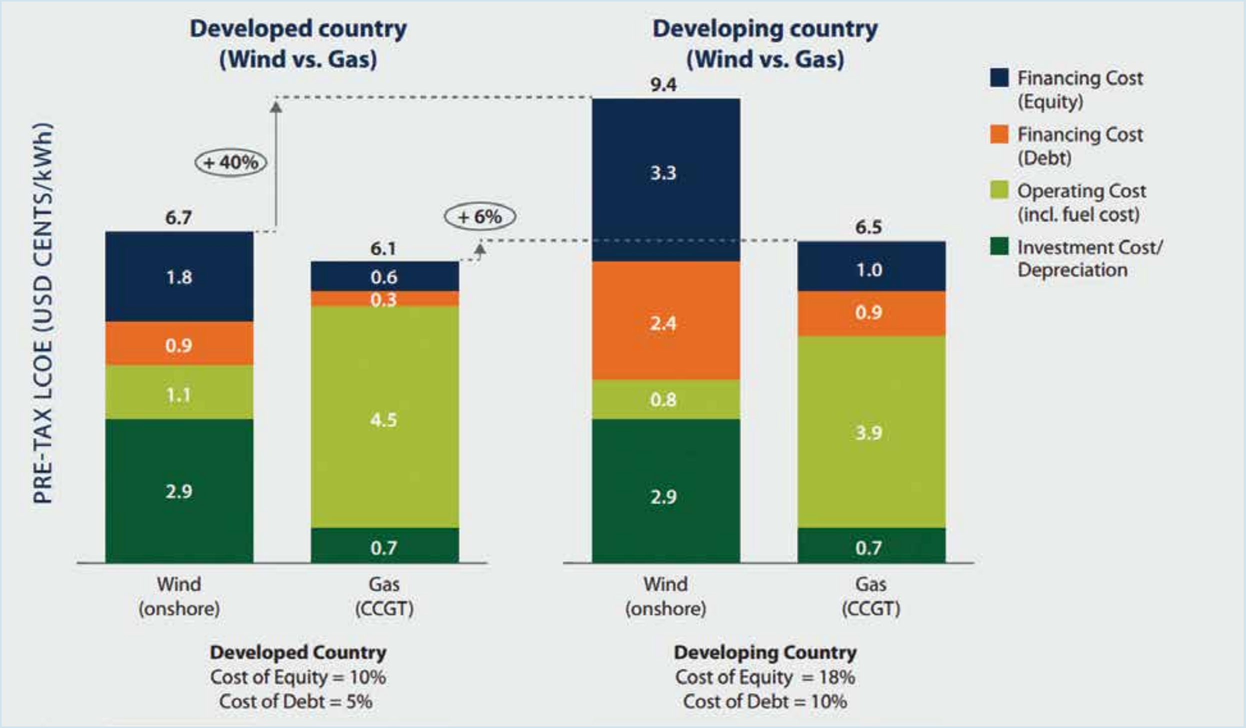


Figure 12.4: Impact of high financing costs of renewable energy on cost competitiveness (UNDP, 2014).

12.2.2. *Ambient air quality*

At the local and regional scales, the main drivers of air pollution include the consumption of biomass or fossil fuels for either industrial processes, heating and cooking needs, and transportation. The resultant air pollutant emissions are dependent on the type of fuel used, the properties of the fuel and the combustion device. For ambient (outdoor) air quality, the amount of air pollution experienced in a particular area will vary in relation to the amount of air pollution emissions released in the vicinity or transported to the region and on the prevailing meteorology. Specifically once gaseous pollutants disperse into the ambient environment, the local transport, distribution and fate of the pollutants are dependent upon the prevailing meteorology associated with temperature, rainfall, wind and atmospheric water vapour. Large-scale weather phenomena also contribute to the regional transport and distribution of pollutants over southern Africa. Subtropical anticyclones are the main large-scale weather systems that recirculate pollutants over distances spanning hundreds of kilometres (Tyson et al., 1996). A haze layer up to 500 hPa in depth within the atmosphere, blankets southern Africa containing aerosols and gaseous pollutants. The haze layer is composed of outgoing air parcels and incoming air parcels that were recirculated over the region (Tyson & D'Abreton, 1998).

Motor vehicle use in southern Africa, largely in urban areas, has substantially increased since 2000 (SADC, 2016). With the exception of South Africa, there is limited knowledge of the extent that motor vehicles and industrial activities contribute to ambient air pollution in southern Africa. Very few countries in the region have adequate industrial emission controls, vehicle emission standards and motor vehicle import control; and furthermore have poor fuel quality standards (Bhattacharjee, 2016). The lack of ambient air quality management and monitoring is a contributing factor to the air pollution that is experienced.

12.2.3. Indoor air pollution

Indoor air pollution from fossil fuel and biomass combustion is dependent on the type of fuel that is used and the combustion device used. Exposure to air pollutants in the case of indoor combustion is linked to the amount of ventilation present and the amount of time spent indoors. The activity of indoor burning usually takes place as open fires or within poor performance stoves, in rooms that have poor ventilation (Bruce et al., 2000). There are numerous political and social barriers to solving the problem of indoor air quality and energy poverty. For example, the introduction of alternative energy sources into rural or informal homes is problematic, as electrified grid connections are seen as the "ideal" form of energy by many within such communities who argue that other sources of energy is a further perpetuation of the second class services provided to the impoverished. It has also been found that the provision of electricity to rural and informal homes is not necessarily followed by its use as many people revert to using cheaper, dirtier forms of energy (Bruce et al., 2000). Furthermore, when dealing with non-permanent infrastructure such as that of informal settlements, complications arise as the source of cleaner energy needs to be autonomous in order to be sustainable.

12.3. Vulnerability of sector to climate change

12.3.1. Energy

The transmission of grid-supplied electricity is likely to be affected by climate change, with changes to temperature, evaporation and air pollution levels likely to contribute to problems with insulators on transmission lines (Mulumba et al., 2012). Fossil fuel power plants use water as a cooling medium to prevent overheating during the electricity production process (Madhlopa et al., 2014). Climate change-induced drought conditions may impact on electricity production, due to the decline of water supplies during such times. Furthermore, the occurrence of extreme rainfall events will negatively impact power plants due to an increase in the water content of coal (Schwela, 2012). Specifically, coal that is stored in open stockpiles during heavy rainfall may result in disruptions to the conveyor systems, with potential for crushed wet coal to clog mill equipment and piping. Such impacts are likely to increase the operating and maintenance costs of coal-fired power plants.

Climate change is also likely to have impacts on renewable energy production and distribution in southern Africa. Specifically, increases in precipitation could have positive implications for hydro-electric power generation whereas flooding could result in increased sediments reducing the catchment capacity (Mulumba et al., 2012). In 2000, Tanzania reported that drought conditions resulted in reduced hydro-electric generating capacity which led to the country experiencing power interruptions (black-outs). The Democratic Republic of Congo also reported a decline in hydro-electric power in July to August 2011, which was linked to the decline of reserves in the Inga Dam (Mulumba et al., 2012). Most of the grid-supplied electricity in Malawi is derived from hydro-power, which has been severely affected by droughts. Specifically, in dry years, low water flows and sedimentation of rivers occur in almost all the areas where the electricity-generating plants are located. The resultant black-outs in all these cases lead to an unreliable electricity supply, prompting greater use of charcoal and firewood and aggravating other environmental issues such as deforestation. Under climate change conditions that result in lower levels of precipitation, drought conditions could have knock-on effects for reduced electricity generation from hydropower and increased air pollution from the burning of fossil fuels and biomass.

In terms of other renewable energy sources, the availability of wind and solar is strongly dependent on climate, and thus likely to be impacted by climate change. However, there are estimates that suggest that by 2050 the long-term mean wind and solar resource potential in southern Africa will remain unchanged (Fant et al., 2016), though it is acknowledged that modelling advancements and further research are still needed to fully understand the potential impacts (Chirambo, 2016).

12.3.2. Air quality

The resultant air pollution from fossil fuel and biomass burning has been directly linked to adverse human health effects including lower respiratory infections; cancers of the bronchus, trachea and lungs; and ischaemic heart disease, stroke and chronic obstructive pulmonary disease (Lim et al., 2013). Southern African populations (e.g. Tanzania, Zambia and Lesotho) are included among the most vulnerable populations in the world to particular matter (PM) related pollution due to cooking using biomass fuels (Chafe et al., 2014). The lack of air quality legislation and controls on emissions from motor vehicles and industrial processes lead to significant air pollution. Furthermore, as a result of being unable to obtain clean energy and the appliances needed to keep their households free of pollutants, poor communities are exposed to numerous health-damaging pollutants and therefore suffer from a variety of health diseases, primarily affecting women and children. The number of deaths linked to respiratory infections is further compounded by HIV infections, resulting in higher numbers of deaths reported in some of these countries. In southern Africa alone, about 0.2 million people were estimated to have died from household air pollution in 2012 (WHO, 2015a).

Climate change is further expected to result in progressive changes to weather patterns that include changes to the distribution and amount of precipitation, temperature, wind speed, wind direction and large-scale weather-producing systems (Meehl et al., 2000). These factors all contribute to atmospheric stability and are key factors responsible for the dispersion of pollutants. These changes will therefore have an impact on the occurrence and severity of air pollution events. Furthermore, climate change is likely to result in changes to the heating and cooling requirements of households, which could result in more fossil fuel and biomass combustion.

12.4. Responses

Southern Africa faces substantial challenges in providing secure energy supply and ensuring that both urban and rural communities have access to these energy sources. It is suggested that financing difficulties inhibit many countries in the region from being able to fully exploit their potential for generating energy (Chirambo, 2016). A key facet to being able to unlock opportunities to provide equitable access to energy and pursue renewable energy technologies is through a policy framework that clearly outlines institutional support and financial mechanisms for delivery. De-risking instruments can be used by policy-makers to make the costs of renewables more affordable by addressing the underlying investment risks within a developing country. Direct incentives can also be used to cover financial cost creep using market-based instruments (UNDP, 2014). Legislation within this sector would also need to support private-public partnerships, creation of local markets for the development and uptake of cleaner energy sources and technologies, and the use of incentives to spur on changes within industrial, transportation and domestic sectors.

Coupled with the need for policy development, is the need to strengthen and retain human and institutional capacity within the energy sector, such that tertiary institutions provide courses related to energy so that within a country there are local capacity/experts on these issues that are able to work within government, industry and research. A strengthened research base will further assist to ensure that policy-makers and decision-makers are equipped with the pertinent information that can support the development of adequate systems, frameworks and supporting policy that regulate energy production, transmission and consumption in the country.

Policy and legislative guidelines are also critical to ensuring effective air quality management in the region. Where there is an absence of ambient air quality legislation, there is a need to ensure that the government is given the authority to regulate air pollution emissions and manage ambient air quality. There is further a need to ensure that air quality management responsibilities are delegated across all spheres of governance. All key sources of emissions should be identified and inventoried. Based on the likelihood to result in harm to human and environmental health, these pollutants should have defined emission limits and ambient air quality standards put in place. There is limited continuous ambient air quality monitoring that occurs in southern Africa, with the most extensive air quality monitoring occurring in South Africa (Forbes & Rohwer, 2009). Expanding on efforts to establish routine air quality monitoring in key hot-spot areas will be critical to assessing if legislation and air quality goals are being met. Air quality management should also take cognisance of potential climate change impacts on air quality by incorporating climate change considerations into air quality management plans.

A significant focus of countries with limited grid-supplied electricity should be on indoor air quality legislation. The issue of indoor biomass and fossil fuel combustion has many impacts that require well co-ordinated, integrative plans that consider air pollution impacts in order to be effectively resolved. The availability of clean energy sources and improved energy combustion devices to poor households will yield benefits of indoor air quality improvements, which are seen as a means to help combat poverty in general (Von Schirnding et al., 2002). The World Health Organization (WHO), for example, lists different types of interventions that can be applied to reduce indoor air pollution (World Health Organization, 2002):

- Interventions at the source (fuel switching, alternative fuels, improved stoves)
- Interventions to the living environment (smoke hoods, enlarged windows, chimneys)
- Interventions to user behaviour (educating people to the health risks of indoor combustion, keeping children out of the kitchen during cooking)

For rural households in particular, interventions to assist them to move up the "household energy ladder" (dung ⟶ crop residues ⟶ wood ⟶ kerosene ⟶ gas ⟶ electrification) in order to reduce exposure to indoor air pollution are needed. As renewable energy is seen as a source of cleaner energy, implementation of these types of interventions ultimately reverts back to the need to have adequate energy policies in place and strong frameworks to ensure the implementation of these policies.

Case study: Renewable energy in South Africa

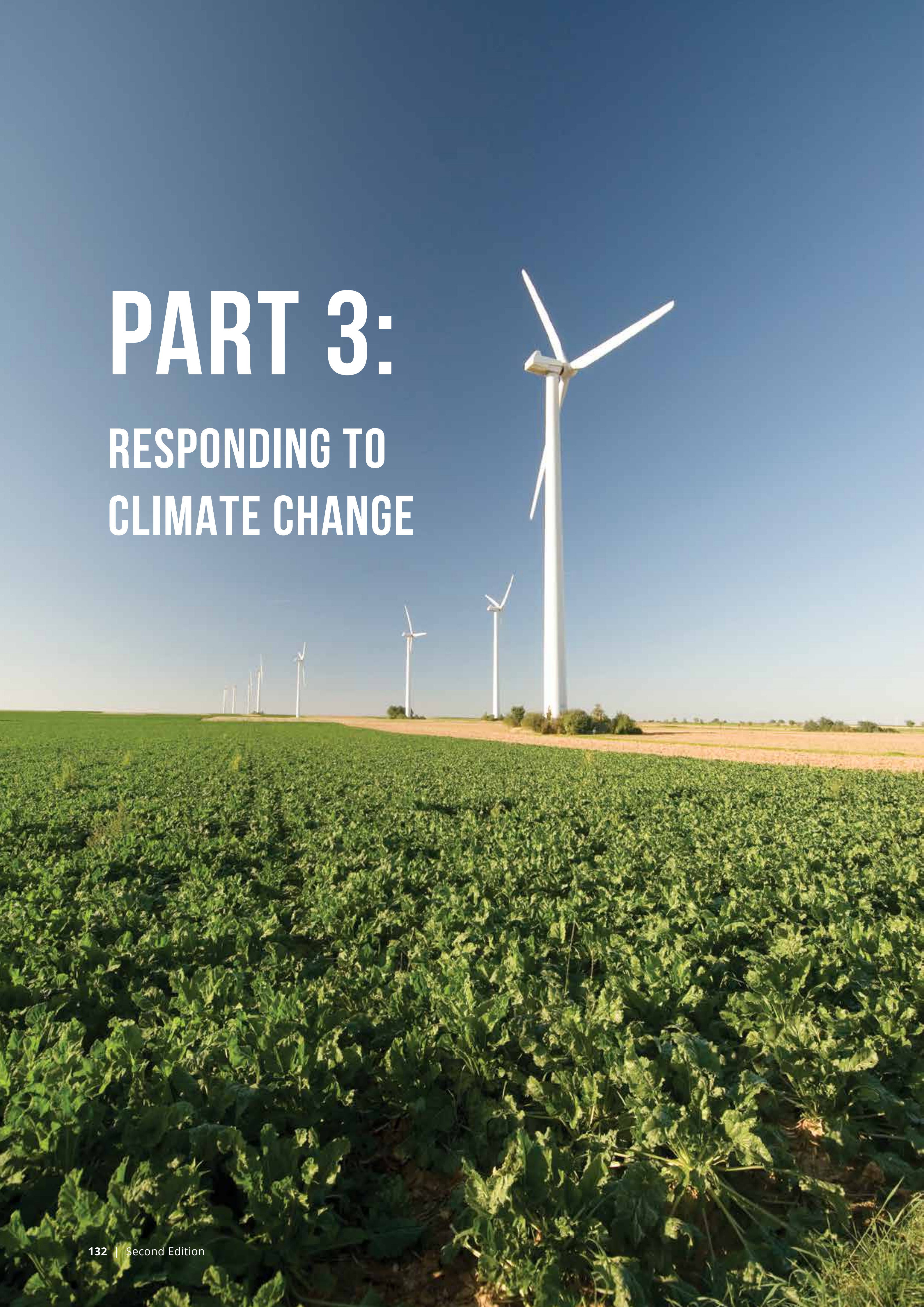
Energy sector initiatives and reforms aimed at improving people's access to modern energy and energy services have faced challenges in southern Africa, on account of incomplete policy reforms, low rates of electrification, and lack of financial investments and technological knowledge (Chirambo et al., 2016). In South Africa, however, the country has implemented numerous policy interventions that have in recent years resulted in the country being ranked among the top 10 countries with respect to Renewable Energy investments.

The road toward this renewable energy pathway began with the country's White Paper on Energy Policy (1998), which recognised that the implementation of renewable energy technologies was imminent, and that such technologies would become cost competitive and cost effective, meaning the country's vast renewable energy base would create numerous opportunities in the future. The development of renewable energy as part of this envisaged energy mix would allow for more sustainable energy generation and was considered to provide the least-cost energy service when social and environmental costs are included in the equation.

The country's White Paper on Renewable Energy (2003) outlined the vision for energy to be produced from renewable energy sources (mainly from biomass, wind, solar and small-scale hydro). The National Climate Change Response Policy White Paper of 2011 lent further support to the country's goals for renewable energy, outlining the Renewable Energy Flagship Programme, integral to deployment of renewable energy technologies. The country sought to find a way to finance and implement its policy imperatives for renewable energy.

A competitive Renewable Energy Independent Power Producers Procurement Bidding Programme (REIPPPP) was implemented in 2011. The REIPPP has supported 92 independent power producers who will contribute in excess of 6,327 MW and is highly regarded as successful in creating an enabling framework for attracting private sector investment and expertise for renewable energy. It is reported that by June 2014, the country had established 1.9GW new renewable energy capacity for electricity production and delivered in excess of 5TWh of clean energy per annum into the energy mix. Through the REIPPPP the country has been successful in unlocking market potential and creating enabling conditions for the development of renewable energy. The effective channelling of private sector expertise and investment into grid-connected renewable energy in the country has been supported by a transparent procurement framework. Further to this, the team implementing the REIPPPP had a strongly established record in private-public partnerships and thus were viewed favourably by both the public and private sectors.

While not all developing countries will have the same resources to duplicate the REIPPPP, it does offer valuable lessons to other countries in terms of how to effectively procure renewable energy (Hagemann, 2013).



PART 3:

RESPONDING TO CLIMATE CHANGE

CHAPTER 13:
REGIONAL CLIMATE CHANGE STRATEGIES AND INITIATIVES

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13.1. Introduction

The transboundary nature of climate change necessitates regional cooperation and action in the form of comprehensive strategies and policy. Article 5(2)(a) of the Treaty of the Southern African Development Community, 1992 (SADC Treaty) states that for the region to attain the objective of sustainable development, the harmonisation of political and socio-economic policies is necessary (Barnard, 2014). The SADC approach to climate change has focused on both mitigation and adaptation to increased climate variability and change (Lesolle, 2012), and has aimed to link climate change with the socio-economic development frameworks of the 15 SADC member states.

In August 1997, all SADC member states ratified the United National Framework Convention on Climate Change (UNFCCC), joining a host of nations in doing so, and providing one key component of post-1994 policy in the environmental sector and beyond. In committing to UNFCCC and the Kyoto Protocol, countries committed to supporting the global goal of stabilising greenhouse gas (GHG) concentrations at a level that would inhibit human-induced global warming and climate change. More recently, all 15 member states have signed the Paris Agreement, which aims to reduce GHG emissions in order to limit global temperatures from rising by more than 2 °C by 2100. In addition, SADC is committed to achieving the Sustainable Development Goals (SDGs) elaborated at RIO+20, with a range of cross-cutting features in the area of climate change (including focusing on co-benefits and multiple synergies).

The number of climate change-related programmes and initiatives are increasing in SADC, with the most recent strategies approved comprising the SADC Climate Change Strategy and Action Plan, the SADC Regional Green Economy Strategy and Action Plan for Sustainable Development, and the SADC Science, Technology and Innovation Implementation Framework to Support Climate Change Response 2020 (SADC/STI-IFCCR 2020). The following section outlines these documents and the progress made to date.

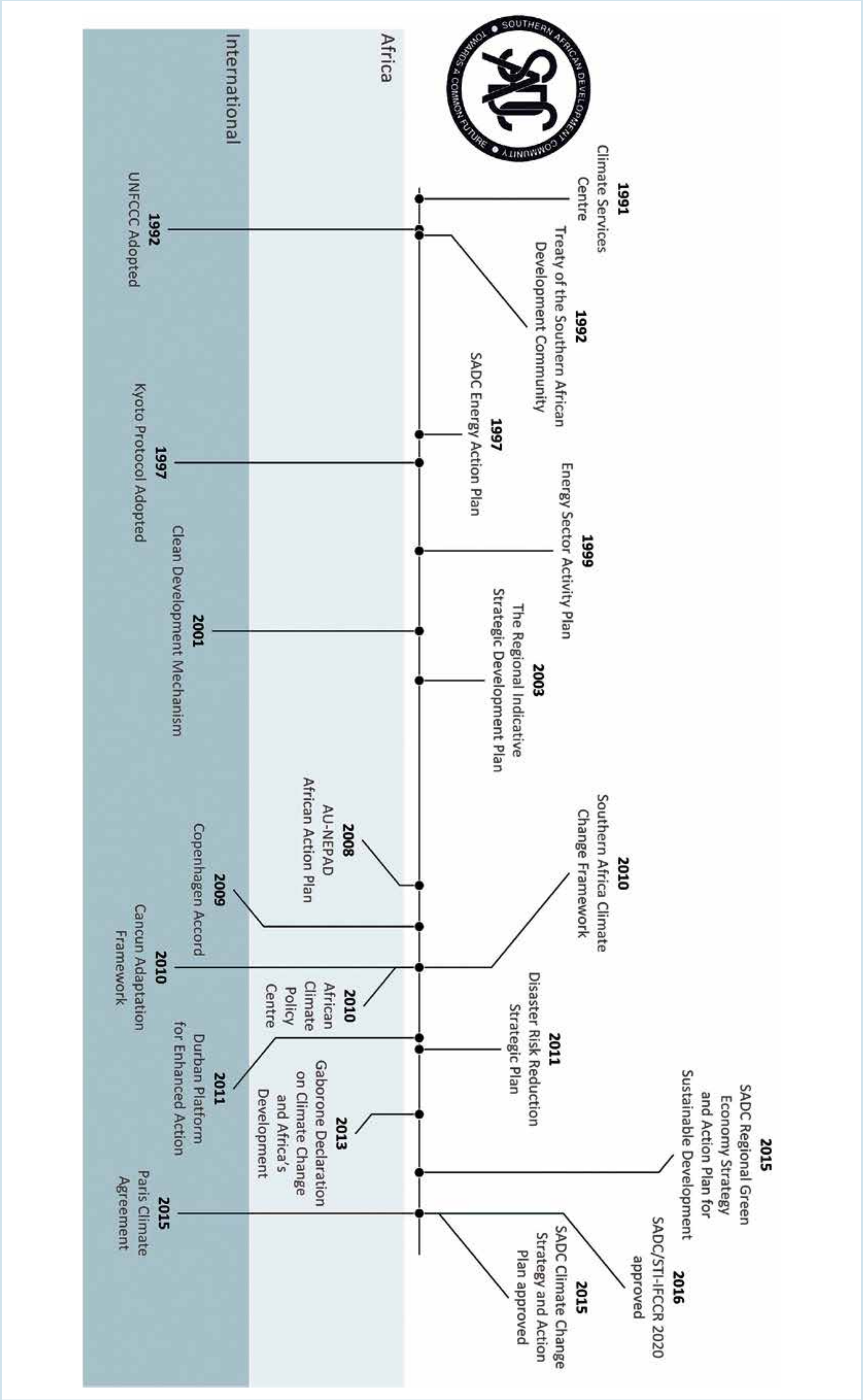


Figure 13.1: Timeline of SADC climate change strategies and relevant regional and international action plans and agreements

13.2. SADC Climate Change Strategy and Action Plan

Status

The SADC Climate Change Strategy and Action Plan was developed in response to requests by the SADC Food, Agriculture and Natural Resources (FANR) Directorate, taking place throughout 2010 and 2011, to develop a Regional Climate Change Strategy, a Regional Synthesis Paper on knowledge gaps and a Position Paper on best practices for developing a Regional Strategy. The two latter products have been rather dynamic in development, but the strategy has gone through a number of drafts, was validated with revisions at the validation workshop in Gaborone, Botswana for the three strategies under discussion there (Green Growth, Climate Change, and Climate Change STI); and revised in a revisions working group in Johannesburg in early July 2015. The strategy, along with the Green Growth Strategy, was approved by the Southern African Ministerial Conference on the Environment (SAMCEN) in November 2015.

Provenance

As in the case of the Green Growth Strategy, the Climate Change Strategy has been years in gestation, but arose in part out of the increased recognition throughout 2010 and 2011 (not unrelated to the COP in Durban) that while national strategies for climate change were in progress, SADC required an aligned, coordinated regional response to climate change, housed in or linked to FANR. One of the more difficult elements going forward is where not only this strategy, but also its sister strategies would be housed and implemented, and writing teams have attempted (with partial success) to align implementation architecture and modalities.

Structure and main adaptation themes

As in the case of the Green Growth Strategy, the Climate Change Strategy has considered impacts and adaptation options by sector. Although authors have attempted to work in cross-sectoral approaches (the strategy has been revised and commented on multiple times across working group teams), this remains a significant challenge to mainstream climate change planning across different sectoral plans and policies (see, for example, Stringer et al., 2014).

Adaptation interventions have been designed per sector, and revised by the working group, with accordant timelines, and, where possible, costs incorporated. Where possible, the interventions have been designed to align with the adaptation interventions identified in the Green Growth Strategy. As one example, alignment has been sought around conservation agriculture, strategies for building resilience in manufacturing and mining (for example, water conservation and quality measures in mining), and strategies for building resilience in the tourism sector. Both strategies include elements of infrastructure, and what investments to create more resilience in this area might comprise.

Implementation and modalities

One of the most difficult areas under discussion in the development of this strategy has been the means for implementation of the strategy. Since all strategies effectively consider the use of the Regional Development Fund as a repository and vehicle for investment in the measures proposed, the question of where implementation would lie is particularly politically charged.

In the case of the SADC Climate Change and Green Growth Strategies, the recommendation is that the body for implementation, with an eye to ensure cross-sectoral coordination, fall above SADC, comprising a SADC Environmental Committee with oversight, as well as modalities around the Regional Development Fund that would fall outside of SADC. This discussion is still in progress, as plans move to implementation.

13.3. SADC Regional Green Economy Strategy and Action Plan for Sustainable Development

Status

After a stakeholder consultation workshop in November of 2014 in Harare, a revised version was presented at the May 2015 validation workshop in Johannesburg. A final version has now been approved by SAMCEN (please note: both the Green Growth Strategy and the Climate Change Strategy fall under FANR, and thus under SAMCEN). The SADC STI Strategy falls effectively with the Science and Technology desk at SADC, and it has thus been presented at the SADC Sectoral Ministerial Committee on Science and Technology (SAMCOST).

Provenance

The strategy was effectively drawn out of the recognition that SADC needed to review progress towards goals of sustainable development (influenced in part by the RIO+20 UN Conference on Sustainable Development, where the SDGs were elaborated), particularly linked to requirements of the Multilateral Environmental Agreements – MEAs (as well as negotiation targets). It theoretically represents recommendations, gaps and requirements in order to address the attainment of such goals. It is designed to link to a range of existing and in progress strategies and protocols, including the RISDP, the Infrastructure Development Masterplan, the SADC Industrialization Policy, and the Regional Agriculture Policy. Discussions are currently under way in terms of linking the strategy (as in the case of the others) to the SADC Resilience Framework (described here).

Structure and main adaptation themes

The Green Growth Strategy comprises six main sections, two of which have particular relevance for adaptation:

GE Policy

Policy options and instruments under discussion include (but are not limited to) feed-in tariffs for renewable energy; removal of fossil fuel subsidies; "polluter pays" and "user pays" taxes; as well as discussions around green market incentivisation (very much an emerging conversation). These obviously have relevance to adaptation – and again, there have been concrete (if ongoing, and challenging) attempts to align these policy and instrument recommendations with the sister climate change strategies – both in terms of adaptation and mitigation (and areas where there are synergies).

GE Action Plan by Sector

Main adaptation themes are covered in the Action Plan by Sector, which, again, has been designed to link to the two sister climate change strategies. Sectors covered comprise Agriculture and Livestock, Water, Forestry and Biodiversity, Fisheries, Energy, Manufacturing and Mining, Waste, Transport, Tourism and Cities. The action plans comprise key interventions with both time and financial scoping. There are significant multiple benefits for adaptation, both directly and acknowledged, as well as indirectly. For example, in the water sector, trans-basin management and adaptive management of dam resources are considered; while in the agriculture and livestock sector, approaches to ensure sustainable agriculture and a more resilient agricultural system are outlined.

Implementation architecture

The implementation architecture for the Green Growth Strategy is designed to align with that recommended for the two sister climate change strategies, although as mentioned earlier, this discussion evolves as the plans move to implementation.

13.4. SADC STI Implementation Framework to Support Climate Change Response (SADC/STI-IFCCR 2020)

Status

The SADC/STI-IFCCR 2020 was revised in response to the validation workshop held in Johannesburg in May 2015, and is currently under consideration by representatives of SAMCOST, and the Science and Technology desk at SADC. A revised implementation plan is also in design (building on older work undertaken in 2011). The strategy was conditionally approved by SAMCOST in Maputo, 2014 and given final approval at the Joint Ministerial Meeting in Gaborone, on June 30th, 2016.

Provenance

The strategy has been some years in design, with iterative consultations and revisions. In August 2008, SAMCOST hinted at the need to develop a coherent STI framework to support climate change response. The following year, in August 2009, STI senior officials met in Pretoria and mandated South Africa (the Department of Science and Technology) to lead the process of developing the framework. In June 2010, the DST secured funding from Australia to support the development of the framework, and two initial drafting workshops were held – in Windhoek, Namibia, in August 2010, and in Gaborone, Botswana, in March 2011. In May 2011, in Windhoek, SAMCOST endorsed the resulting report containing the draft framework and mandated further development of the framework.

In June 2011, in Pretoria, the draft framework was finalised, and presented to a technical cooperating partner's forum, while in November 2011 the draft framework and the process of developing it were presented as a COP11 side event. In December 2012, the task team responsible for refining the plan met in Benoni, South Africa, to develop the framework's implementation plan.

In June 2014, the implementation plan was tabled at the Joint SADC Ministerial Meeting on STI and Education and Training, in Maputo, Mozambique, obtaining conditional ministerial approval (technical content approved, institutional arrangements and budget to be refined). In December 2014, further refinement was undertaken by the task team, at SADC House in Gaborone, including alignment with the 'sister' Climate Change and Green Economy Strategies. All three strategies were reviewed and revisions recommended at a Validation Workshop in May 2015. The framework and schedule were given final ministerial approval in Gaborone, on June 30th, 2016.

Structure and main adaptation themes

The strategy has four areas of focus, including adaptation – but interventions under other areas of focus also have adaptation implications/components:

- Systematic observation and monitoring;
- Impacts, vulnerability and risks;
- Mitigation;
- Adaptation.

Intervention areas under Adaptation are as follows, with their relevant section numbers shown. At present, older time and costing details have been omitted – they are currently under renewed design.

- Downscaling of climate change models – to inform adaptation strategies and responses (4.4.1);
- Develop portfolio of projects in green technologies (4.4.2);
- Long-term adaptation scenarios (4.4.3);
- Research focusing on the facilitation of value addition, optimisation and commercialisation (including appropriate IPR instruments) for indigenous knowledge systems (IKS) (4.4.4);
- Research and development with reference to disease-resistant and stress-tolerant crops; and key species in the biodiversity sector (4.4.5).

It is important to note that interventions shown here (as well as in other sections) are edited for repetition and redundancy, as far as possible.

Implementation and modalities

The means of implementation and modalities for taking the strategy forward, have, as in the case of the other strategies, been one of the more challenging areas of work.

In response to edits in December 2014, the STI Strategy was given precisely the same modalities for implementation as the Climate Change and Green Growth Strategies – namely the establishment of a Sustainable Development Committee, or similar body, that would sit above FANR, and report directly to the office of the Deputy Executive Secretary (with similar financial arrangements around the Regional Development Fund). This has proved, for all strategies, to be a challenging discussion.

In the case of the STI Strategy, working groups at the Validation Workshop in May 2015 made a slightly different recommendation, and a compromise has now been reached and approved.

Conclusion

It is clear that a priority area for work on the strategies described here includes how to align them, such that co-benefits may be realised, and action on the strategies has the opportunity to mutually reinforce each other. In southern Africa, and on the continent more broadly, successful examples of such alignment and achievement of multiple synergies are still somewhat thin. With increased attention in this area, however, including a clear focus within international process such as the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), it is hoped that the next decade will be more successful in this regard.

CHAPTER 14:
ADAPTATION AND MITIGATION: SYNERGIES AND TRADE-OFFS

AUTHORS: TIRUSHA THAMBIRAN AND SASHA NAIDOO

14.1. Introduction

Typically, mitigation and adaptation research has been developed separately, with the mitigation research community focused on taking a global approach to limiting cumulative greenhouse gas (GHG) emissions. The adaptation research community, however, emphasises locally-focused analysis aimed at minimising the impacts of climate change, especially within the most vulnerable communities. International climate policy has historically developed with a focus on mitigation, though in recent years increased attention has been placed on adaptation. For example, at the 21st Conference of the Parties (COP-21) to the UN Framework Convention on Climate Change, countries also committed toward adaptation responses within their Nationally Determined Contributions.

As adaptation is increasingly receiving attention in the international climate policy and financing space, there has been a growing body of literature (Launder et al., 2015; Berry et al., 2014; van Vuuren et al., 2011 and Wilbanks et al., 2007) that indicates that there are many complex interactions and interdependencies between climate change impacts, adaptation and mitigation. It is increasingly recognised that decisions that are made now could lock in development trajectories for a long time and that there is a need to understand how the mitigation of GHG emissions and climate impacts (and vice versa) interact in the development of policy.

Mitigation and adaptation strategies within southern African countries have typically been developed without explicit consideration of interactions and linkages between these strategies. Focusing on the synergies, trade-offs and conflicts between these issues provide an opportunity to bridge the gap between responding to priorities to address vulnerability to climate change impacts in developing areas and achieving global engagement in mitigation. Specifically, developmental growth could proceed in a way that will allow countries to become more resilient while maximising opportunities to synergistically reduce emissions and minimise potential trade-offs for mitigation. This chapter explores common synergies and trade-offs between mitigation and adaptation and considers the implications for climate change policy responses in southern Africa.

14.2. Linking adaptation and mitigation

Adapting to the impacts of climate change, mitigating GHG emissions and enhancing sinks are effective strategies in managing climate risk. Typically, adaptation and mitigation have been viewed in a linear manner such that emissions are first characterised to understand how climate will change, to then understanding the potential impacts of climate change and the responses that are needed, as shown in Figure 134.1 (van Vuuren et al., 2011).

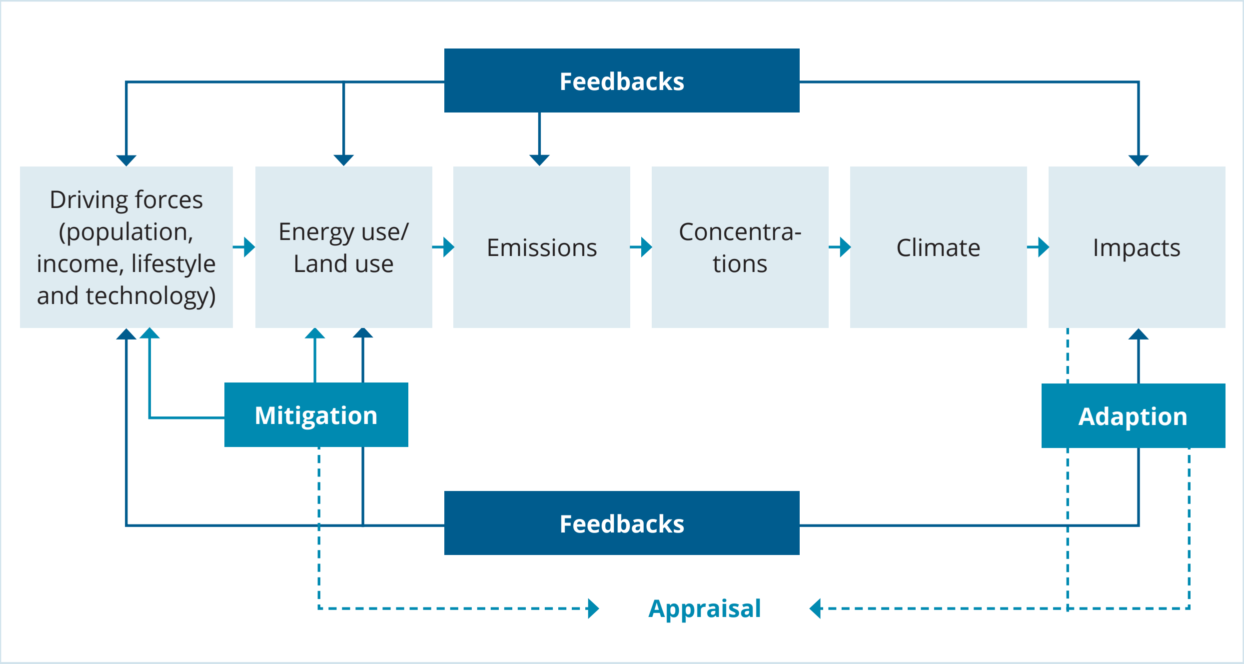


Figure 14.1: Linkages and potential feedbacks between climate change mitigation and adaptation using the driving force-pressure-state-impact-response framework (van Vuuren, 2011).

There are various links and potential feedbacks that exist between adaptation and mitigation (Figure 14.1). As such, responses may not always complement each other, and in some instances, may be counterproductive. At a global level, the potential impacts of mitigation for adaptation, and vice versa, are perhaps easier to conceptualise. Intuitively, more mitigation will equate to less adaptation, however, the type and location of mitigation measure could have trade-offs for adaptation (Calvin et al., 2012). Likewise, climate impacts on key socio-economic sectors may increase the costs of mitigation (Calvin et al., 2012). Most often win-win solutions (or measures that have synergies) for simultaneously addressing both adaptation and mitigation are found at a local level (Laukkonenen et al., 2009; Walsh et al., 2011; and Vigué and Hallegate, 2012), notably through options such as climate-smart agriculture interventions (Lipper et al., 2014) and through measures for mitigating the urban heat island (UHI) effect (Laukkonenen et al., 2009; Dulal, 2017).

Cities are potential hotspots of vulnerability to the impacts of climate change owing to their high concentration of people and assets (Walsh et al., 2010). Climate is variable locally and regionally and this means that the magnitude of climate impacts also varies from city to city. Vulnerability of individuals and communities to climate change impacts is determined by various factors linked to the location and the level of development of each community. In addition, urban climate policies are implemented in conjunction with economic and social policies, which results in interactions between policy goals. As such, socio-economic change can be just as crucial in determining the magnitudes of impacts as climate change (Hall et al., 2005).

The interrelationship between adaptation and mitigation at a local level is complex and there are different implications for each response for spatial planning (see Beisbroek et al., 2009). There is also a tendency for certain sectors to have an adaptation or mitigation focus: sectors vulnerable to climate change usually prioritise adaptation, whereas mitigation is predominantly considered within the energy, transport and industry sectors (Huq & Grubb, 2007).

The Agriculture, Forestry and Other Land Use (AFOLU) sector and infrastructure planning are considered integral components of an urban environment. These sectors are known sources and sinks of GHGs and are important to consider from the perspective of developing low-carbon cities. Due to the dual role these key sectors could play in the areas of mitigation and adaptation, there are likely to be synergies and trade-offs from different policies that are implemented. The AFOLU sector (Box 134.1) highlights potential for synergies that have been exploited by SADC within the REDD+ initiatives. Further to this, the interrelationships between climate change response strategies and land use and land cover changes are complex and diverse. When planned and managed properly, urban agriculture can contribute to climate change mitigation efforts by lowering the ecological footprint associated with food production, and contribute to adaptation efforts by increasing vegetation cover and reducing surface water run-off, while at the same time conserving biodiversity (UN-Habitat, 2014). Urban vegetation can also contribute to the reduction of the UHI effect, and microclimate amelioration (Chang et al., 2007), in conjunction with urban forestry (e.g. the formation of urban parks and tree planting along streets), which promotes adaptation to heat stress due to warming while also leading to carbon sequestration in trees and soil. A multi-species, multi-purpose approach would help reduce the vulnerability of trees to climate change (Ravindranath, 2007).

Agroforestry, one of the most conspicuous land-use systems across landscapes and agroecological zones in Africa, provides another good example of a mitigation-adaptation synergy in the AFOLU sector. Trees planted provide assets and income from carbon and provide wood energy, improved soil fertility, while ecosystem services and tree products can provide livelihood benefits to communities, especially during drought years. Most of these benefits have direct value for local adaptation while also contributing to global efforts to control atmospheric GHG concentrations (Mbow et al., 2014).

In conjunction with synergies, it is necessary to consider trade-offs that may occur between adaptation and mitigation activities that do not always complement each other, and may in some instances be counterproductive. Afforestation and reforestation contribute to enhanced carbon sequestration potential while increasing soil water retention, preventing erosion and landslides. There may be competition between land uses where some monocultures planted could have a negative impact on water availability or reduce biodiversity (Bustamante et al., 2014). Similarly, mangroves contribute to storing carbon in addition to protecting coastal areas. However, there may be trade-offs between carbon and the local ecosystem services prioritised by an adaptation project where, for example, spatial priorities for the conservation of hydrological ecosystem services and carbon may be different (Locatelli, 2011).

Infrastructure and planning in cities encompass issues of energy, transport, building, industries and water where the interactions across sectors have the potential for many synergies and trade-offs. Spatial configurations of urban areas and land-use plans have significant implications for both adaptation to climate change (Hurlimann and March, 2012) and reduction of GHG emissions (Lindley et al., 2007). For example, ensuring the survival of mangroves as a barrier against storm surges (adaptation-related responses) involves land-use and land-management decisions, while GHG emission and energy use (mitigation-related responses) are dependent on urban form (Walsh et al., 2013). The case study shown later in this chapter, highlights the co-benefits of using an integrated approach toward adaptation and mitigation responses in the AFOLU and infrastructure planning sectors to alleviate the impact of the UHI. Other examples of the synergies and trade-offs of measures that are typically taken within each of these sectors are shown in Tables 14.1 and 14.2.

Box 14.1: Synergies and trade-offs in the Agriculture, Forestry and Other Land Use (AFOLU) sector

The sector is considered multifunctional, diverse and unique since it is the only sector with sources and sinks of GHGs. The mitigation potential of the AFOLU sector is extremely important in meeting emission reduction targets. The sector offers a variety of cost-competitive mitigation options and most approaches indicate a decline in emissions largely due to decreasing deforestation rates (Bustamante et al., 2014). While references to adaptation or the development of adaptive capacity are rarely included in these mitigation activities, adaptation practices could be included synergistically in most mitigation projects and contribute to the sustainability of the project outcomes.

Carbon emission reduction through REDD+ can contribute significantly to land-based mitigation in two ways: firstly, reducing land-based GHG emissions and secondly, sequestering carbon dioxide through reforestation and agroforestry. Forest mitigation projects such as REDD+ and CDM, for example, have the potential to facilitate the adaptation of forests to climate change by reducing anthropogenic pressures on forests, enhancing connectivity between forest areas and the conservation of biodiversity hotspots, and increasing the value and resilience of forests (Locatelli, 2011). A priority for SADC in their REDD+ programmes was not just to reduce emissions, but for REDD+ to be used as a mechanism for enhancing national development and thus creating the capacity to curb emissions from land-use change and forestry.

Table 14.1: Examples of climate change synergies and trade-offs in the AFOLU sector

Sector	Measure	Synergies		Trade-offs	
		Mitigation	Adaptation	Mitigation	Adaptation
Forestry	Afforestation/ reforestation	Enhanced carbon sequestration potential; Increase C storage (on newly planted land)	Increased habitat diversity and habitat availability; restore water quality	Subsequent thinning and management can reduce C storage	Competition between land uses; some monocultures may have a negative impact on water availability
	Controlled burning of grasslands	Increases soil carbon stock; carbon sequestration	Control invasive plant species, reduce fuel loading to reduce catastrophic wildfire risk; manage land for endangered species (ensure ongoing recruitment of important plant species); reduces risk of runaway fires (through use of firebreaks); ensures catchments are functioning effectively	Increases black carbon emissions	
Land-based agriculture	Cropland management and grazing and land management	Increases soil carbon stock; carbon sequestration	Appropriate management practices can support regulation of the hydrological cycle and protection of watersheds; soil conservation; improvement of soil quality and fertility		Competition between land uses; Impacts on N&P cycle; potential water depletion due to irrigation; some monocultures may have a negative impact on water availability
	Conservation agriculture	Possible increase in soil C storage, reduce energy inputs	Improve crop water efficiency; increase soil water storage; reduce N leaching	Increase GHG emissions depending on measure and implementation	Possible weed and pest control problems
Other land uses	Wetland/ coastal habitat creation	Enhanced carbon sequestration	Increased habitat; species richness and carrying capacity; long- term improvement in water quality; decreased flood risk	Increase in CH_4 and N_20 emissions	Loss of agricultural land; short-term impact on water quality may be negative

Table 14.2: Examples of climate change synergies and trade-offs in the infrastructure planning sector

Sector	Measure	Synergies		Trade-offs	
		Mitigation	Adaptation	Mitigation	Adaptation
Energy	Energy-efficient stoves	Reduced emissions due to more efficient burning, improved carbon sequestration due to avoided deforestation	Reduced vulnerability to landslides, droughts and extreme events due to ecosystem management. More resilient livelihoods due to health benefits, time and cost saving sin households	-	-
	Improve thermal and electrical efficiency of buildings	Reduce GHG emissions related to the generation of electricity from coal	Retrofitting inefficient bulidngs can enhance the existing building stock through densification in the land-use and the use of green infrastructure.	-	-
Transport	Reduce energy consumption from road transportation	Reduce air pollution and GHG emissions	Reduced vulnerability to air pollution	-	-
Building/ Infrastructure	In designing new buildings use green roofs	Carbon sequestration	Stormwater. infiltration and flow reduction	-	-
	Storm surge barriers	-	Protection urban areas from flooding	-	Potential to damage natural coastal defences and increase rates of erosion
Water	Urban densification	Reduce GHG through reduced distance for travel	-	Increase GHG and air pollution due to congestion	Possible increased run-off

14.2. Responses to linking mitigation and adaptation

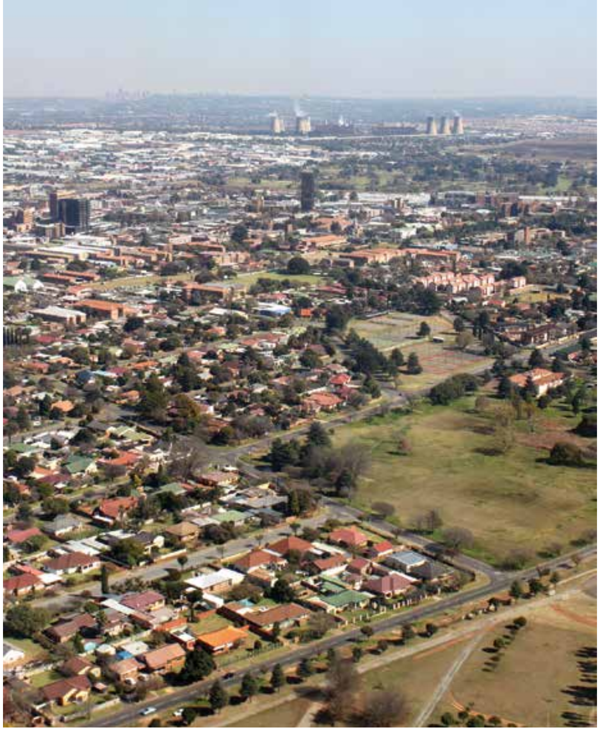
The prospect of balancing mitigation and adaptation endeavours is attractive, especially within a developing country context with competing priorities. Synergies among mitigation and adaptation actions should be enabled to support sustainable development (Suckall et al, 2015) and the creation of more efficient, responsive and comprehensive climate policies. Without integrative decision-making, climate change mitigation and adaptation interventions could result in energy-intensive adaptation or mitigation that contributes to maladaptation; either of which can lock a city into a development trajectory (function and form) that has unintended trade-offs. The development or intensification of UHI effects (refer to case study on the UHI below) impacts on air and water quality, as well as increased risks to natural disasters such as floods due to reduced permeability, being key examples of concern.

Cities in developing countries are expected to be most impacted by climate change, however, these areas still have significant potential for further growth and development, and thus present opportunities for the planning of energy provision, infrastructure, roads and waste management in a manner that will facilitate a reduction of GHG emissions, while simultaneously building the resilience of communities to the potential impacts of climate change and vice versa. Given the developmental trajectory of many southern African countries, opportunities for sustainable development pathways can be charted by enhancing our understanding of how these sectors are likely to be impacted by climate change in conjunction with processes of long-term change, e.g. economy, changes in demography.

Comprehensive responses that link and integrate climate change adaptation and mitigation activities to support the sustainable development of vulnerable communities within urban environments are essential to ensure that development goals are met in a sustainable and cost-effective way. A broad interdisciplinary approach is needed to develop a better understanding of cross-cutting issues and interactions between the different sectors and stakeholders within the city, and beyond the urban limits to address climate change effectively in an urban environment (Viguié et al., 2012; Illman et al., 2013).

The complexity of integrated approaches may hamper decision-making. For this reason, methods and tools to facilitate and inform integrated assessment are needed to help design integrated responses (Walsh et al., 2011). Internationally, numerous initiatives have begun to build the capacity to work on integrated assessments of mitigation and adaptation (see for example Masson et al., 2014) and simulating the effects of different mitigation and adaptation options (Hoyman and Goetzke, 2016). While many integrated assessment models (IAMs) have been proposed, few are fully developed and tested, with the result being that there is little quantified information on synergies and trade-offs. From a southern African perspective, we lack access to comprehensive and suitable integrated assessment models or tools that can be used for further investigation into understanding the opportunities for synergies and trade-offs for different climate change responses. However, policy-makers can still create enabling conditions for synergies, through the design and implementation of climate change strategies that address both mitigation and adaptation.

This is key to facilitating institutional arrangements such that there can be an implementing body with a mandate to ensure that these issues are considered for synergies, to source financing, and undertake programmes and projects that are likely to yield substantial benefits for mitigation and adaptation (Duguma et al., 2014).



Case study A: Mitigating the urban heat island in African cities

By Sasha Naidoo and Tirusha Thambiran

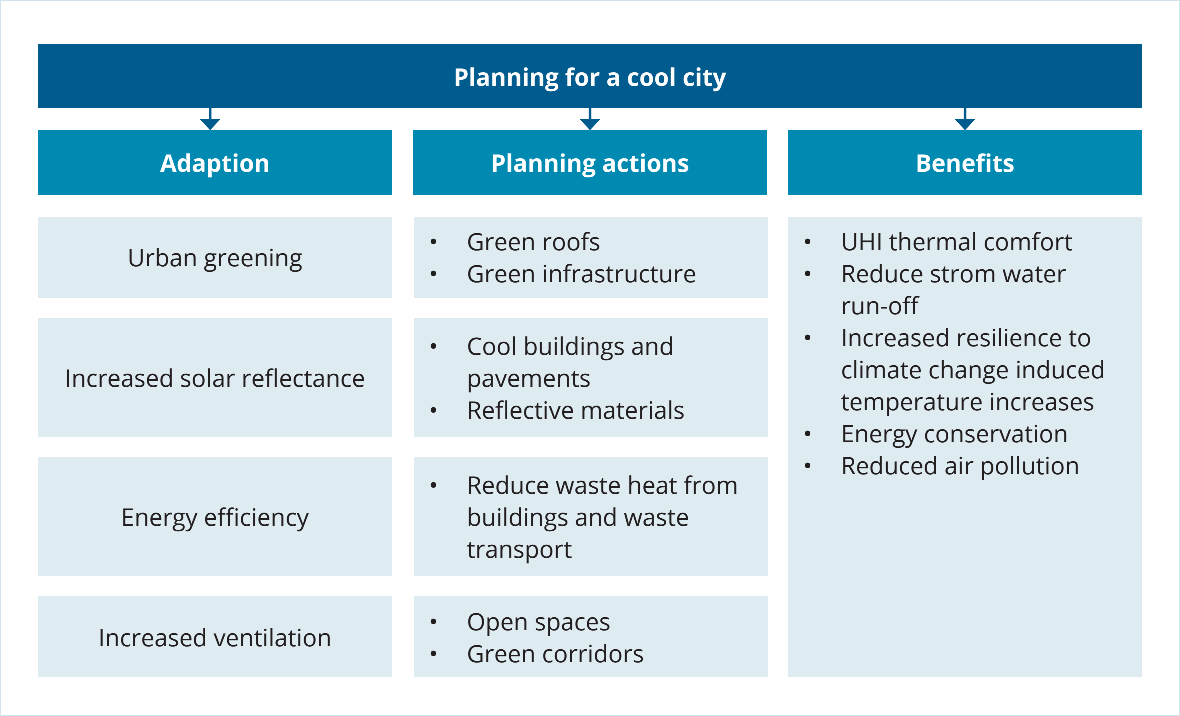
Africa has the highest rate of population growth among major areas, growing at a pace of 2.55% annually in 2010-2015, with the population projected to increase by 1.3 billion people between 2015 and 2050 (United Nations, 2015). While Africa remains mostly rural, with 40% of the continent's population living in urban areas, this figure is projected to increase to 56% by 2050 (United Nations, 2014). African governments have been advised to take early action to position themselves for predominantly urban populations (UN-Habitat, 2010). Johannesburg (South Africa), Dar es Salaam (Tanzania), and Luanda (Angola) are expected to emerge as megacities by 2030 and each of their populations is projected to surpass the 10 million mark (United Nations, 2014). The increasing urbanisation rate is adding pressure on cities to provide services, housing and infrastructure to an increasing population.

Urbanised cities generally have replaced natural land surfaces with materials that retain heat, as well as experience waste heat from buildings, motor vehicles and industries. Altering the local environment can result in local environmental stresses. Rapid urbanisation coupled with climate change could, among other issues, increase the local urban heat island (UHI) effect. The UHI, a phenomenon where a temperature difference between the built-up environment and the surrounding (natural) environment exists, is of increasing concern given that more people are moving to cities each year. This contributes to the intensity of the UHI increasing and the number of people affected by it. The extent of the temperature differences varies in time and space due to the influence of meteorological, locational and urban characteristics. The UHI effect is of increasing concern in Africa given that more people are moving to cities each year and are thus likely to be affected by it. It is critical to understand the interactions that take place among the urbanisation process, current local environmental change, and accelerating climate change, and how they influence each other (Revi et al., 2014). It is also expected that the UHI will be compounded by the temperature increases projected for Africa.

Limited studies have previously been undertaken to characterise the UHI in African cities, e.g. in Ibadan, Nigeria (Adebayo, 1987) and Johannesburg, South Africa (Goldreich, 1992). More recently, studies have been undertaken in South Africa, e.g. Johannesburg (Hardy & Nel, 2015); eThekwini (Durban, KwaZulu-Natal) (Odindi et al., 2015a; Odindi et al., 2015b); Buffalo City and Nelson Mandela Bay (Eastern Cape) (Odindi et al., 2015b); Dar es Salaam, Tanzania (Lindley et al., 2015; Kibassa, 2014); and Cairo, Egypt (Rehan, 2014; Abutaleb et al., 2015). While these studies provide evidence of urban temperatures being higher in urban than rural areas, there are still gaps in understanding how these temperatures will change in the future under climate change, with greater urbanisation. As such, cities should not just plan to manage heat as an extreme event, but rather also respond to urban energy/heat challenges through addressing the built environment and adopting systematic approaches to cooling cities.

Open spaces, buildings, and road transport are key areas in which interventions can be implemented in support of reducing the occurrence of the UHI. Key interventions include expanding green spaces in cities, increasing the albedo of the urban environment, reducing energy consumption and waste heat from buildings and road transport, as well as increasing ventilation (refer to Figure 14.2). A 'one-solution-fits-all' approach cannot be adopted across cities in Africa since UHI mitigation measures vary in scale and each key area has different drivers and associated challenges. As such, optimal strategies for managing and responding to the UHI should be done on a city-by-city basis.

Case study A: Mitigating the urban heat island in African cities (continued)



Planning for a cool city

Adaption	Planning actions	Benefits
Urban greening	Green roofs Green infrastructure	UHI thermal comfort Reduce strom water run-off Increased resilience to climate change induced temperature increases Energy conservation Reduced air pollution
Increased solar reflectance	Cool buildings and pavements Reflective materials	
Energy efficiency	Reduce waste heat from buildings and waste transport	
Increased ventilation	Open spaces Green corridors	

Figure 14.2: Planning for a cool city (Rehan, 2014)

Exploring options such as creating 'green infrastructure systems' can support efforts by municipalities in South Africa to bring service delivery and resource sustainability closer together (CSU,l 2014). The City of Cape Town and eThekwini Municipality have started developing green agendas to promote green infrastructure at a city scale. These plans, which are rooted in preserving biodiversity, aim to create a shift in the way green assets are planned and managed. These green agendas also have a particular focus on service-specific plans to assist with adapting to or mitigating climate change (Bobbins and Culwick, 2014). In the City of Johannesburg in South Africa, improving its capacity to manage the threat of the UHI is addressed as part of the City of Johannesburg's 2040 strategy in terms of building climate change resilience and environmental protection, along with managing the threats of urban flooding, investing in more green infrastructure, making the built environment more energy efficient, and making the transport sector greener (CSU, 2014). The city has also developed practical guidance on ways of designing buildings that minimise energy requirements and has implemented the Rea Vaya Bus Rapid Transit to help curb congestion on the roads.

UHI thus presents an opportunity for cities to make targeted interventions toward increasing green spaces, increasing building resilience and reducing road transport emissions. Cities with potential for significant new development, should consider mandating that integrative assessments are completed for mitigation and adaptation. Implementing such interventions to reduce the occurrence of the UHI now, will provide benefits to society now and into the future under a changing climate.

Case study B: Technologies for low-carbon and climate-resilient development CTCN: Mozambique

By Julia Mambo

Feasibility study on the use of waste that is refuse-derived fuel (RDF) for cement factories mitigation

Mozambique generates an estimated 2.5 million tons of municipal solid waste per year, 60% of which is organic waste. Most solid waste ends up in open bins and uncontrolled dumpsites, with no or very little waste treatment. The cement industry in Mozambique, which has been developing rapidly in recent years, requires substantial amounts of energy for cement processing, which is done at very high temperatures. This consumes ten times more energy than the average needed for other manufacturing.

The Department of Science and Technology requested technical assistance from the Climate Technology Centre Network to provide support for the assessment of the technical and financial feasibility of generating energy using waste materials that are generally reusable (refuse-derived fuel - RDF) from municipal solid waste in cement factories in Mozambique. RDF, which is also referred to as solid recovered fuel or specified recovered fuel, is a fuel produced from shredding and dehydrating solid waste using waste-converter technology, usually from combustible municipal waste, for example plastics and biodegradable waste (Velis et al., 2010).

Technical assistance was requested to:

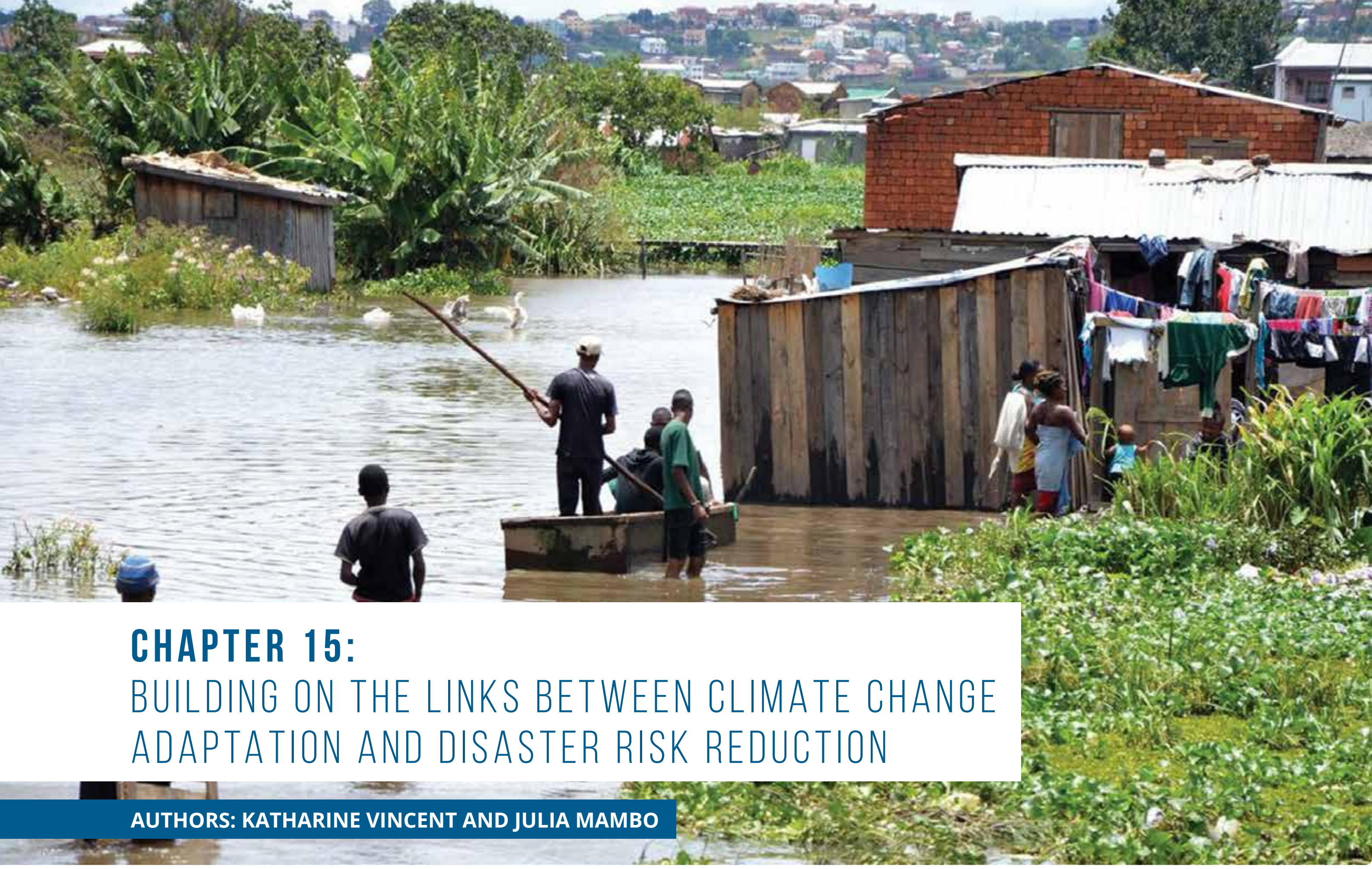
- develop the technical specifications needed to turn waste into RDF;
- provide recommendations to cement factories on how to adapt their infrastructure to receive RDF;
- propose a monitoring and evaluation system to estimate impact in terms of greenhouse gases; and
- analyse potential funding opportunities which might support financing of technology needs.

Outcomes of the technical assistance:

- Cement kilns are able to use energy generated by the waste material.
- The result was a decrease in the consumption of non-renewable resources.
- Subsequent lowering of greenhouse gas emissions.
- Longer useful life of waste disposal sites.
- Boost of the recycling/waste management sector.

Country partners

Association of Municipalities (ANAMM); Carbon Africa; Investment Promotion Centre (CPI) – Mozambique; Centro de Gestao de Conhecimento; Global Cement; Fund of the Environment (FUNAB); Ministry of Earth, Environment and Rural Development (MITADER); Mozambican Association of Recycling (AMOR); and Reduce, Reuse, Recycle (3R).



CHAPTER 15:
BUILDING ON THE LINKS BETWEEN CLIMATE CHANGE ADAPTATION AND DISASTER RISK REDUCTION

AUTHORS: KATHARINE VINCENT AND JULIA MAMBO

15.1. Introduction

Climate change adaptation (CCA) and disaster risk reduction (DRR) have similar aims and are very closely related. However, they tend to differ in their timeframes of focus, with CCA looking at the longer term (e.g. five to 40 years) and DRR more concerned with the more immediate term. Despite their similarities in aim, the two fields have arisen with a false degree of separation. The separation is perpetuated by them typically being addressed within different government departments, and guided by different international agreements. However, taking a holistic risk management approach offers the opportunity for greater complementarity. This chapter outlines the links between CCA and DRR and how they are variously guided by global commitments in terms of the UNFCCC, Sendai Framework and Sustainable Development Goals. It then highlights institutional challenges in addressing CCA and DRR in the SADC region.

Box 15.1: Definitions of DRR and CCA (according to the IPCC Fifth Assessment Report)

Disaster risk reduction "denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience". (IPCC, 2014: 1763)

Climate change adaptation is "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects." (IPCC, 2014: 1758)

15.2. Links between CCA and DRR

CCA and DRR have similar aims – both are concerned with reducing the potential negative impacts of exposure to hazards by improving the ability to anticipate, resist, cope with and recover from such events (see Box 15.1). However, they have evolved from different circumstances and continue to have small differences.

DRR has evolved from disaster risk management and disaster response. Typically, response to disasters was reactive, and planning focused on capacity to respond. The SADC Disaster Preparedness Forum, for example, would look at potential disaster exposure on an annual basis in order to prepare for response, for example through stockpiling and contingency planning. DRR arose as an attempt to be more proactive in addressing the likelihood of disasters occurring, as opposed to being ready to react to them. DRR typically addresses a range of hazards, from tectonic (e.g. earthquakes and volcanoes) to man-made as well as hydrometeorological (extreme weather events such as droughts, floods and cyclones – on which we focus here). In the context of a changing climate, climate hazards make up the majority of disasters which occur (WMO, 2014).

Disasters have a long history and are not only related to climate events (such as droughts, floods and cyclones) – although in the context of a changing climate, these make up the majority of disasters which occur. The costs of disasters arising from extreme climate events are also increasing (see Chapter 3). It is important to remember that an increasing incidence of extreme events or climate hazards will not necessarily lead to more disasters – it is the combination of exposure with a vulnerable population that leads to increased disaster risk. Climate change will contribute to exposure, and it will also contribute to vulnerability through the changes in water and food availability, and on livelihoods.

The focus with DRR is on reducing disaster risk at the present time. Mechanisms focus on early-warning systems – providing information and establishing an institutional infrastructure for awareness raising and response preparedness, such that appropriate activities can be implemented in case of different alert levels.

CCA is very similar in its aims of reducing vulnerability to reduce the likelihood of harm. As well as changing the context of disasters, climate change will also manifest itself in incremental change in temperatures and rainfall, as well as through extreme events that may lead to disasters. Adaptation is thus necessary in addition to DRR. However, CCA takes a longer-term and more forward-looking perspective. In order to reduce vulnerability and build resilience, climate change adaptation requires a different approach to development (Schipper, 2007; Jones et al., 20165). In reality, all adaptation should also be development (particularly in an African context, where immediate development improvements are so pressing), but not all development is adaptation. In essence, development becomes adaptation when it has no or low regrets – i.e. its sustainability and robustness under a range of potential feasible climate futures have been taken into account. Adaptation-related activities can thus involve two main components (McGray et al., 2007). One of these is helping populations and institutions cope better with climate change, particularly where it involves the incremental intensification of currently familiar climate hazards. The other is interventions that are specifically designed to address particular aspects of climate change. These actions are typically “hard” and often involve climate proofing of existing or new planned infrastructure at a variety of scales. This marks another way in which CCA and DRR can be different: while both DRR and CCA involve soft knowledge-based interventions, typically only CCA involves the large-scale hard infrastructural interventions.

15.3. Global commitments to addressing CCA and DRR

15.3.1. United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) acknowledges vulnerability to climate change and calls for efforts to reduce the consequences through adaptation. This is to be enabled through financial support, capacity building and technology transfer to developing countries. Commitment to adaptation has grown within the UNFCCC framework since its signing in 1992.

The first key activity came with the Least Developed Countries Programme, which was signed at the 7th Conference of the Parties (COP) in Marrakech in 2001. This provided a mechanism for least developed countries to outline their particular adaptation needs through creating National Adaptation Programmes of Action, which were to inform particular needs for financial, capacity building and technology transfer support.

The second wave of support for adaptation came in the form of the Nairobi Work Programme, which was the outcome of the 12th COP in Nairobi in 2006.

The most recent development with regards to adaptation within the UNFCCC is the Cancun Adaptation Framework, signed at the 16th COP in Cancun in 2010. Within the Cancun Adaptation Framework is a mechanism to enable Least Developed Country Parties to formulate and implement National Adaptation Plans, as well as consider how to determine loss and damage. The Cancun Adaptation Framework also mandated the establishment of a dedicated institution within the UNFCCC – the Adaptation Committee. This committee is tasked with providing technical support, enabling information sharing and knowledge management, and providing inputs to Parties and the COP on adaptation actions (e.g. UNFCCC Adaptation Committee, 2014).

As the first legal agreement under the UNFCCC – the Kyoto Protocol – comes to an end in 2020, it will be superseded by the Paris Agreement. The Paris Agreement was negotiated at the 21st COP of the UNFCCC, held in Paris in December 2015, and was opened for signature on 22 April 2016. Its main focus is mitigation, and attempting to keep global temperature increase well below 2 °C in the twenty first century, and pursue efforts to limit the increase to 1.5 °C. However, the text also outlines adaptation, as well as finance, capacity building and technology. The Paris Agreement will be reached through Nationally Determined Contributions (NDCs) from each Party, some of which contain adaptation commitments. National Adaptation Plans will support planning for adaptation.

15.3.2. Sendai Framework

The Sendai Framework for Disaster Risk Reduction 2015-2030 arose out of the UN World Conference on Disaster Risk Reduction in 2015. It builds on, and is a successor to, the Hyogo Framework for Action (HFA) 2005-2015: Building the Resilience of Nations and Communities to Disasters. During the lifetime of the HFA there was a discernible shift from disaster management to risk reduction, on which the Sendai Framework builds. In addition, it highlights the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability and hazard characteristics and the strengthening of disaster risk governance (priorities one and two). Sendai is implemented by the United Nations International Strategy for Disaster Reduction (UNISDR), with the support of a Global Platform for Disaster Risk Reduction and the regional platforms for disaster risk reduction as mechanisms for coherence across agendas, monitoring and periodic reviews in support of UN governance bodies.

15.3.3. Sustainable Development Goals

The Sustainable Development Goals (SDGs) were agreed in New York in 2015 and provide targets up to 2030 across a range of development spheres. The purpose of the SDGs is essentially to build on the Millennium Development Goals (MDGs) and complete what they did not achieve in attaining sustainable development. Unlike in the MDGs, climate change is expressly included in the SDGs, with goal 13 to “take urgent action to combat climate change and its impacts”. International recognition of the need to bring together CCA and DRR is embedded in this goal, which has among its targets “Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries” (13.1) and “Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning” (13.3).

15.4. Bringing together CCA through a risk management approach

Taking a risk management approach goes a long way to bridge the fields of climate change adaptation and disaster risk reduction. As described in Chapter 4, the IPCC AR5, in the Working Group on Vulnerability, Impacts and Adaptation, has taken this on board, and is highly concerned with risk identification and management (Figure 4.1). The Figure shows that climate risk, or the probability of an impact, is a function of hazards, exposure and vulnerability. This means that for climate risk to exist, there needs to be a combination of those three elements. Disaster risk can be seen as a subset of climate risk.

Taking this one step further, the IPCC AR5 highlighted a mechanism for defining tolerable risks. Figure 15.1 shows how tolerable risks exist in the space between adaptation limits and acceptable risks. Expanding the adaptation limits will lead to a greater range of tolerable risks and, ultimately, lowered risks of adverse impacts of climate change.

Recognising the normative nature of adaptation in the risk management approach opens up politicisation of adaptation decisions. For every objective, there may be multiple adaptation options, each of which is associated with a particular set of costs, benefits and externalities. Major challenges of adaptation are its incompatibility with political timeframes and its relative invisibility (i.e. if an adaptation has been successful there will be no negative impact in the face of hazard exposure; yet such "non-events" do not receive the media coverage and scrutiny of negative impacts). Relative to other immediate development priorities, adaptation can thus be deprioritised (Jones et al., 2015).

As well as the temporal scale, the spatial scale of analysis is also important in considering adaptation. While damming a river to enable irrigation of fields may reduce the vulnerability of one community to lower rainfall and drought, it does so at a cost to downstream settlements whose surface water supply will subsequently be reduced. In some southern African countries, genetically modified organisms (GMOs) have been embraced to address challenges of low productivity and related occurrences of food insecurity; but that adaptation to climate change may be seen as placing an increased risk on genetic diversity and terrestrial ecosystems. This is because it can "out-compete" other varieties locally, reducing species composition and thus the gene pool; but also because forces such as wind dispersal and erosion mean that containing the effects of GMOs in one area is difficult. The same challenges apply for DRR activities, except that they tend to be a subset of adaptation. In addition, DRR activities tend to cover a smaller scale and be more immediate in focus, relative to CCA (Birkmann & von Teichman, 2010).

Bearing in mind a risk-management framework, there are many examples of activities that are considered both CCA and DRR, for example:

- preparing risk assessments,
- protecting ecosystems,
- improving agricultural methods,
- managing water resources,
- building settlements in safe zones,
- developing early-warning systems,
- improving insurance coverage, and
- developing social safety nets.

For sustainability, integrating adaptation and disaster risk reduction into development planning is also key (UNISDR, 2008).

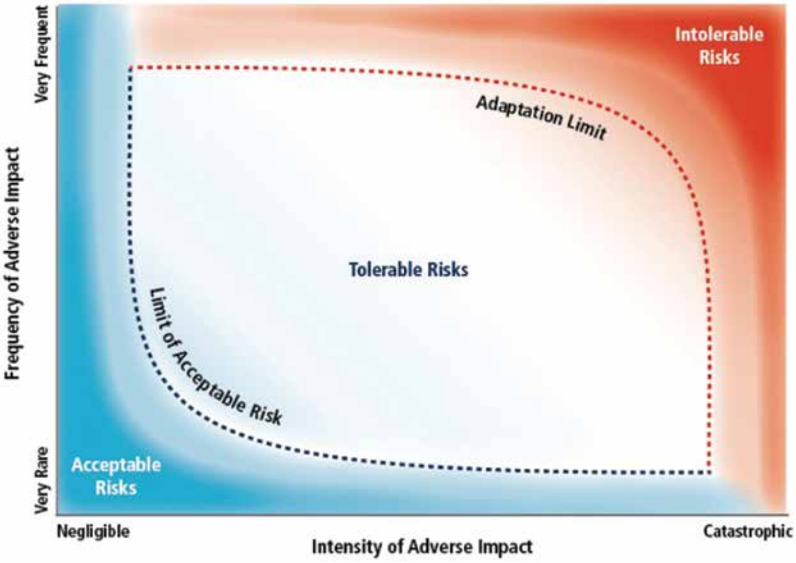


Figure 15.1: Conceptual model of the determinants of acceptable, tolerable, and intolerable risks and their implications for limits to adaptation (Dow et al., 2013)

15.5. Climate Smart Disaster Risk Management

Climate Smart Disaster Risk Management (CSDRM) has been born out of the need to integrate disaster risk reduction and climate change adaptation as discussed above under chapter 15.4. The magnitude of the challenge requires that new ways of addressing disaster be developed, which will include learning to adapt while addressing the drivers of vulnerability in an effective and articulate way. CSDRM is considered as the initial step to adapting to climate change and variability, providing policy-makers with practical measures to allocate resources to reduce current and future risks at all levels. This is an evidence-based approach to incorporating climate change into the current disaster reduction models (Mitchell et al., 2010). The twelve components of CSDRM are divided into three action-oriented pillars:

- Pillar 1 - Addressing changing disaster risks and uncertainties.
- Pillar 2 - Enhancing adaptive capacity.
- Pillar 3 - Tackling poverty and vulnerability and their structural causes.

Pillar 1 – Addressing changing disaster risks and uncertainties

This pillar is based on the Hyogo Framework for Action, indicating the importance of a multi-stakeholder approach as well as information from detailed risk assessments that are done using various sources of knowledge. Access to information through a myriad of forms such as education, early warning and the media can be used to understand and tackle the circumstances that are increasing risk as well as issues of vulnerability (Mitchell et al., 2010).

Pillar 2 – Enhancing adaptive capacity

Under this pillar, enhancing adaptive capacity and building resilience is the key focus. This needs to be done at institutional and network levels by allowing learning, knowledge and experience to be shared to create flexibility in devising solutions for problems faced (Berkes et al., 2003). The following are some the factors essential to increase the resilience:

- Ensuring community participation, promoting diversity and learning, making allowances for all perspectives, integrating uncertainty, and acknowledging the importance of social values and structures in striving for planning, preparedness and readiness.

Enhancing adaptive capacity enables affected communities and institutions to respond to the shocks and threats posed by unexpected events resulting from a changing climate. CSDRM integrates the above-mentioned factors of adaptive capacity and presents these in a practical way (Mitchell et al., 2010).

Pillar 3 – Tackling poverty and vulnerability and their structural causes

The third pillar is premised on the pressure and release models as well as research on the factors that extend from the cause of disasters to the failure of development (Wisner et al., 2004). The pressure and release model considers the root causes, dynamic pressures, unsafe conditions and hazards as all contributing to disaster risk. The contributing factors to vulnerability include population growth, urbanisation, and the lack of skills and institutional arrangements to manage with disaster risk. CSDRM does, however, acknowledge the interdependencies and complications encountered and advocates the integration of the three pillars. Figure 15.2 below highlights guiding questions and includes actions to be taken.

CSDRM needs to be context-specific and tailor-made to address local challenges (Mitchell et al., 2010). For CSDRM to be effective, there is a need for heavy investment in human capacity, institutional cooperation, technical solutions as well as technical innovation. Access to climate science information, and transparent and democratic decision-making will create the environment necessary for the success of CSDRM (Mitchell et al., 2010). Figure 15.2 highlights components of the three pillars that should be considered when promoting CSDRM.

1. Tackle changing disaster risks and uncertainties	**2.** Enhance adaptive capacity	**3.** Address poverty and vulnerability and their structural causes
1a **Strengthen collaboration and integration between diverse stakeholders working on disasters, climate and development** To what extent are climate change adaptation, disaster risk management and development integrated across sectors and scales? How are organisations working on disasters, climate change and development collaborating?	2a **Strengthen the ability of people, organisations and networks to experiment and innovate** How are the institutions, organisations and communities involved in tackling changing disaster risks and uncertainties creating and strengthening opportunities to innovate and experiment?	3a **Promote more socially just and equitable economic systems** How are interventions challenging injustice and exclusion and providing equitable access to sustainable livelihood opportunities? Have climate change impacts been considered and integrated into these interventions?
1b **Periodically assess the effects of climate change on current and future disaster risks and uncertainties** How is knowledge from meteorology, climatology, social science, and communities about hazards, vulnerabilities and uncertainties being collected, integrated and used at different scales?	2b **Promote regular learning and reflection to improve the implementation of policies and practices** Have disaster risk management policies and practices been changed as a result of reflection and learning-by-doing? Is there a process in place for information and learning to flow from communities to organisations and vice versa?	3b **Forge partnerships to ensure the rights and entitlements of people to access basic services, productive assets and common property resources** What networks and alliance are in place to advocate for the rights and entitlements of people to access basic services, productive assets and common property resources?
1c **Integrate knowledge of changing risks and uncertainties into planning, policy and programme design to reduce the vulnerability and exposure of people's lives and livelihoods** How is knowledge about changing disaster risks being incorporated into and acted upon within interventions? How are measures to tackle uncertainty being considered in these processes? How are these processes strengthening partnerships between communities, governments and other stakeholders?	2c **Ensure policies and practices to tackle changing disaster risk are flexible, integrated across sectors and scale and have regular feedback loops** What are the links between people and organisations working to reduce changing disaster risks and uncertainties at community, sub-national, national and international levels? How flexible, accountable and transparent are these people and organisations?	3c **Empower communities and local authorities to influence the decisions of national governments, NGOs, international and private sector organisations and to promote accountability and transparency** To what extent are decision-making structures de-centralised, participatory and inclusive? How do communities, including women, children and other marginalised groups, influence decisions? How do they hold government and other organisations to account?
1d **Increase access of all stakeholders to information and support services concerning changing disaster risks, uncertainties and broader climate impacts** How are varied educational approaches, early warning systems, media and community-led public awareness programmes supporting increased access to information and related support services?	2d **Use tools and methods to plan for uncertainty and unexpected events** What processes are in place to support governments, communities and other stakeholders to effectively manage the uncertainties related to climate change? How are findings from scenario planning exercises and climate-sensitive vulnerability assessments being integrated into existing strategies?	3d **Promote environmentally sensitive and climate smart development** How are environmental impact assessments including climate change? How are development interventions, including ecosystem-based approaches, protecting and restoring the environment and addressing poverty and vulnerability? To what extent are the mitigation of greenhouse gases and low emissions strategies being integrated within development plans?

Figure 15.2: The 12 factors of Climate Smart Disaster Reduction Management grouped into three pillars (Source: Mitchell et al., 2010).

CHAPTER 16:
CLIMATE FINANCE AND FINANCING ADAPTATION PROJECTS

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16.1. Introduction

The costs of adaptation have widely been estimated. Figure 16.1 provides a summary of the estimated annual adaptation costs in developing countries. By 2030 estimates range from around $20 billion to nearly $200 billion; and by 2050 estimates range from around $60 billion to $300 billion. In keeping with the principle of common-but-differentiated responsibilities, which is enshrined in the United Nations Framework Convention on Climate Change (UNFCCC), developed countries, whose period of industrialisation has contributed to the augmented levels of greenhouse gases in the atmosphere, have a responsibility to support adaptation in developing countries. In particular, article 4.9 of the convention states that "Parties shall take full account of the specific needs and special situations of the Least Developed Countries in their actions with regard to funding and transfer of technology" (UNFCCC, 1992). This chapter provides an overview of major multilateral public finance sources as relevant to southern Africa. It then outlines the particular nature of some of the major adaptation finance sources, as well as providing details of the application and approval procedures.

16.2. Overview of adaptation finance sources

There are more than 60 different international funds available for developing countries through bilateral, multilateral and private sources.[24] Although there is positive evidence that these finance sources are making a difference, a major critique is that the climate finance landscape has become too complicated – with a stifling array of options with different eligibility requirements (Nakhooda et al., 2014). Broadly speaking, there are key differences between the approaches of different funders that affect the availability of adaptation finance for different purposes, and this differs between the multilateral and bilateral sources.

There are examples of international multilateral adaptation finance sources that are open access, or targeted to countries. Examples of multilateral open access relating to the UNFCCC include the Least Developed Countries Fund (LDCF) and Special Climate Change Fund (SCCF) under the convention, the Adaptation Fund (under the Kyoto Protocol), and the Green Climate Fund (commitment to the establishment of which was made in Copenhagen in 2009 at the 15th

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[24] Climate Finance Options, (2013), World Bank, UNDP, climatefinanceoptions.org.

Estimated annual adaption finance needs for developing countries through the years

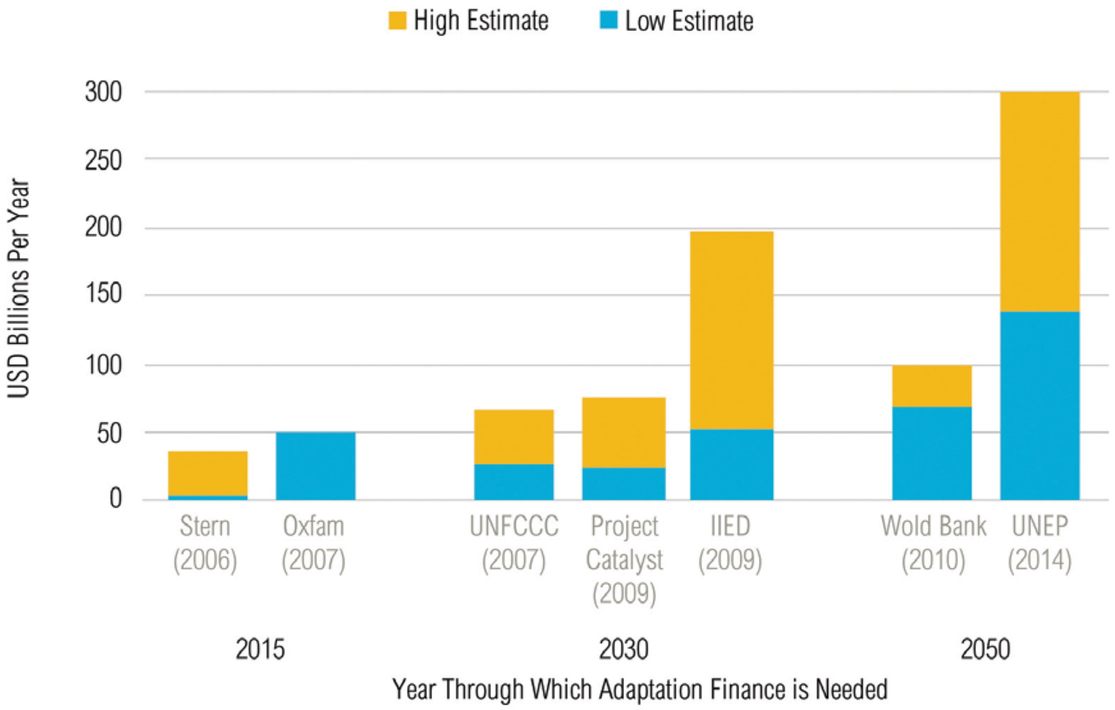

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Figure 16.1: The 12 factors of Climate Smart Disaster Reduction Management grouped into three pillars (Source: Mitchell et al., 2010).

Conference of the Parties to the UNFCCC). Critically, these funds require demonstration that adaptation impacts of a project will be above and beyond the development achievements under a "business as usual" case. This is known as "additionality". As well as administering the LDCF and SCCF (among other funds under international conventions), the Global Environment Facility (GEF) also provides climate finance through its Trust Fund.

The Climate Investment Funds (CIF) are supported, and administered, by the Multilateral Development Banks (MDBs). CIF includes a wide variety of funds, but the most relevant to adaptation is the Pilot Program for Climate Resilience (PPCR). In keeping with their priorities and core business, the Multilateral Development Bank (MDB)-managed funds often have emphasis on the underlying project and finance criteria, and apply investment (potential)-related criteria within a climate-relevant context more than the idea of additionality. With the exception of PPCR, which recently expanded to 30 countries, developing countries are eligible to access any of these international multilateral adaptation finance sources.

As well as multilateral adaptation finance, there are a number of funds created by more than one country. Some of these target specific countries, or offer different funding windows targeting specific countries; while others are regional-based. The Nordic Development Fund (Denmark, Finland, Iceland, Norway and Sweden) issues calls targeting specific countries, while the Global

Climate Change Alliance (under the European Union) identifies countries for support a *priori*. Other funds exist which are regional in focus. In Africa, for example, there is the ClimDev Special Fund – a multi-donor trust fund administered by the African Development Bank (AFDB), the Climate Change Fund under the New Economic Partnership for Africa's Development (NEPAD) and the African Climate Change Fund under the AFDB.

Dedicated bilateral climate funds are typically linked to existing development cooperation and aid flows, and increasingly bilateral donors are mainstreaming climate change into their development activities. Table S.1 in the supplementary material provides an overview of all these adaptation financing sources.

16.3. Availability of adaptation finance

The size of the various adaptation funds varies significantly, and they are also dynamic depending on the rate at which finance flows in through donors, and out through projects. Figure 16.2 shows the size of the funds. Currently the Green Climate Fund is the largest multilateral international fund. The UK's International Climate Fund is also significant, at over $6 billion – although this is largely used to fund country-developed programmes and projects, as opposed to being open for applications.

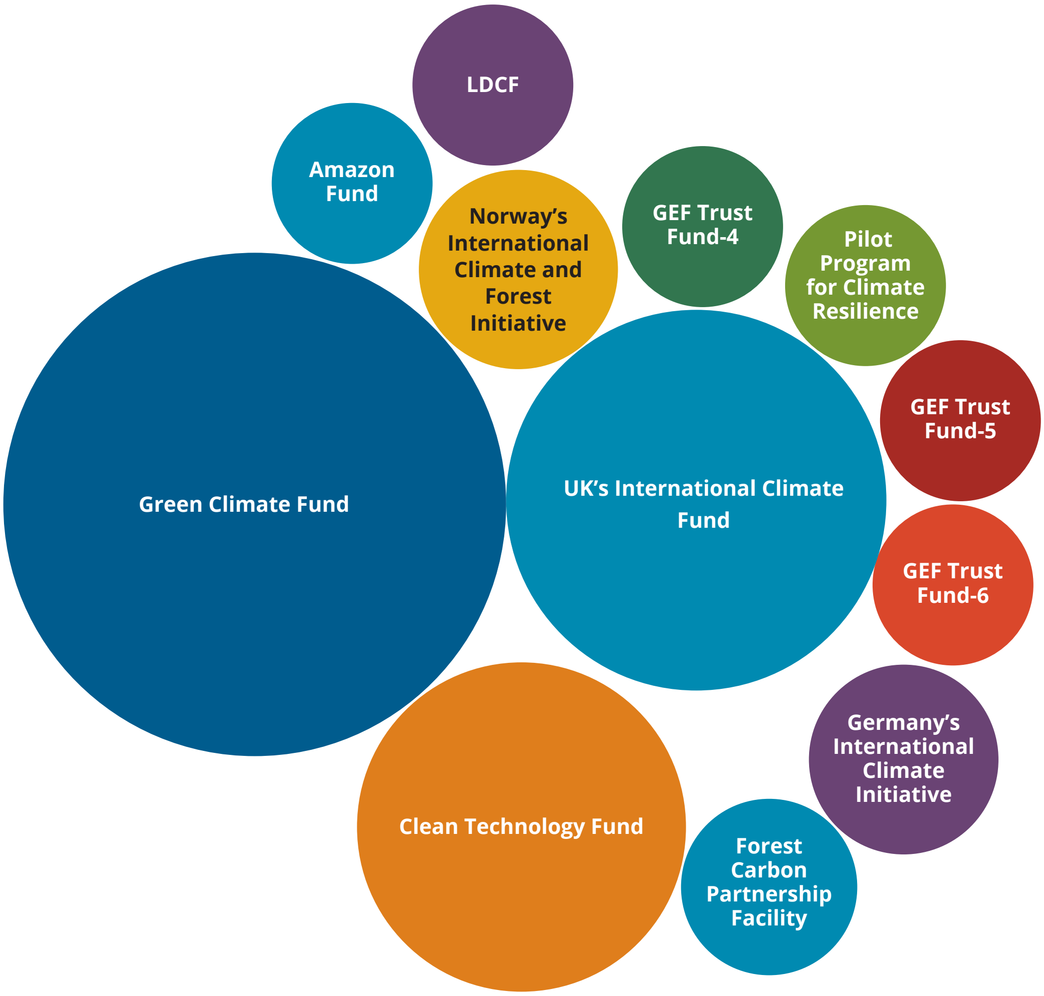

Figure 16.2: Size of various multilateral and bilateral adaptation finance sources based on pledges (includes both mitigation and adaptation sources). Source: www.climatefundsupdate.org (data from May 2016).

UNFCCC negotiations and other high-profile international events are key platforms at which pledges are made to different funds. At the recent 21st Conference of the Parties (COP) to the UNFCCC in Paris, pledged annual public concessional climate finance spend equated to at least $19 billion per year in 2020. In terms of pledges made to existing funds: $252 million was pledged to the Least Developed Countries Fund, $75 million to the Adaptation Fund, $260 million to the Green Climate Fund, and $380 million to the Global Climate Change Alliance+ (Nakhooda et al., 2015). A number of new financing initiatives were also announced, including those led by charitable foundations.

Figure 16.3 highlights adaptation finance disbursement in sub-Saharan African countries. The greater the size of the circle, the larger the amount that has been disbursed, and the colours reflect the ND-GAIN vulnerability rank 2013 (the darker the colour, the more vulnerable the country). Within SADC, Mozambique and Zambia have received the largest amounts of adaptation finance to date. This is partly as a result of their participation in the Pilot Program for Climate Resilience, which is a multi-year, multi-million-dollar initiative under the MDB-managed Climate Investment Funds.

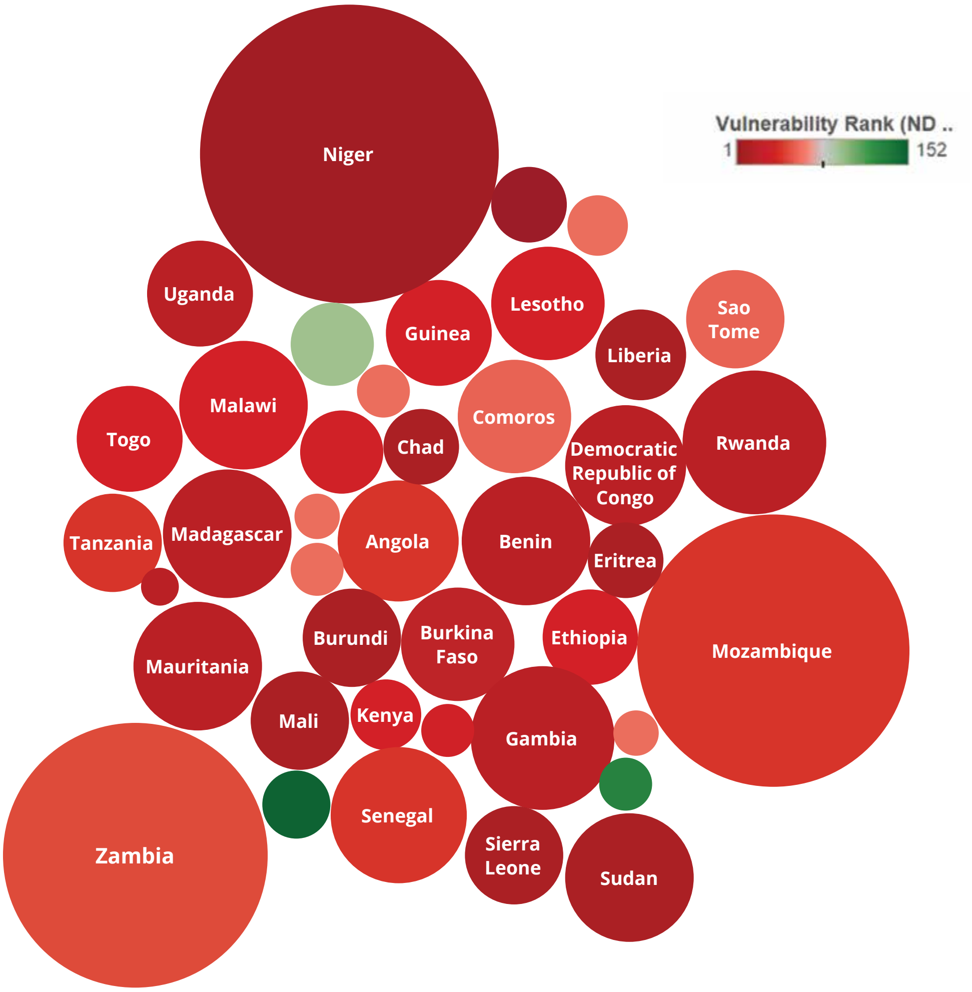

Figure 16.3: Funds distributed for adaptation in sub-Saharan Africa (Source: www.climatefundsupdate.com, accessed 16th August 2016).

16.4. Adaptation finance opportunities

16.4.1. Green Climate Fund

The Green Climate Fund (GCF) is the most recently established – and largest – climate finance mechanism under the UNFCCC. It first came into being at the UNFCCC COP in Copenhagen in 2009; was then concretised the following year as part of the Cancun Accords, and finally capitalised to the value of $10 billion – the starting rate for operationalisation – in 2014. The intention, first tabled in Copenhagen and reiterated at COP21 in Paris, is that the GCF will be resourced to the value of $100 billion per year by 2020. The fund aims to balance its funding disbursements to 50% mitigation and 50% adaptation.

The GCF follows the Direct Access modality of the Adaptation Fund. Entities which have already been accredited by other relevant funds – including the GEF or AF, are eligible for the GCF's fast-track accreditation process. The GCF also follows a flexible "fit for purpose" accreditation approach, which enables entities to be accredited with certain fiduciary function, size of project within a programme, and environmental risk category (GCF, 2014). The aim is to make Direct Access easier, and to ensure more timely disbursement of funds. Accredited entities can thus be national, regional and international. Currently the only difference between the GCF and AF is that accredited entities to the former have to be able to manage a small grant disbursement procedure.

A unique focus of the GCF is its emphasis on the private sector – both in capitalisation of the fund, and as recipients. New incentives for the institutions, investors and businesses that are shaping infrastructure and development finance choices can encourage them to step up their efforts to increase climate resilience (Nakhooda et al., 2014). To do so requires a wider range of finance opportunities (beyond grants and concessional loans), and the opportunity for blending of finance opportunities. The GCF embraces this with a dedicated private sector facility to enable greater engagement, and the scope for a broader range of implementing partners. The adoption of an active risk-management framework also means that loan contributions will be complemented with a capital cushion that will be calibrated to help ensure the fund can make relatively risky investments. This should allow it the potential to offer the range of forms of finance required to target national needs (Nakhooda et al., 2014).

The access procedures for the GCF are not dissimilar to those for the GEF-managed funds. A full proposal can be developed, or there is the option for a concept note (significantly more detailed than the GEF-managed funds or the AF) to be submitted to the GCF with the approval of the National Designated Authority – NDA (Table S.3 in the supplementary material). The recommendation will clarify whether the concept is endorsed, not endorsed with a possibility of resubmission, or rejected. The GCF board makes decisions on the full proposals, taking into account external reviews.

The GCF accepted the first round of applications at its November 2015 board meeting, and its second in July 2016. Seventeen proposals were successful. So far one of these ("Scaling up the use of modernised climate information and early warning systems in Malawi", to the value of $12.3 million, under the accredited entity UNDP) is within the SADC region.

16.4.2. Least Developed Countries Fund

The Least Developed Countries Fund (LDCF) was established in 2001 by the UNFCCC Conference of the Parties to support the adaptation needs of 48 developing countries classified as least developed countries (LDCs). Initially it financed the production of National Adaptation Programmes of Action (NAPAs) – country-specific documents that highlighted and then prioritised adaptation needs. The LDCF then moved its focus to funding the projects outlined in the NAPAs. This is the key element of country ownership that is core to the LDCF.

The LDCF is administered by the Global Environment Facility (GEF) and financed on a voluntary basis by Annex 1 (developed) countries. Funds are accessed by way of Multilateral Implementing Entities (MIEs) (such as development banks and UN agencies). Since it came into operation in 2002 it has disbursed nearly $600 million. The fund is financed by pledges from developed countries. In order to enable equal access, a gentleman's agreement is in place, which provides a cap for the total value of LDCF-funded projects that may be funded within a country. The approximate range of each

LDCF-funded project to date has been to a maximum of approximately $10 million. Each country is represented in LDCF discussions by a political operational focal point (OFP), while a technical operational focal point coordinates applications (Table S.2 in supplementary material).

A key feature of the LDCF and its sister fund, the Special Climate Change Fund (SCCF), is that monies are distributed on the principle of additionality. This means that the funds do not finance projects in their entirety – rather that they cover the additional costs inherent in "climate-proofing" existing development interventions. For example, a recently-funded LDCF project in Madagascar was based on a proposal to increase the height of a dyke being installed in the flood-prone southwest of country. The dyke was intended to address the problem of cyclone-induced flooding causing destruction to crops and rendering farmland uncultivable. However, the design of the dyke did not take into account that the magnitude of flooding is projected to increase, and thus a higher and stronger dyke will be necessary for the benefits to remain robust in the context of a changing climate. LDCF monies need to have a focus on tangible "hardware" interventions – the investment needs of adaptation. Projects cannot have as primary activities "software" technical assistance in the form of studies, vulnerability assessment, training, capacity development or policy strengthening. However, there is scope for ancillary inclusion of relevant "software" activities, such as capacity building and alteration of policy and institutional frameworks. Due to the nature of additionality, each project proposal needs to demonstrate co-financing (i.e. the costs of the business-as-usual project). This co-finance can be bilateral or multilateral development assistance, government direct budget, civil society organisation contributions, cash/grant, loan, soft loan or in-kind contributions.

In 2014, the GEF published its *Programming Strategy on Adaptation to Climate Change for the Least Developed Countries Fund* and the *Special Climate Change Fund*. The future direction charted by this strategy is captured in two strategic pillars that will guide programming under the LDCF and the SCCF, namely:

(1) Integrating climate change adaptation into relevant policies, plans, programmes and decision-making processes in a continuous, progressive and iterative manner as a means to identify and address short-, medium- and long-term adaptation needs; and
(2) Expanding synergies with other GEF focal areas.

Based on the two pillars of the strategy, the GEF, through the LDCF and the SCCF, will focus its programming on ten priority areas: agriculture and food security; water resources management; coastal zone management; infrastructure, including transport and energy; disaster risk management; natural resources management; health; climate information services; climate-resilient urban systems; and small-island developing states. There is also particular interest in enhancing private sector involvement, looking at risk transfer and insurance mechanisms, and ecosystem-based adaptation (GEF, 2014).

There is a two-phase application procedure in place for accessing funds from the LDCF. Initially a concept note, or project identification form (PIF) must be completed and submitted to the GEF Secretariat. Revisions may be required based on comments, but the target timeframe for decisions on PIFs is within 10 days of receipt at the GEF. It is then posted for LDCF/SCCF Council approval on a "no objection" basis for four weeks. Once the PIF has been accepted, a project preparation grant (PPG) of up to $200,000 (depending on the value of the intended project) is released in order to facilitate a process of detailed project design and feasibility, leading to the production of a project document. Project documents must be submitted to the GEF within 18 months of the decision on the PIF. These are then sent for CEO endorsement, which takes place on a continuous cycle. Depending on the time taken from the project preparation phase, the time lapse between the submission of the PIF and the start of a successful project is between 12 and 18 months.

16.4.3. Special Climate Change Fund

The Special Climate Change Fund (SCCF) is a sister fund to the LDCF – but open to developing countries that are not classified as LDCs (i.e. Botswana, Mauritius, Namibia, Seychelles, South Africa, Swaziland and Zimbabwe in SADC). It has four priority areas: adaptation to climate change; technology transfer; energy, transport, industry, agriculture, forestry and waste management; and economic diversification. For the adaptation window, like LDCF, SCCF funds concrete "hard" adaptation activities in the form of investments needed for adaptation, and such needs are also expected to be country-driven, as shown as priorities in the National Communications to the UNFCCC.

The SCCF is significantly less well-resourced than the LDCF. This is partly due to scepticism and fears of misuse of the economic diversification window. However, this was a criterion for the establishment of the fund by the Organization of the Petroleum Exporting Countries (OPEC).

16.4.4. GEF Trust Fund: Climate change focal area

The GEF Trust Fund was created in 1991 and has been operational since 1994. It is funded by donor pledge commitments in four-year cycles. It has three focal areas, reflecting the priorities of the 1992 Rio Conventions, i.e. climate change (UNFCCC), land degradation (United Nations Convention to Combat Desertification) and biodiversity (Convention on Biological Diversity). The adaptation component of the GEF Trust Fund is concerned with supporting developing countries to become climate-resilient by promoting both immediate and longer-term adaptation measures in development policies, plans, programmes, projects, and actions.

Unlike the LDCF and SCCF, whose capacity to fund projects is determined by the nature of ad hoc contributions by donors, resources under the GEF Trust Fund are made available in predictable cycles. The 6th GEF cycle (GEF-6) began in July 2014 and will end in June 2018. Following the receipt of pledges, resources are allocated to countries through the System for Transparent Allocation of Resources (STAR). There are four types of projects: full-sized or medium-sized (depending on the budget), enabling activities and programmes. Enabling activities typically relate to commitments under the UNFCCC (for example Intended Nationally Determined Contributions, INDCs), while programmes tend to have a regional focus. Depending on the type of modality selected, different templates have to be completed describing the project proposal for its review and approval.

In terms of accessing resources of the GEF Trust Fund, there has been a recent change. Initially resources were only channelled through selected implementing entities including the African Development Bank, Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD), United Nations Development Programme (UNDP), United Nations Industrial Development Organization (UNIDO) and the World Bank. Under the process of GEF reform, however, it was decided to allow GEF Project Agencies to apply for accreditation to assist recipient countries in the preparation and implementation of GEF-financed projects, which will enable them to access resources from GEF-managed trust funds directly. Project Agencies can be national institutions, regional organisations, civil society organisations/non-governmental organisations (NGOs) and United Nations specialised agencies and programmes. As of 2012 eight Project Agencies were accredited, of which Conservation International, International Union for Conservation of Nature (IUCN), the Development Bank of Southern Africa, and World Wide Fund for Nature (WWF)-US are of relevance to SADC countries.

Projects are eligible for GEF Trust Fund resources based on several criteria. The GEF financing should be for agreed incremental costs on measures to achieve global environmental benefits (i.e. transformation of a project with national benefits to one with global environmental benefits). This means, as with LCDF and SCCF, there needs to be some co-financing/underlying project. The GEF Trust Fund also requires that projects must involve the public in both design and implementation, in keeping with the GEF Policy on Public Involvement (GEF, 2012).

A recent review of 92 adaptation projects managed by the GEF (under the LDCF, the SCCF and Strategic Priority for Adaptation), found a number of common activities relating to information and communications technology, to early warning systems, to new or improved infrastructure, in funded adaptation projects (Figure 16.4). Activities include "hard" adaptations such as green infrastructure, physical infrastructure, warning or observing systems and technology; "soft" adaptations such as practice and behaviour, information and capacity building; and institutional adaptations such as policy, financing and management and planning. The Subsidiary Body for Scientific and Technical Advice (SBSTA) under the UNFCCC commissioned a report investigating the effectiveness of various adaptation options to further inform the selection of appropriate adaptation actions (UNFCCC SBSTA, 2014).

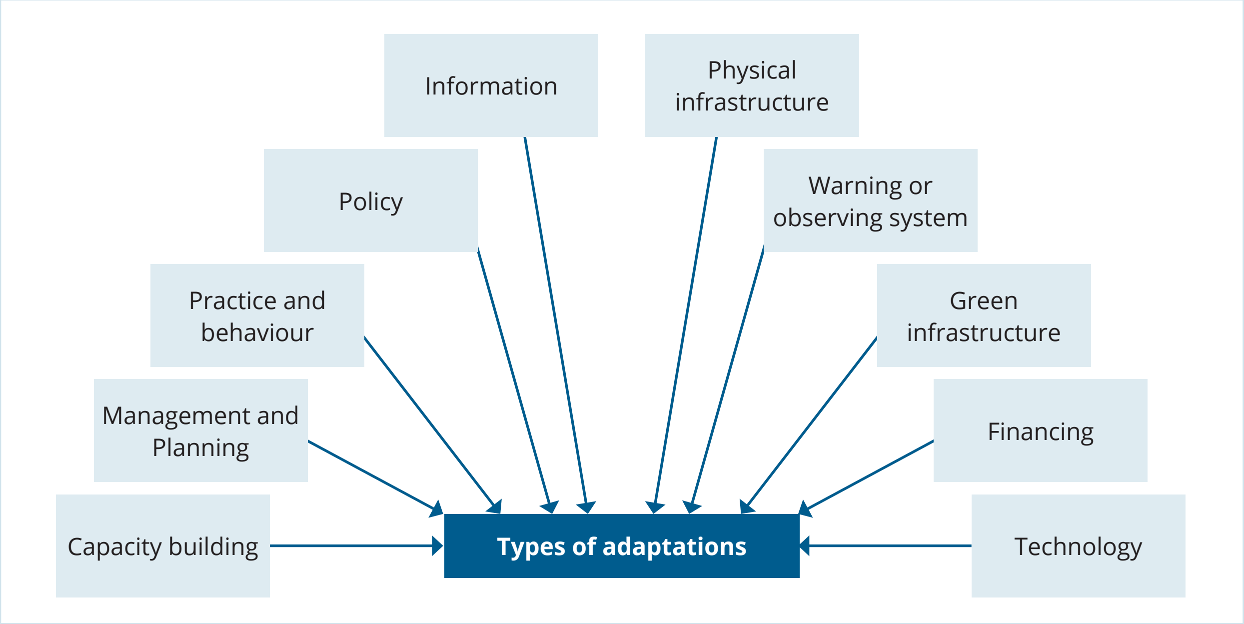

Figure 16.4: Categories of adaptation financed by GEF adaptation funds (Source: Biagini et al., 2014, 103).

Case study: GEF project case study – Zambezi Valley Market-led Smallholder Development

The Zambezi Valley Market-led Smallholder Development project, which was led by the World Bank in its capacity as a GEF agency, ran for six years from September 2006. The total value of the project was $27,550,000.

The goal of the project was to accelerate poverty reduction within the Central Region of Mozambique through increasing the income of selected districts through broad-based and environmentally sustainable agricultural growth. The global environmental objectives were to:

(a) prevent land degradation and rehabilitate degraded land to harness local ecosystem services and global environmental benefits, and

(b) identify land and natural resource management strategies to overcome vulnerability of local communities to predicted climate variability and climate change in the Central Zambezi Valley.

The project was made up of four components:

- **Community group organisation and local and national institutional strengthening.** This component was to institutionally strengthen smallholders organised in community-based production, marketing and savings and loan groups to secure access to technical and financial resources that contribute to the sustainable economic development of their members.
- **Agricultural production and market development.** Activities under this component were concerned with the provision of technical services to the agricultural supply chain, with a focus on market-led growth.
- **Community Agricultural and Environmental Investment Fund.** Under this component, a fund was created that provided grants to facilitate accelerated agricultural development and more sustainable land and water management in the project area.
- **Project management, coordination and monitoring and evaluation.** This component included technical supervision and coordination, financial management, workplan and reporting functions at district, provincial and national levels, and monitoring and evaluation of the project.

Source: www.thegef.org/gef/

16.4.5. Adaptation Fund

The Adaptation Fund (AF) was established in 2001 under the Kyoto Protocol to finance concrete adaptation projects that reduce the vulnerability of developing countries to climate change. Initially it was funded through the flexible mechanisms of the Kyoto Protocol, with a levy of 2% on Clean Development Mechanism – CDM (carbon reduction) projects. Certified Emissions Reductions (CERs) were only a feasible source of funding until the end of the first commitment period of the Kyoto Protocol – after which the CDM and carbon market essentially collapsed. Under the second commitment period, the Parties to the Kyoto Protocol voted for continued capitalisation through a 2% share of the proceeds levied on the international transfers of Assigned Allowance Units (AAU) – units that countries could sell if their emissions reductions had exceeded their targets in the 2008-2012 period. Since then, direct financial contributions from several countries enabled the AF to achieve its goal of $100 million funds raised by the end of 2013. The second review of the AF in 2014 highlighted the need to systematically consider alternative revenue streams, and direct donor contributions are now significant (UNFCCC, 2014). Six of the 54 projects financed to date are in the SADC region – two in South Africa, and one each in Madagascar, Mauritius, Seychelles and Tanzania (Table 16.1). Four additional proposals for national and regional projects in southern Africa are under review.

The AF is unique in several ways. Firstly, it is managed by a board that comprises a majority of developing country representatives, and secondly it uses the Direct Access modalities (Trujillo & Nakhooda, 2013). Each country has a designated authority (DA) through which communications with the AF board take place. The DA is also responsible for coordinating the procedure for the Direct Access modalities. This means that eligible (i.e. developing) countries can apply directly for resources, as opposed to having to partner with a Multilateral Implementing Entity (MIE), as is practice with the GEF-managed UNFCCC funds. This increases the efficiency of resources by reducing the management fee charged by the MIEs. However, in order to be eligible for this direct access, countries had to propose National Implementing Entities (NIEs), which had to undergo a series of checks on their fiduciary capacity, and financial management procedures and capacity, prior to being accredited. There are two NIEs in SADC – the Desert Research Foundation in Namibia, and the South African National Biodiversity Institute, and 11 MIEs that operate globally. MIE-managed projects are capped at 50% of the fund's resources, with additional approved projects being placed in a pipeline awaiting further capitalisation – in order to remain true to the Direct Access modality. The recent second review of the AF recognised this, and highlighted as a priority the need to target the readiness programme to assist accreditation of more NIEs or RIEs; and to ensure that accredited NIEs have increased and facilitated access to the AF, including for small-size projects and programmes (UNFCCC, 2014).

Table 16.1: Adaptation Fund project status in SADC
(https://www.adaptation-fund.org/projects-programmes/project-information/projects-table-view/)

Country	Name of project	Amount (US$)
Madagascar	Promoting Climate Resilience in the Rice Sector	5,104,925
Mauritius	Climate Change Adaptation Programme in the Coastal Zone of Mauritius	9,119,240
Seychelles	Ecosystem Based Adaptation to Climate Change in Seychelles	6,455,750
South Africa	Taking Adaptation to the Ground: A Small Grants Facility for Enabling Local Level Responses to Climate Change	2,442,682
	Building Resilience in the Greater uMngeni Catchment	7,495,005
Tanzania	Implementation of Concrete Adaptation Measures to Reduce Vulnerability of Livelihood and Economy of Coastal Communities in Tanzania	5,008,564

Case study: Adaptation Fund case study – Building Resilience in the Greater uMngeni

South Africa's NIE SANBI (South African National Biodiversity Institute) was awarded USD 7,495,055 for the Building Resilience in the Greater uMngeni Catchment project from the Adaptation Fund. The project, which targets the water sector in South Africa, was approved on 10 October 2014. It is expected to run from April 2015 to December 2019.

The project aims to reduce climate vulnerability and increase the resilience and adaptive capacity in rural and peri-urban settlements and small-scale farmers in productive landscapes in the uMgungundlovu District Municipality (UMDM), KwaZulu-Natal Province, South Africa, that are threatened by climate variability and change, through an integrated adaptation approach. The majority of the population in the province of KwaZulu-Natal live in rural or peri-urban areas, often in informal settlements. The UMDM has a population of one million people, with a high percentage of poverty, HIV/AIDS prevalence and a very high proportion of female-headed households.

In order to achieve its aim, the project is comprised of four components:

- Early warning and response systems to improve the preparedness and adaptive capacity of local communities and small-scale farmers, drawing on and integrating scientific and local knowledge;
- A combination of ecological and engineering solutions to help local communities to reduce vulnerability to the existing and anticipated impacts of climate variability and change;
- To improve the resilience of small-scale farmers and reduce their vulnerability to existing and anticipated impacts of climate variability and change; and
- To build capacity and share lessons and policy recommendations in order to facilitate scaling up and replication.

Source: https://www.adaptation-fund.org/project/building-resilience-in-the-greater-umngeni-catchment/

16.5. Climate finance readiness

In preparation for the availability of large sums of climate finance, a number of donors have been supporting initiatives aimed at building climate finance readiness in countries. The purpose of these has been capacity support to establish systems and procedures to enable efficient absorption and deployment of climate finance (see Figure 16.5 for key components of climate finance readiness according to UNDP). The process of developing climate finance readiness supports the attainment of criteria which must be met in order for a country to successfully achieve national accreditation status. These criteria include financial absorptive capacity, but also evidence of the capacity to design robust policies and execute appropriate projects (Figure 16.6). A key underlying component of successful climate finance readiness is also building on the political economy context in order to ensure that actors have a shared vision of adaptation and the investment decisions required to enable this (Rai et al., 2014; Rai et al., 2015).

Various resources have been published by diverse agencies to support the process of applying for climate finance (e.g. Christiansen et al., 2012). As the climate finance landscape continues to rapidly evolve, increasing numbers of lessons will be learned on the most appropriate institutional structures and policy frameworks to make effective use of international funds available for adaptation (e.g. Rai et al., 2015; GIZ, 2014, 2012; UNDP & ODI, 2011). With growing evidence, there is also interest in investigating the internal capacity of governments to effectively disburse funds from national level to local level for implementation once they are in country (e.g. Pervin & Moin, 2014).

Financial planning	**Accessing finance**	**Delivering finance**	**Monitor, report and verify**
• Assess needs and priorities and identify barriers to investment • Identify policy-mix and sources of financing	• Directly assess finance • Blend and combine finance • Formulate project, programme, sector-wide approaches to access finance	• Implement and execute project, programme, sector-wide approaches • Build local supply of expertise and skills • Coordinate implementation	• Monitor, report and verify flows • Performance-based payments

Figure 16.5: Key components of climate finance readiness (financial and management) (Source: UNDP, 2012).

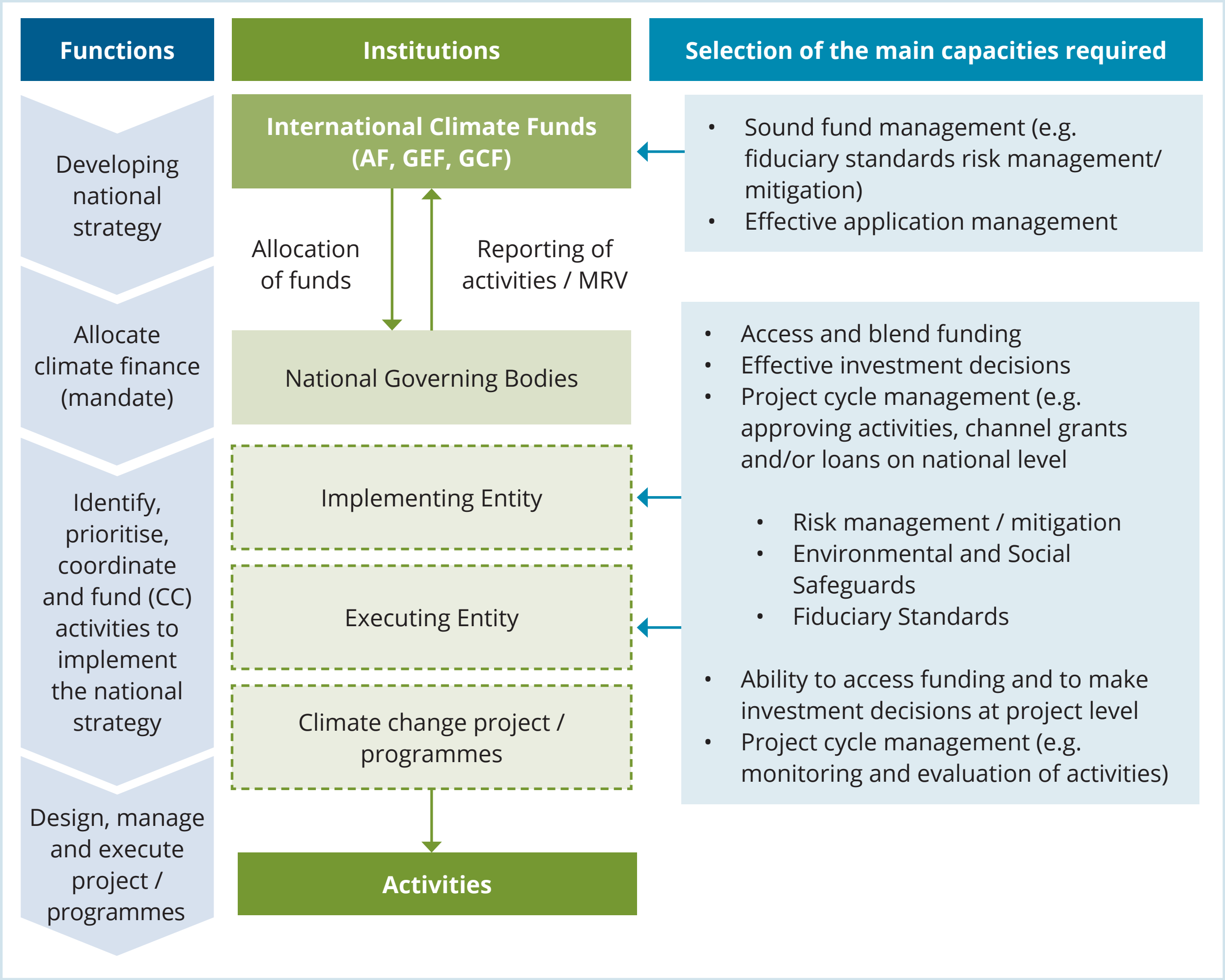

Figure 16.6: Representation of the components of climate finance readiness (both financial and technical capacity) (Source: Druce et al., 2013).

16.6. Conclusion

The international climate finance landscape continues to evolve rapidly. Alongside the already-established UNFCCC funds – the Least Developed Countries Fund and the Special Climate Change Fund, and the direct access Adaptation Fund, the recently operationalised Green Climate Fund has further catalysed interest in financing for adaptation projects. In addition to the growing variety of open application funds, other multilateral donors and bilateral donors are increasingly devising their own funds and mainstreaming climate into their development activities.

Box 16.1: Online sources

Climate Fund Inventory Database (OECD)
http://qdd.oecd.org/subject.aspx?subject=climatefundinventory
A qualitative database of 99 bilateral and multilateral public climate funds that target different fields of activities (e.g. adaptation, mitigation, REDD, capacity-building), sectors and regions, and enable support via different financing mechanisms. Similar to Annex 1, it contains information relevant to selecting and then applying to the relevant fund.

Climate Funds Update
http://www.climatefundsupdate.org/
An independent website that provides information on the various international climate finance initiatives, including the scale of proposed and actual financing and the focus in terms of geographical area and sector/ theme. The website has the capacity to generate custom diagrams depending on particular information requirements.

Climate Finance Landscape
http://www.climatefinancelandscape.org
Website managed by the Climate Policy Initiative, this provides an inventory of climate finance investment. Statistics and graphics are available on climate finance sources, flows, uses, instruments, and both policies and technologies for increased effectiveness.

Climate Finance Ready
http://www.climatefinanceready.org/
A repository of information and case studies (jointly launched by the Adaptation Fund and CDKN – but not Adaptation Fund-specific) targeted at countries as they aim to develop readiness for climate finance.

German Climate Finance
http://www.germanclimatefinance.de/
This website was intended to increase transparency regarding the German government's contribution to international climate finance. It has become much more than that, and is now a comprehensive source of climate finance publications (including case studies) and related links.

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ACRONYMS

AAO	Antarctic oscillation
AAU	Assigned allowance units
AF	Adaptation Fund
AFDB	African Development Bank
AFIS	Advanced Fire Information System
AFOLU	Agriculture, Forestry and other Land Use
AGCM	Atmospheric global circulation model
AQ	Air quality
BAU	Business as usual
BFAP	Bureau for Food and Agricultural Policy
BMU	The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BRT	Bus rapid transit
BWS	Best-worst scaling
CA	Conservation agriculture
CAZ	Ankeniheny-Mantadia-Zahamena Corridor
CBD	Convention on Biological Diversity
CBNRM	Community-based natural resource management
CCA	Climate change adaptation
CCAM	Conformal-Cubic Atmospheric Model
CCD	Convention to Combat Desertification
CCSM3	Community Climate System Model Version 3
CDKN	Climate and Development Knowledge Network
CDM	Clean Development Mechanism
CEO	Chief executive officer
CERs	Certified Emissions Reductions
CGIAR	Consortium of International Agricultural Research Centers
CHPC	Centre for High Performance Computing
CIF	Climate Investment Funds
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on Migratory Species of Wild Animals
CO	Carbon monoxide
COP	Conference of the Parties
CORDEX	Coordinated Regional Downscaling Experiment

CPI	Investment Promotion Centre (Mozambique)
CRED	Centre for Research on the Epidemiology of Disasters
CRU	Climatic Research Unit
CSDRM	Climate Smart Disaster Risk Management
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Council
CSU	Central Strategy Unit
CTCN	Low-carbon and climate-resilient development
DA	Designated authority
DAFF	Department of Agriculture, Forestry and Fisheries, South Africa
DEA	Department of Environmental Affairs, South Africa
DECC	Department of Energy and Climate Change
DJF	December-January-February
DOA	Department of Agriculture
DRC	Democratic Republic of Congo
DRFN	Desert Research Foundation of Namibia
DRR	Disaster risk reduction
DTR	Diurnal temperature range
DWA	Department of Water Affairs, South Africa
EM-DAT	Emergency Events Database
ENSO	El Niño-Southern Oscillation
ETM	Enhanced Thematic Mapper
EU	European Union
EVA	Extreme value analysis
EWS	Early warning systems
FANR	Food, Agriculture and Natural Resources
FAO	Food and Agriculture Organization of the United Nations
FCFA	Future Climate for Africa
FES	Friedrich Ebert Stiftung
GCCA	Global Climate Change Alliance
GCF	Green Climate Fund
GCM	Global climate model
GDP	Gross domestic product
GE	Green economy
GEF	Global Environment Facility
GGHH	Global Green and Healthy Hospitals
GHCN	Global Historical Climate Network

GHG	Greenhouse gas
GI	Geographical indication
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Technical Cooperation)
GMO	Genetically modified organism
GSH	Groote Schuur Hospital
HACI	Household adaptive capacity index
HFA	Hyogo Framework for Action
HWI	Well-being Index
IAM	Integrated assessment model
IBT	Interbasin water transfer
ICF	International Climate Fund
ICI	International Climate Initiative
ICLEI	International Council for Local Environmental Initiatives
ICM	Integrated coastal management
IFAD	International Fund for Agricultural Development
IFRC	International Federation of Red Cross and Red Crescent Societies
IKS	Indigenous knowledge systems
INDCs	Intended Nationally Determined Contributions
IOD	Indian Ocean Dipole
IPBES	Intergovernmental Panel on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual property rights
ITCZ	Inter Tropical Convergence Zone
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
IWRM	Integrated water resources management
JJA	June-July-August
LDCF	Least Developed Countries Fund
LDCs	Least developed countries
LTAS	Long-Term Adaptation Scenarios Flagship Research Programme
LVI	Livelihood vulnerability index
MAM	March-April-May
MDB	Multilateral Development Bank
MDG	Millennium Development Goal
MEAs	Multilateral Environmental Agreements

MHWS	Mean high water spring
MIEs	Multilateral Implementing Entities
MITADER	Ministry of Earth, Environment and Rural Development
MJO	Madden-Julian Oscillation
MODIS	Moderate-resolution imaging spectroradiometer
Munich RE	Munich Reinsurance Company
NAP	National adaptation plan
NAPA	National Adaptation Programme of Action
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NDAs	National Designated Authorities
NDC	Nationally Determined Contribution
NDF	Nordic Development Fund
NEPAD	New Economic Partnership for Africa's Development
NGOs	Non-governmental organisations
NIEs	National Implementing Entities
NMT	Non-motorised transport
NOAA	National Oceanic and Atmospheric Administration
NWA	National Water Act
OCHA	Office for the Coordination of Humanitarian Affairs
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
OFDA	Office of Foreign Disaster Assistance
OFP	Operational Focal Point
OPEC	Organization of the Petroleum Exporting Countries
ORASECOM	Orange-Senqu River Commission
PAH	Polyaromatic hydrocarbons
PIF	Project identification form
PM	Particulate matter
PPCR	Pilot Program for Climate Resilience
PPE	Personal protective equipment
PPG	Project preparation grant
PWC	PricewaterhouseCoopers
PWV	Pretoria-Witwatersrand-Vereeniging
RCP	Representative Concentration Pathways
RDF	Refuse-derived fuel
REDD	Reducing Emissions from Deforestation and Land Degradation

REIPPPP	Renewable Energy Independent Power Producers Procurement Bidding Programme
RIDMP	Regional Infrastructure Development Master Plan
RIEs	Regional implementing agencies
RISDP	Regional Indicative Strategic Development Plan
RSA	Republic of South Africa
RWH	Rainwater harvesting
SABC	South African Broadcasting Corporation
SADC	Southern African Development Community
SAMCEN	Southern African Ministerial Conference on the Environment
SAMCOST	SADC Sectoral Ministerial Committee on Science and Technology
SAPP	Southern African Power Pool
SAVI	Southern Africa Vulnerability Initiative
SBSTA	Subsidiary Body for Scientific and Technical Advice
SCCF	Special Climate Change Fund
SDG	Sustainable Development Goal
SLR	Sea level rise
SON	September-October-November
SPI	Standardized Precipitation Index
SREX	Special Report on Managing the Risks of Extreme Events and Disasters
SST	Sea surface temperature
STAR	System for Transparent Allocation of Resources
STI	Science, technology and innovation
STI-IFCCR	Science, Technology and Innovation Implementation Framework to Support Climate Change Response
SU25	The number of days when maximum temperature >25 °C
SVA	Index of Social Vulnerability to Climate Change for Africa
SWAN	Simulating WAves Nearshore
TSP	Total suspended particulate
TX90p	Maximum temperature 90th percentile of the baseline average
UCT	University of Cape Town
UHI	Urban heat island
UMDM	uMgungundlovu District Municipality
UN	United Nations
UN DESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Rights and Emergency Relief Organization
UNIDO	United Nations Industrial Development Organization
UNISDR	United Nations Office for Disaster Risk Reduction
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
WCMC	World Conservation Monitoring Centre
WCRP	World Climate Research Programme
WFP	World Food Programme
WHC	Convention concerning the Protection of the World Cultural and Natural Heritage
WHO	World Health Organization
WMO	World Meteorological Organization
WSDI	Warm spell duration index
WWF	World Wide Fund for Nature

KEY TERMINOLOGY

Adaptive capacity refers to the varying social characteristics of people (at various units of analysis, from individual to community to country) that determine how hazard exposure is experienced. Adaptive capacity can reflect the status of poverty, health, knowledge/education, and governance (at collective levels). A high adaptive capacity is equivalent to a low vulnerability, and a low adaptive capacity is equivalent to a high vulnerability (Davis 2011).

Climate change adaptation is “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects.” (IPCC, 2014: 1758)

Climate change refers to a change in the average weather experienced in a particular region or location. The change may occur over periods ranging from decades to millennia. It may affect one or more seasons (e.g. summer, winter or the whole year) and involve changes in one or more aspects of the weather, e.g. rainfall, temperature or winds. Its causes may be natural (e.g. due to periodic changes in the earth’s orbit, volcanoes and solar variability) or attributable to human activities, e.g. increasing emissions of greenhouse gases such as CO_2, land use change and/or emissions of aerosols. Commonly, the term ‘climate change’ often refers to changes due to anthropogenic causes (IPCC, 2014).

Climate refers to the average of individual weather conditions in an area, taken over sufficiently long periods of time.

Climate extreme (extreme weather or climate event) is the occurrence of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of historical observed values. Extreme events include unusual, severe or unseasonal weather (IPCC 2014).

Climate variability refers to variations in climate on all spatial and temporal scales beyond that of individual weather events. This variability may be caused by natural internal processes within the climate system. One of the most important (and widely known) examples of natural climate variability is the El Niño-Southern Oscillation (ENSO). Variations may also be caused by external influences which may be due to naturally-occurring phenomena (such as periodic changes in the earth’s orbit around the sun) or anthropogenic causes (IPCC, 2014).

Disaster risk management includes all forms of activities to avoid (prevention) or to limit (mitigation and preparedness) the adverse effects of hazards.

Disaster risk reduction “denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience”. (IPCC, 2014: 1763)

Exposure refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (Field et al. 2014).

Global warming refers only to the overall warming of the Earth, based on average increases in temperature over the entire land and ocean surface. Climate change is more than simply an increase in global temperatures; it encompasses changes in regional climate characteristics, including temperature, humidity, rainfall, wind, and extreme weather events, which have economic and social dimensions Davis 2011).

A natural hazard refers to a "process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage" (www.unisdr.org). A hazard can be incremental temperature or precipitation change, which unfolds gradually over a long time, or it can refer to weather-related hazards, such as droughts, floods and heat waves.

Impacts refer to the effects of climate change on natural and human systems (Field et al. 2014).

Mitigation refers to the measures taken to reduce the emission of greenhouse gases and to enhance sinks (i.e. ways of reducing) of greenhouse gases.

Projection is a statement of a possible (hopefully likely) future state of the climate system dependent on the evolution of a set of key factors over time (e.g. carbon dioxide emissions).

Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere.

Representative Concentration Pathways (RCPs) are four greenhouse gas concentration trajectories adopted by the IPCC Fifth Assessment Report and describe four possible climate futures. The RCP's are named according to their 2100 radiative forcing level. There are four pathways - RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

Resilience is defined as the capacity for a socio-ecological system (or sector in this case) to (a) absorb stresses and maintain normal functioning in the face of external stress and (b) to adapt in order to be better prepared to future impacts (Folke 2006).

Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (Field et al. 2014).

Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (Field et al. 2014).

Vulnerability is defined as the "propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (Field et al. 2014).

Weather describes the set of meteorological phenomena we experience on a daily basis. Weather conditions might be sunny and hot, or cloudy and rainy. We expect changes in weather to occur from day to day.

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The lead authors of this handbook are Claire Davis-Reddy (Council for Scientific and Industrial Research, South Africa) and Katharine Vincent (Kulima Integrated Development Solutions, South Africa), with key inputs from a multidisciplinary team with experience in climate modelling, impacts, vulnerability and adaptation.

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NOTES

NOTES

The Climate Risk and Vulnerability Handbook for Southern Africa was conceived and designed with the intent to provide decision-makers with up to date information, appropriate for country planning, on impact and risk of climate change. It provides an overview of evidence for climate change, projected climate futures, potential impacts across sectors, and responses to reduce risk (adaptation and disaster risk reduction).

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