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Understanding the Social & Environmental Implications of Global Change
[Second edition of the Risk and Vulnerability Atlas]

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Understanding the Social & Environmental Implications of

Global Change

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Minister's Preface

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Africa is particularly vulnerable to climate variability and change, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels, and low adaptive capacity. Even if the Paris Agreement is adhered to and the global temperature increase is kept to 2 degrees Celsius or less, climate-modelling studies suggest that Africa may still see a temperature rise that is higher than 2 degrees Celsius. Effectively, climate change, interacting with multiple stressors, will have detrimental effects on the development of the continent, on food and water security, and will continue to hinder Africa's ability to achieve the SDGs. With the fastest growing and youngest population in the world, this is a situation that demands immediate action.

The South African Risk and Vulnerability Atlas project is a flagship science- into-policy initiative of the Department of Science and Technology's Global Change Grand Challenge. The Atlas is a repository of the most up to date information to support decision making at the local and national level in South Africa. In a data driven world, the importance of analytical tools that can make sense of the plethora of data available is self-evident. Proper analysis and the capacity to use such information will inform the innovation and technological improvements that enable South Africa to implement its nationally determined contributions to combat climate change.

The Department of Science and Technology is on the verge of putting in place its new Decadal Plan, as the 10-year Innovation Plan (TYIP) comes to an end in 2018. The Grand Challenges outlined in the TYIP included the Global Change Grand Challenge, which has built much needed capacity within the climate change and earth sciences research community in South Africa. The research cohort in South Africa has contributed to the IPCC reports, some as lead authors on certain chapters. This is a testament to the quality of research being conducted in South Africa. In addition, South African academics occupy key positions in the Future Earth initiative. South Africa has two co-chairs on the Inter-governmental Panel on Biodiversity and Ecosystem Services (IPBES), with a female researcher as co-chair for the African chapter of the initiative, and a South African as co-chair on the Land Degradation Assessment and the Africa Assessment of (IPBES) Africa. South Africa provides valuable assistance by hosting the Technical Support Unit for the Africa Assessment.

The DST is proud to be supporting and driving the SARVA initiative and the revamped electronic spatial database and information system curated by the South African Earth Observation Network (SAEON) is proving valuable to municipal and national government in South Africa. The Department of Environmental Affairs, for example, uses the Atlas as part of the monitoring and evaluation of South African climate change interventions.

We still face climate change denialists, and instruments such as SARVA can serve as an educational tool to provide the evidence of potential impacts of climate change to all communities and decision- makers in an accessible and easy to understand manner. Unless climate change is addressed proactively, we will not be providing future generations with a world fit for human life.

Indeed in the African proverb quoted by Kofi Annan in his farewell speech as Secretary General of the United Nations:

"The earth is not ours but something we hold in trust for future generations."

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Introduction

Julia Mambo

In recent years, South Africa has experienced an El Niño-related drought reported to be one of the worst meteorological droughts since 1904. The average rainfall in this drought period (late 2014–2016) was about 403 mm compared to 608 mm over the last 112 years (Manderson et al. 2016). El Niño is associated with the warming up of the Pacific Ocean, which is normally at a rate of 0.01% but has increased to a rate of 0.1% and the danger of exceeding the 1% critical threshold is imminent. The warming of the Pacific Ocean interrupts the usual weather patterns and affects the global climate. This could result in droughts in one region and intense storms in another (CPC 2015; Manderson et al. 2016:5). El Niño brings dry conditions to most of southern Africa (Makhubu 2015). The drought and heat conditions have impacted on the already dry and drought-stricken country, exacerbating existing vulnerabilities and affecting sectors such as water and agriculture. Provinces in the country, especially the Western Cape, Free State and the Northern Cape, have experienced water restrictions, widespread crop failure and substantial depletion of livestock. From late 2016, intense storms followed this drought, which resulted in flooding in some parts of the country including Gauteng, Mpumalanga, KwaZulu-Natal and Limpopo. The Western Cape winter rainfall region is, however, still suffering one of its worst droughts in decades. The frequency of extreme weather events has increased, as shown by the increased frequency of the El Niño (from 20 to 10 years), and some climate scientists have attributed this to climate change (Manderson et al. 2016; Pearce 2016). Although there may be debate about the factors influencing the frequency of extreme weather events there is evidence to show that these events have a detrimental impact on our lives and we cannot afford to be complacent.

The success of the first edition of the South African Risk and Vulnerability Atlas (SARVA), both as a publication and at COP17 (17th meeting of the 'Conference of the Parties' of the international treaty known as the United Nations Framework Convention on Climate Change), as shown by the feedback received, has prompted the production of this second edition with more chapters based on themes and case studies. While this publication still targets local government, it has been designed to appeal to other users including academia. We do however, acknowledge that more integration is needed in terms of balancing between the social and the physical impacts of climate and global change.

Nationally, there has been increased momentum in the implementation of the National Climate Change Response Policy. The Department of Environmental Affairs (DEA) increased its support to provincial governments and local municipalities so that they can conduct their own climate risk and vulnerability assessments, as well as to draw up climate change adaptation plans for local level climate change response, in line with the adaptation goals of the country. The increased momentum has also been evidenced by the implementation of the Climate Change Adaptation Monitoring and Evaluation framework and the completion of the Long-Term Adaptation Scenarios (LTAS) Phase 2 in 2014.

The second Global Change Summit co-hosted by the Department of Science and Technology (DST) and the National Research Foundation was held in December 2014. Various other sectors have also held meetings focussing on climate change, such as the Understanding Urban Risk International Conference. Such engagements have created opportunities for cross-sectoral dialogue around issues including risk and vulnerability, mitigation, and adaptation and responses to global climate change. In 2016, the DEA commissioned the production of the Third National Communication and the Technological Needs Assessment as required by the United Nation's Framework for the Convention on Climate Change (UNFCCC).

South African Risk and Vulnerability Atlas

The *South African Risk and Vulnerability Atlas* was conceived by the DST in 2008 as a flagship programme under the 'Global Change Grand Challenge', which falls under one of the themes of the 'Innovation Towards a Knowledge Economy' plan. One of the themes in this programme focuses on the use of science and technology in responding to global change. It aims to enhance scientific understanding of global change and to develop innovative technologies to respond to global change, with an emphasis on climate change. The SARVA falls within this theme and was designed to ensure that existing knowledge on global change risks and vulnerability is made available for those who could benefit from its use.

Three products have since been developed under the SARVA: the online electronic spatial database, the Reading Risk SARV-GAP tool and the first edition of the SARVA, published in 2012.

The SARVA data platform provides data and information on the vulnerabilities and risks associated with global change, including climate change, for various sectors in South Africa. The portal, which is structured according to twelve different themes, contains theme-specific spatial data and case studies. The online portal is managed by the South Africa Earth Observation Network (SAEON) and can be accessed at http://sarva2.dirisa.org/. The Reading Risk SARV-GAP, which is an offline tool, was developed to cater to local government officials, especially those with limited reliable internet access. This tool can be accessed through the SARVA website (mentioned above). It offers information on the basic concepts of risk and vulnerability in the context of climate change to enhance the users understanding of the spatial and non-spatial information on the portal.

The first edition of the SARVA atlas contained chapters and case studies based on the themes on the portal and as defined in the National Climate Change Response White Paper. This second edition of the atlas differs from the first edition in several respects and comprises more chapters, which are more detailed and incorporate feedback received from the first edition.

The selection of the contributing authors to the second edition atlas was based on the experiences and knowledge that they brought to the book through their expertise in the different disciplines. The authors are diverse and include leading academics, scientists as well as social scientists. Unlike the first edition, this publication has been peer-reviewed, making it more scientifically credible. Other improvements in this publication include provision of the concept, meaning and understanding of the terms 'risk' and 'vulnerability' (Chapter 2). Chapter 3 highlights the risk and vulnerability of the socio-economic landscape and includes issues associated with the service delivery protests in the past few years. Chapter 4 explores the factors influencing global and climate change, such as the present-day climate. Chapter 5 presents the predicted changes in climate and provides evidence of increased concern regarding climate risk. Other specific sectors in this edition include the impact of climate on air quality (Chapter 6), on water (Chapter 7), on human health (Chapter 8), on the agricultural sector (Chapter 9) and on commercial forestry (Chapter 10). The book includes a chapter on the impact of climate change on biodiversity (Chapter 11), as well as a chapter on its impact on ecosystems such as coastal zones (Chapter 12), which is critical in terms of understanding global change. Chapters 13 and 14 illustrate the use of SARVA data by local government in response to global change, as well as its impact at the local level and its application in the business and insurance sectors respectively. The final chapter (Chapter 15) concludes the atlas by characterising trends of local disasters in the country.

The DST continues to fund research programmes under the Global Change Research Plan intended at building a climate change resilient society and projects aimed at transitioning South Africa towards a green and low-carbon economy. All these efforts contribute to the production of substantial amounts of information on climate change mitigation and adaptation. This publication is for decision makers in government, as well as for private and civil society and provides them with locally-produced knowledge on sector vulnerability to climate change as well as the drivers of sector vulnerability. The case studies showcase vulnerability to climate change in the sector at a local or grassroots level while other case studies highlight responses to climate change at the local level, in the different sectors. This information will increase the knowledge and understanding of the country's decision makers on climate change, its impacts and responses.

Acronyms

ADM	Amathole District Municipality
AEL	Atmospheric Emission License
AGCM	Atmospheric Global Circulation Model
AMCOW	African Ministers' Council on Water
AQMP	Air Quality Management Plan
AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Change
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
CCAM	Conformal-Cubic Atmospheric Model
CoGTA	Department of Cooperative Governance
CORDEX	Coordinated Regional Climate Downscaling Experiment
CSIR	Council for Scientific and Industrial Research
CSIR GAP	Council for Scientific and Industrial Research, Geospatial Analysis Platform
CSIRO	Commonwealth Scientific and Industrial Research Council
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DJF	December to February
DoH	National Department of Health
DPCD	Department of Planning and Community Development
DST	Department of Science and Technology
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
FFC	Financial and Fiscal Commission
GCIS	Government Communication Information Systems
GCM	Global Circulation Model
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse Gas
ICLEI	Local Governments for Sustainability
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LED	Local Economic Development
LTAS	Long-Term Adaptation Scenarios Flagship Research Programme
MAR	Mean Annual Runoff
MDG	Millennium Development Goal
NCCRP	National Climate Change Response Policy
NFA	National Forests Act of 1998
NPC	National Planning Commission
NRE	Natural Resources and Environment (unit)
NWA	National Water Act (No. 36 of 1998)
PCIS	Principles, Criteria, Indicators and Standards
PM	Particulate Matter
RCM	Regional Climate Model
RCPs	Representative Concentration Pathways
SAAQIS	South African Air Quality Information System
SACN	South African Cities Network
SALGA	South African Local Government Association
SANBI	South African National Biodiversity Institute
SARVA	South African Risk and Vulnerability Atlas
SDFs	Spatial Development Frameworks
SEI	Stockholm Environment Institute
SFM	Sustainable Forest Management
SRES	Special Report on Emissions Scenario
Stats SA	Statistics South Africa
SWPN	Strategic Water Partnerships Network
UGEP	Utilisable Groundwater Exploitation Potential
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UN-HABITAT	United Nations Human Settlements Programme
UNISDR	United Nations Office for Disaster Risk Reduction
WEF	World Economic Forum
WHO	World Health Organization
WRI	World Resources Institute

CHAPTER 1

Risk and vulnerability to global and climate change in South Africa

Julia Mambo[1]

Introduction

The Intergovernmental Panel on Climate Change (IPCC) defines 'vulnerability' as 'the degree to which a system is susceptible to, or unable to cope with the adverse effects of climate change, including climate variability and extremes' (IPCC 2007: 883). This definition assumes vulnerability and its impacts to be mainly physical causes. The definition by Schneider et al. (2007) refers to vulnerability as the 'degree to which aforementioned earth systems are susceptible to and unable to recover from and cope with climate and global change'. This definition considers coping as a part of the vulnerability process.

The issue of vulnerability is usually spoken of in the same context as the element of risk where risk can be the result of climate change or variability. Climate risk includes droughts, floods, heat waves and other extreme climate events to which people, ecosystems and economic sectors are exposed. 'Exposure' is regularly defined as the character, magnitude and rate of climate variation and change to which a system is exposed (Climate-ADAPT n.d.). Human exposure to climate change and variability is often exacerbated by human activities such as urbanisation and deforestation, as well as development in high-risk areas, which increases the vulnerability of ecosystems to change.

1 Council for Scientific and Industrial Research (CSIR) – Natural Resources and the Environment

The concept of vulnerability originated from the field of disaster risk management and is defined by UNISDR as 'the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards' (UNISDR 2009). This definition considers the social factors that affect the different population groups, which are often differentiated by income, socio-economic status and even the type of livelihoods. This type of vulnerability is often dynamic and complex, changing over time. Vulnerability is, therefore, considered an inherent characteristic of a social system or societal group (UNISDR 2009, 2011).

In the field of climate change, the definition of vulnerability has also evolved from the early assessment reports, which focused more on the susceptibility of a system to harm, to adopting a risk approach (Davis et al. 2017). The *IPCC Assessment Report 5* defines vulnerability as 'the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (Field et al. 2014: 5). This definition considers the ability of an affected system to adapt to or to cope with change. However, almost all definitions of vulnerability consider three key elements: exposure, sensitivity and adaptive capacity. Figure 1.1 gives a description of these elements/components.

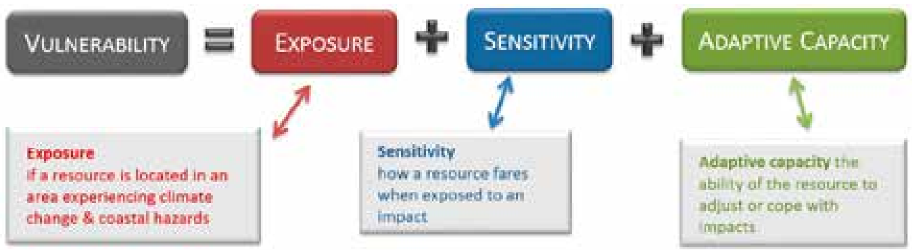

Figure 1.1 The components of vulnerability (Source: NPS 2017)

Understanding risk and vulnerability

Understanding risk and vulnerability to both global and climate change require a multi-dimensional approach due to the complexity and concurrent nature of all the factors that need to be considered (SARVA n.d.; IPCC 2007). Vulnerability should therefore also consider factors such as social, economic, political, cultural and institutional among others (SARVA n.d.; Davis et al. 2017). Given this complexity, there is no prescribed formula or procedure for doing vulnerability assessments, since of vulnerability is dynamic. Many of the earth's social, economic and natural systems face increased risks from climate change and variability, thus turning the focus more towards the impacts of and adaptation to these changes.

Exposure

Exposure to hazards is the nature and extent to which a population or system experiences climate-induced, environmental, socio-political, and/or external stress (IPCC 2012). The characteristics of these stresses include the magnitude, frequency, duration and extent of the hazard. The hazards for climate-induced stress would include increases in temperature, increases in the occurrence and intensity of extreme climate events, such as droughts and floods, sea level rise, coastal hazards and changes in rainfall and temperature (UNDP 2010; NPS 2017). For example, agriculture, forestry, water, or biodiversity (both terrestrial and marine) are systems that will be affected by projected changes and variability in climate (Lavelle et al. 2012). The magnitude and rate of exposure are very crucial in assessing the level of vulnerability (UNDP 2010; Lavelle et al. 2012).

Sensitivity

Sensitivity is based on the understanding of how resilient the system is to changes in climate variables as well as the current physical state and location of the systems in question, which increases or reduces their sensitivity to climatic changes (Adger 2006; UNDP 2010; Bronkhorst et al. 2012). Sensitivity is important in assessing the social vulnerability of societies or communities to climate change and variability.

Adaptive capacity

Adaptive capacity is based on information about the activities that the different sectors are engaged in to adapt or reduce their vulnerability to climate change. The adaptive capacity would include policies and institutional or legal instruments, finance and capacity that are available to tackle climate change (Adger 2006; IPCC 2007; SEI 2014). For example, in South Africa, adaptive capacity is strongly influenced by social factors such as poverty, unemployment and types of housing, with informal settlements posing high risks to extreme weather events. In such cases, reducing inequality and enhancing basic services could significantly reduce vulnerability to climate change and extreme events.

Climate change and disaster risk reduction

The concept of exposure and vulnerability are closely linked to disaster risk reduction and management and both adaptation and disaster risk reduction need to be understood in the context of broader socio-economic development (see Figure 1.2 below).

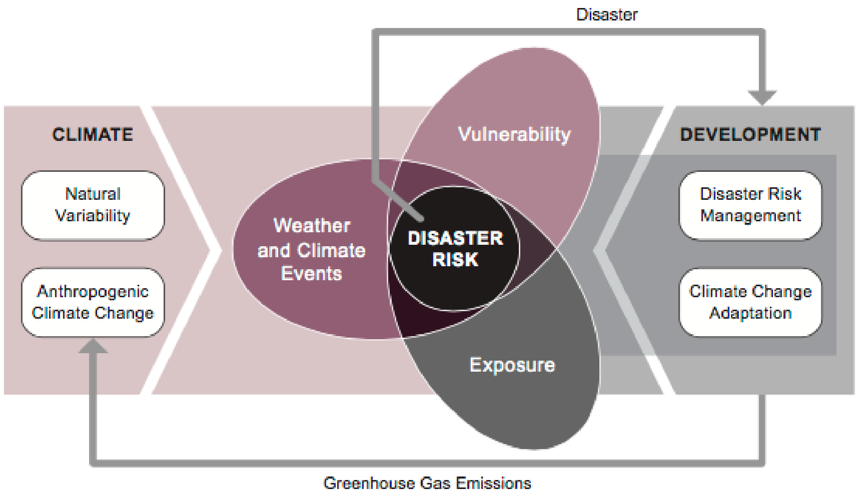

Figure 1.2 A framework for understanding vulnerability, exposure and risk in the context of climate change and disaster risk reduction (We-Adapt 2015).

Vulnerability is, therefore, determined as a function of the character, magnitude and rate of climate variation and change to which a system is exposed, together with its sensitivity and adaptive capacity (Climate-ADAPT n.d; UNISDR 2011). Regardless of the context in which vulnerability is viewed, both vulnerability and exposure vary across temporal and spatial scales and are dependent on economic, social; geographic, demographic, cultural, institutional, governance and environmental factors (IPCC 2012). Vulnerability is thus not static and different individuals, institutions, communities and even economic sectors are affected differently based on the above factors. Vulnerability is, therefore, both content- and location-specific and needs to be assessed with consideration of the socio-economic and natural factors of that location (Vogel and O'Brien 2004; Field et al. 2014). In particular, changes in settlement patterns, such as urbanisation and changes in socio-economic conditions will directly influence exposure and vulnerability to extreme events (IPCC 2012). Fast-paced urbanisation has increased the vulnerability of poor populations, particularly through the growth of informal settlements. This has increased the prevalence of social vulnerability (IPCC 2012).

Social vulnerability is one dimension of vulnerability to multiple stressors and shocks, including natural disasters. Social vulnerability to disasters refers to the inability of people, societies, and organisations to withstand adverse impacts from multiple stressors to which they are exposed, due in part to characteristics inherent in social interactions, institutions, and systems of cultural values (Warner 2006). Social vulnerability is, therefore, a pre-existing condition that affects people's ability to prepare, respond or and recover from a disruptive event. The pre-existing condition will be based on the aspects that limit the ability of communities to withstand or respond to adverse climate change impacts. These aspects include poverty, inequality, marginalisation and lack of access to basic services (Davis et al. 2017).

In summary, social vulnerability can be understood as a dynamic state experienced by an individual or group, who through various and interacting socio-economic characteristics, are susceptible to stresses that may leave them negatively affected when compared to someone in the same setting who does not experience these same socio-economic characteristics (Rance & Fünfgeld 2014).

Vulnerability assessment

There are many definitions of vulnerability and exposure, however, the key concepts of risk and vulnerability and the frameworks used to assess these are often similar in that they are identify potential areas of loss and impact as well as the source of the threat, thus answering the questions of who is vulnerable, to what, how and why? (SARVA n.d.).

Vulnerability assessment is the analysis of the expected impacts, risks and the adaptive capacity of a region or sector to the effects of climate change. Vulnerability assessment includes more than simple measurement of the potential harm caused by events resulting from climate change; it also includes an assessment of the region's or sector's ability to adapt in the face of these events (We-Adapt 2015). Vulnerability assessment is extensively used in many disciplines such as disaster risk reduction, food security, and recently, climate change (O'Brien et al. 2009).

Several methods of measuring or observing vulnerability have been applied, ranging from indicator or proxy-based methods to geographic information systems (GIS) and multiple-stressor-based methods. The intended purpose of a vulnerability assessment, the scale and the available resources usually determine the type of method used for the vulnerability assessment. In some instances, a combination of methods is used to better understand vulnerability (Davis et al. 2017).

Contextual (bottom-up) methods of vulnerability assessment often take into account that climate variability and change interact with socio-economic, political and institutional issues/factors in a dynamic way (Füssel 2009). Other assessment methods adopt a more linear approach, focusing on impacts of projected changes in climate on the different social, economic and natural systems. In these assessments, the impacts are counter-balanced with the adaptive capacity. Some of the common approaches to vulnerability assessment are discussed below.

Indicator-based methods

Indicator-based methods employ the use of indicators to measure vulnerability; thus, requiring measurable indicators. These methods can be used to assess different levels of vulnerability within one community or system (Davis et al. 2016). This approach is also appropriate for decision making and for monitoring changes in vulnerability. The key challenges associated with this approach include the lack of data at appropriate scales, which captures the spatial and temporal heterogeneity of vulnerability, and its uncertainty (Vincent 2007; Davis et al. 2017). Some elements of adaptive capacity are difficult to measure quantitatively (Vincent 2007).

GIS-based methods

GIS-based methods involve the visualisation of vulnerability through the mapping of trends and patterns through spatial analysis. As modelling is used for this type of spatial analysis, vulnerability is portrayed as being geographically-based and represented by both place and people. This approach often highlights the drivers of vulnerability per sector (Davis et al. 2017). Some challenges associated with these methods include the representation of vulnerability as a snapshot in time and of a place. This approach is, therefore, not appropriate/useful for decision making or policy development (Hinkel 2011; Davis et al. 2017). For the mapping of vulnerability to be effective (to incorporate information for decision making), stakeholder involvement in the process is essential (Preston et al. 2011).

Multi-stressor approach

The multi-stressor approach uses a combination of biophysical and social factors to determine the tendency of a system to be affected by change, especially when analysing local vulnerability. This approach acknowledges that vulnerability is a result of multiple stressors occurring concurrently (Ziervogel & Calder 2003). Various frameworks of vulnerability use the multiple-stressor approach to understand both vulnerability and its drivers, as well as resilience (Leichenko & O'Brien 2008).

Participatory methods

Affected communities or population groups help in the identification of their own vulnerability using tools such as participatory or cognitive mapping, stakeholder engagement workshops and interviews, surveys and expert-based inputs (Davis et al. 2017). This participatory approach acknowledges the interaction of exposure, sensitivity and adaptive capacity over time. Overall vulnerability changes over time and that this happens at different scales. This type of assessment is usually used to identify community-based vulnerability (Davis et al. 2017).

It is, however, acknowledged that there is no one-size-fits-all solution to vulnerability assessment, given its multi-faceted nature (Davis et al. 2016) and that there can therefore also not be one strict or enforced definition of vulnerability either (We-adapt 2015). To date, methodologies for conducting vulnerability assessment have been fragmented and various approaches have been used. In this edition of the second edition hardcopy Atlas, the sector vulnerability is assessed in terms of the natural resources and ecological systems upon which key economic activities depend. The economic activities such as agriculture, forestry, water and biodiversity are crucial in the economic development of the country. The ecosystems such as air quality and water are crucial for human health, and a negative impact on any of these resources will have negative effects on the economy. Social vulnerability is assessed in the 'Socio-economic and Settlement Vulnerability' chapter.

Conclusion

In conclusion, vulnerability, as a concept, is a powerful analytical tool that can be used to define the exposure to damage, powerlessness and marginality of physical and social systems. The multifaceted nature of risk and vulnerability, and how it is influenced by physical, social, economic and political frameworks makes it dynamic and ever-changing. This means that vulnerability, as well as the ways in which it is assessed, will continue to evolve. This is crucial in the face of projected changes and variability in climate as well as in global change and the projected impacts of these changes on socio-economic sectors. The identification and mapping of the aspects of vulnerability are, therefore, a criterion for identifying vulnerable economic sectors, populations and spatial locations, the nature of their vulnerability, and the likely future impacts, before interventions are planned. Such information is needed in order to develop strategies and plans that:

- will introduce appropriate measures to reduce the current harmful impacts of change, and
- will further ensure that those societies are resilient to extreme future events.

Information on identified vulnerability may thus be utilised for multiple climate-related purposes, including informing policy, climate change adaptation as well as the prioritisation of response actions for climate change.

The author would like to acknowledge the research done on Defining Vulnerability in South Africa which was conducted as part of the Third National Communication Report to the UNFCCC. This work was partly used as a basis for this chapter. The research is referenced as follows:

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Photo by: Johan Malherbe

CHAPTER 2

South Africa's present-day climate

Willem A. Landman,[1] Johan Malherbe[2] and Francois Engelbrecht[2]

South African climatic regions

The term 'climate' refers to patterns of variation in meteorological variables such as temperature, rainfall, wind, etc. over a particular region as determined over long periods and spanning several decades. On the other hand, the term 'weather' refers to the present atmospheric conditions of these mentioned variables.

South Africa is associated with a variety of different weather phenomena. These include thunderstorms over the Highveld, frontal rain over the south-western Cape, berg wind conditions (and their often associated coastal low pressure systems), frost and snow during the winter months, and wide-spread flooding caused by intense cut-off low pressure systems, or even by tropical cyclones making landfall. When these weather conditions are organised into unique clusters, vastly different climatological regions are identified. For example, the south-western Cape receives most of its rainfall during winter, while the interior area of the country is a predominantly summer rainfall area. Over the east of the country, the mid-summer months are the wettest, while over the western parts most of the rainfall is received during late summer and autumn. With its latitudinal location between 22°S and 35°S, South Africa has a predominantly subtropical climate. The country is often under the influence of

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high-pressure systems of the subtropical high-pressure belt. These systems cause air to sink over southern Africa, thereby suppressing thundercloud formations and, subsequently, rainfall. As a consequence, large parts of South Africa have a semi-arid climate. As is typical of the subtropics, rainfall patterns over the country display well-pronounced, intra-seasonal and inter-annual variability.

South Africa's complex regional topography (which may cause severe convective storms) as well as its surrounding oceans (which form sources of moisture required for organised cloud bands to develop), are amongst the factors which control the country's climate. The western, southern and eastern escarpments form part of a high plateau which is on average approximately 1 250 m above sea level. Although this plateau experiences hot summers and cold winters, the oceans tend to make the climate of the coastal plains more moderate, resulting in mild winters.

South Africa generally has a warm climate, and a large area of the country experiences average annual temperatures higher than 16°C (see Figure 2.1). The southern and eastern escarpments are the regions with the lowest mean temperatures due to the decrease in temperature as the altitude increases. The warmest areas are the coastal areas of KwaZulu-Natal, the Lowveld of Mpumalanga, northern KwaZulu-Natal, the Limpopo Valley, the North West province, and the interior of the Northern Cape. The oceans surrounding South Africa have a moderating influence on temperatures experienced along the coastal areas. The warm Agulhas Current causes the eastern coastal areas to have a warm and humid climate, while the cold Benguela Current along the west coast contributes to the arid climate of this region.

Rainfall over South Africa is highly variable in space, and a west-east gradient in rainfall totals is evident (see Figure 2.2). The west coast and western interior include arid to hyper-arid areas, with humid areas over the south-eastern and eastern parts as well as over the far southern parts (see Figure 2.3). Rainfall totals are high over and to the east of the eastern escarpment of South Africa. Moist air from the warm Indian Ocean and Agulhas Current is frequently transported into eastern South Africa by easterly winds. The air is forced to rise along the eastern escarpment, resulting in orographic precipitation. There are also pockets of high rainfall along the south-western Cape and Cape south coast areas, which similarly result from orographic forcing when moist frontal air is transported inland.

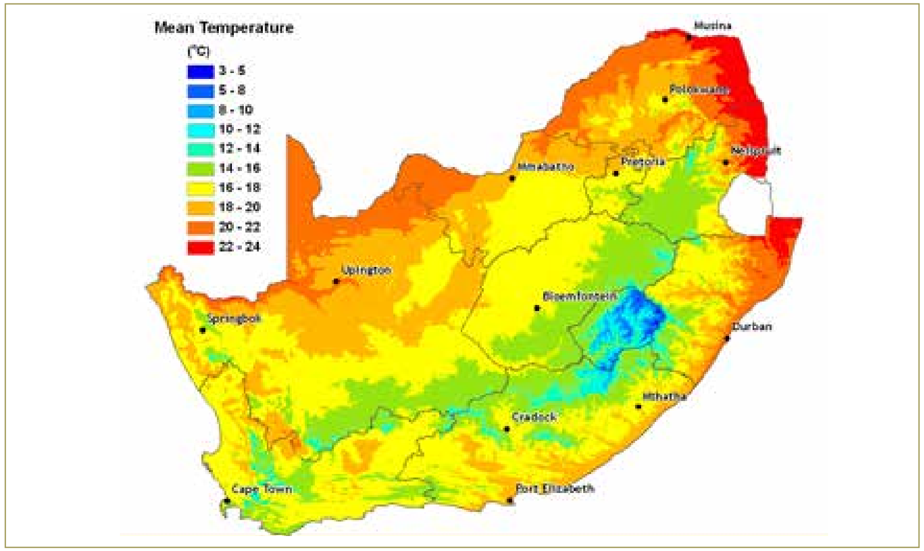

Figure 2.1 Average annual temperature (Compiled by ARC-ISCW. Data from ARC and SAWS networks)

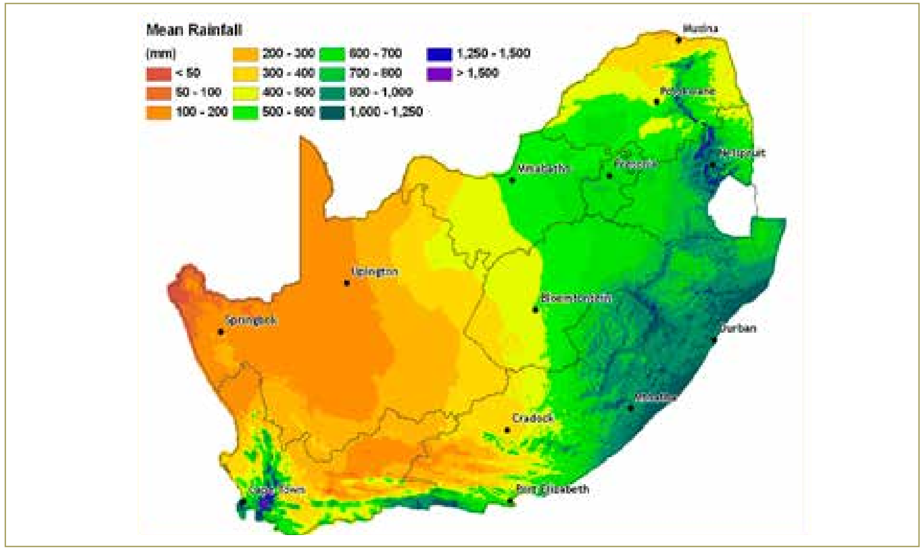

Figure 2.2 Average total annual rainfall (Compiled by ARC-ISCW. Data from ARC and SAWS networks)

Figure 2.3 Aridity Zones, based on the ratio between rainfall and potential evapotranspiration. (Compiled by ARC-ISCW. Data from ARC and SAWS networks and University of KwaZulu-Natal)

A major driver of climate variability

South Africa's weather and climate are often associated with extreme weather and climate events such as flash floods and severe droughts – all of which have societal impacts and should be predictable. The most well-known natural phenomenon linked with South African summer rainfall and temperature variations is the El Niño – Southern Oscillation (ENSO). This phenomenon involves prolonged warming (El Niño) or cooling (La Niña) of the east-central Pacific Ocean sea surface temperatures, and affects weather and climate patterns globally. Although summer rainfall is usually above normal during La Niña years, it is possible for the summer rainfall totals to be unusually high during this time, without any floods occurring. The reason for this could be the frequent occurrence of moderately wet days during the season. On the other hand, the summer rainfall total may also be unusually low during El Niño years, yet isolated flooding events may still occur. South Africa occasionally experiences drought or flood seasons when neither an El Niño nor a La Niña event occurs. For example, non-ENSO wet seasons occurred during 1980/81, 1993/94 and 1996/97, and non-ENSO drought seasons occurred in 1981/82, 1985/86 and the larger part of 2003/04. The impact of the El Niño-related drought of 1982/83 was worsened by the drought of 1981/82.

Annual cycles of rainfall and temperatures

The annual cycles of rainfall and of minimum and maximum temperatures for the towns and cities depicted in Figures 2.1 to 2.3, are presented in Figure 2.4. Cape Town and Springbok are located in the winter rainfall region, while Port Elizabeth receives rainfall throughout the year with peaks found in spring and autumn. Towns like Cradock and Upington receive most of their rainfall during late summer and autumn. The rest of the towns and cities have a predominantly summer rainfall peak, with some of them, such as Mthatha and Bloemfontein, associated with complex rainfall annual cycles. Monthly average minimum temperatures are seldom below freezing point, although places like Sutherland, situated in the south of the Northern Cape, often experience temperatures lower than -15°C. The highest maximum temperatures are mostly found over the arid regions of the Northern Cape (e.g. Upington), where temperatures in excess of 45°C are often observed.

Winter

During winter (June to August), the subtropical high-pressure belt is well-established over South Africa. As a result, winter rainfall over the interior of the country is sparse. Although occasional cut-off low pressure systems during winter have a tendency to enhance rainfall over the summer rainfall regions, the weather (during this season) over the interior parts is mostly characterised by sunny days, clear skies, and cold nights that are often associated with frost. At the southern periphery of the subtropical high-pressure belt, cold fronts regularly sweep in over the southern parts of South Africa during winter. These cold fronts tend to bring rain to the south-western and north-western Cape (a predominantly winter rainfall region), as well as the Cape's south coast to the east. The latter is an all-season rainfall region. Cold fronts and associated atmospheric circulation systems occurring in the mid- and upper-levels of the atmosphere, also cause snowfall over the mountains of the Western and Eastern Cape, over the Drakensberg Mountains in the east (with its highest elevation just under 3 500 m above sea level), and, occasionally, over the interior parts of the country. When cold fronts intrude northwards into the interior of South Africa, the associated 'cold snaps' may result in snowfall to occur over the Free State and the Highveld regions of Gauteng and Mpumalanga.

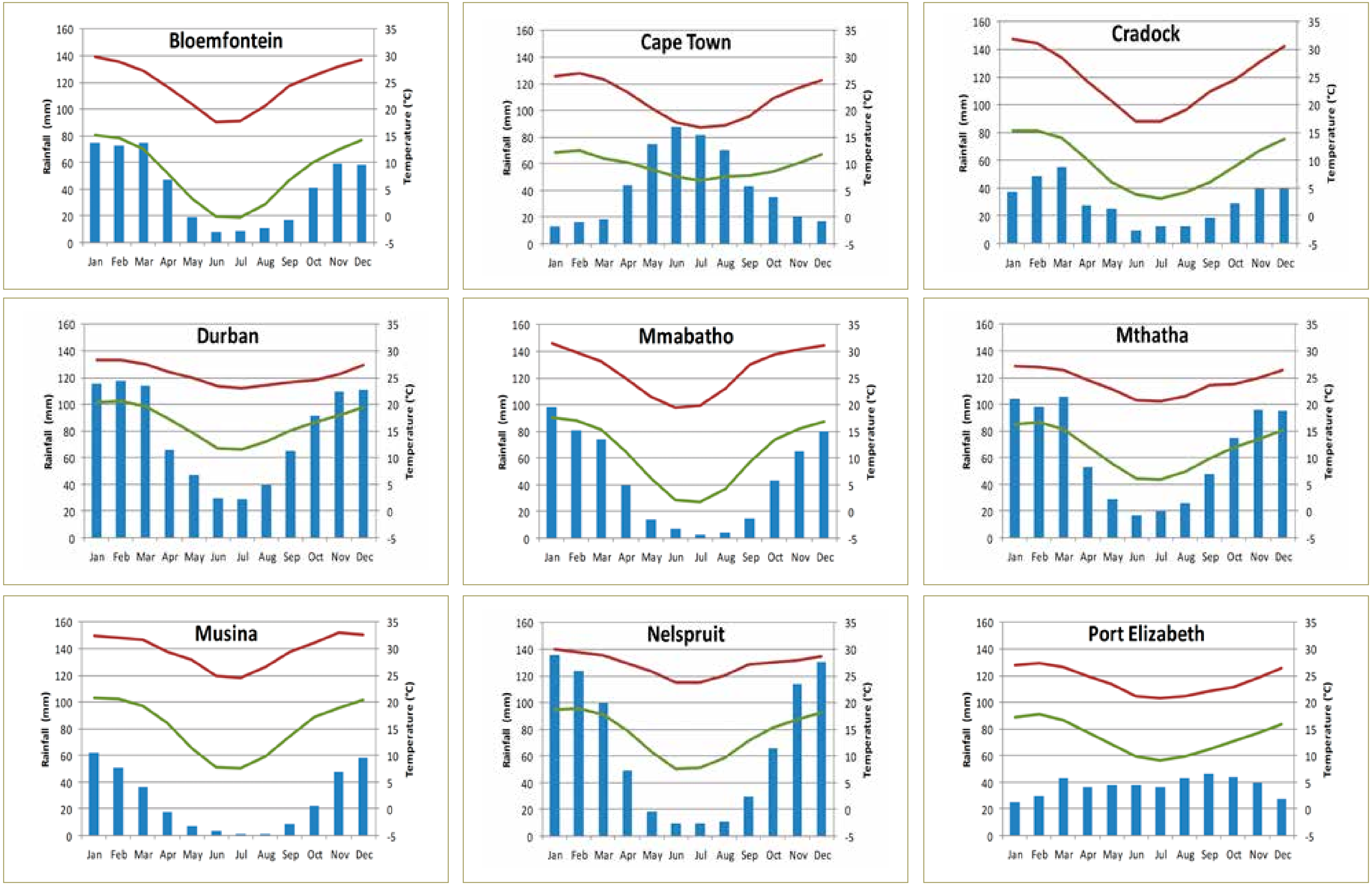

Figure 2.4 Annual cycles of rainfall (blue bars) in mm, and of minimum (green line) and maximum (red line) temperatures in °C, of towns and cities in South Africa

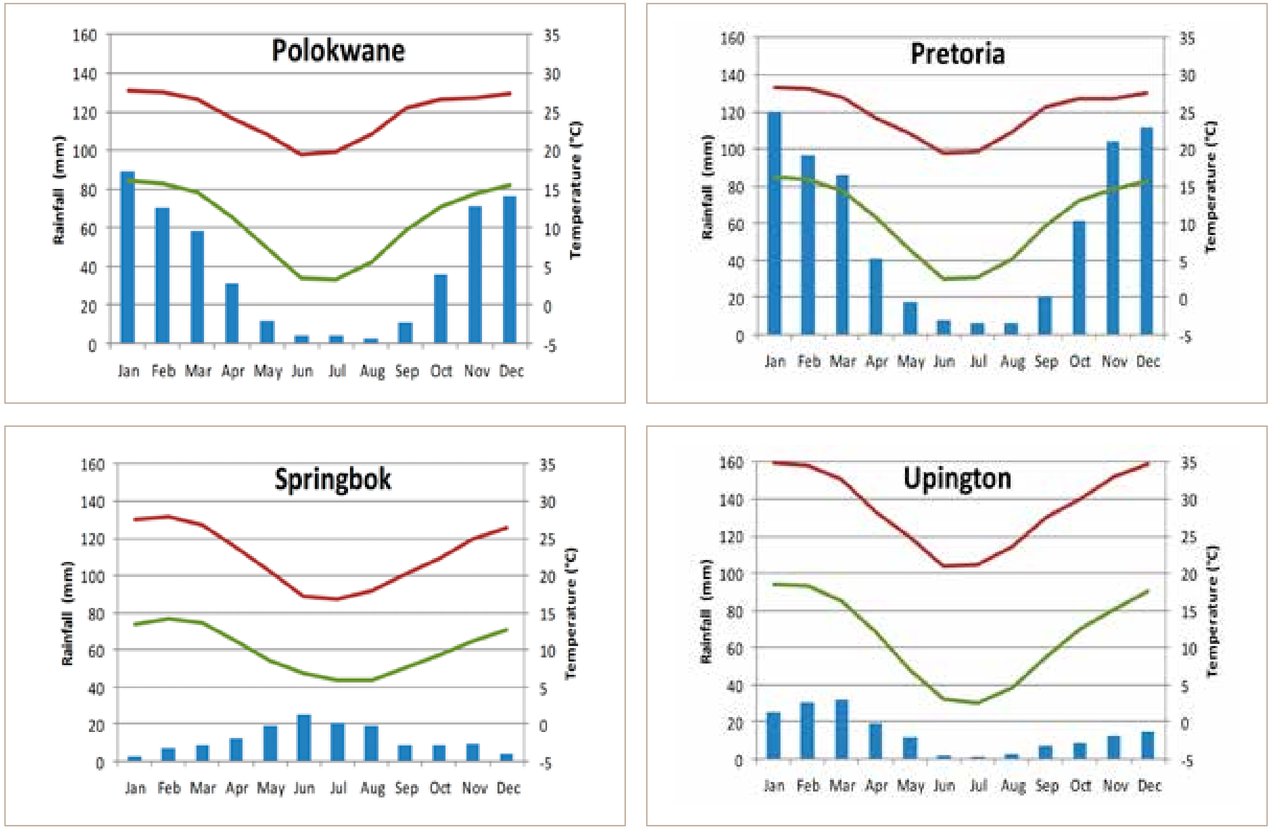

Figure 2.4 (Continued) Annual cycles of rainfall (blue bars) in mm, and of minimum (green line) and maximum (red line) temperatures in °C, of towns and cities in South Africa

Spring

During spring (September to November), a heat low develops over the western parts of southern Africa, in response to enhanced solar radiation. From spring to autumn, this low pressure triggers the formation of thunderstorms to the east. Spring is characterised by the onset of the summer rainy season, with the first significant falls of rain typically occurring over KwaZulu-Natal before spreading deeper into the interior. The rainfall that occurs over the interior parts of the country during spring is usually caused by weather systems of the westerly wind regime, referred to as 'westerly waves', when occurring in combination with ridging high pressure systems in the lower levels of the atmosphere. Such high pressure systems usually originate over the Atlantic Ocean and are subsequently responsible for the transport of moisture into the South African interior from the Indian Ocean. Cut-off low pressure systems may bring snow and heavy rainfall events over the interior during spring. These weather systems may occur at any time of the year, but are most common during spring and autumn.

Summer

The summer months (December to February) are the most important rainfall months for the central and northern interior of South Africa. During this season, the Intertropical Convergence Zone (ITCZ) reaches its most southern location, and pulses of moisture from the tropics frequently reach South Africa. Most of the rainfall occurs through tropical-temperate trough events, where a westerly wave combines with a tropical trough or low pressure system. This combination results in an extended cloud band formation which then causes wide-spread rainfall to occur over several consecutive days. During summer, heat-induced thunderstorms also frequently occur over the South African interior – especially over the eastern escarpment and Highveld areas. The summer seasonal rainfall and temperatures are also most strongly linked to El Niño and La Niña events, and is the season of highest seasonal predictability. Dry spells frequently occur during the summer season – the highest (lowest) frequency of dry spells occur during El Niño (La Niña) events, and their occurrence is associated with a displacement in the location of tropical-temperate troughs. Tropical cyclones and tropical depressions are also most prevalent during summer, and can make landfall. A recent example of such a tropical system occurred in January 2012 (see Figure 2.5 – tropical depression Dando), which resulted in hundreds of tourists and locals in the Kruger National Park to be left stranded after damage to bridges, numerous buildings, and roads in the area. Six people died in Mpumalanga during this event.

Autumn

Throughout autumn (March to April), the ITCZ advances northwards, and subsidence once again sets in over the larger part of southern Africa. During this time, rainfall decreases rapidly over the eastern interior of South Africa, while significant amounts of rainfall from cloud bands occur over the interior of the Northern Cape and the Eastern Cape provinces that are located to the west of the regions of most pronounced subsidence.

Figure 2.5 EUMETSAT satellite image on 16 January 2012 of tropical depression Dando

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CHAPTER 3

Future climate change over Southern Africa

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Introduction

There is strong scientific evidence that recent changes in climate are likely attributable to human activities and have resulted in increased annual global temperatures, as well as associated increases in temperature extremes (New et al. 2006; IPCC 2012, 2013). Global mean annual temperatures have increased by 0.85 °C since 1880 (Stocker et al. 2013), and extreme rainfall events have increased in frequency (Mason et al. 1999; DEA 2013). The rate of warming has also increased during the latter half of the 20th century (IPCC 2007), while over Africa temperatures are expected to rise at a faster rate than the global mean increase (IPCC 2013). It is clear that southern Africa is highly vulnerable to climate variability, and the region is predicted to be significantly affected by climate change. Climate change therefore poses a critical threat to the region's water resources, agriculture, health, infrastructure, and ecosystem services and biodiversity, amongst other sectors.

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Since the first edition of the *South African Risk and Vulnerability Atlas* (SARVA), increased public attention has been directed towards climate change, in part due (in South Africa and the sub-region) to the COP-17 held in Durban in December 2011. Significant progress has been made in projecting and understanding climate change for the southern African region, providing an increasingly robust basis for strategy and policy in various countries as well as the sub-region. The South African Government's National Climate Change Response Policy (NCCRP) was approved on October 2011 and was formally published as a White Paper in the Government Gazette (Gazette No. 34695, Notice No. 757). (RSA 2011).

This strategy supplies South Africa with a clear roadmap on how the impacts of climate change should be managed through interventions in social, economic and environmental sectors. In response to the NCCRP, the Department of Environmental Affairs (DEA) and the South African National Biodiversity Institute (SANBI) have developed long-term adaptation scenarios for South Africa (DEA 2013). Globally, in 2014, the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (hereafter referred to as AR5) was released which provides up to date information on the current state of knowledge relevant to climate change (IPCC 2013).

This chapter presents key messages drawn from recent subsets of future climate projections for the southern Africa region. Material in this chapter is drawn from Chapter 3 of *Climate Risk and Vulnerability: A Handbook for Southern Africa* (Davis 2011), entitled 'Regional scenarios of future climate change over southern Africa' (Tadross et al. 2011), as well as recently released studies comparing multiple Global Circulation Models (GCMs), and statistically and dynamical downscaled models (Hewitson et al. 2014). Key messages from the latest Intergovernmental Panel on Climate Change (IPCC) report on climate change as well as those from the long-term adaptation scenarios for South Africa are also discussed. The latest dynamically downscaled temperature and rainfall projections from the Natural Resources and Environment (NRE) unit of the Council for Scientific and Industrial Research (CSIR) are described for southern Africa for the short term (2015–2035) and long term (2040–2060 and 2080–2100). Some of the changes assume an A2 SRES (Special Report on Emissions Scenario) (Nakicenovic & Swart 2000), representing an unmitigated and unconstrained world; whereas others are based on the latest set of Representative Concentration Pathways (RCPs). This chapter adopts a multi-model ensemble approach[1] in order to describe the range of uncertainty associated with climate change projections (see Box 1).

Determining future climate

Global circulation models, comprise the fundamental tools used for assessing the causes of past change and to project long-term future change (2030–2060). 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 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. The term 'projection' refers to estimates of future climate possibilities decades into the future.

Future levels of greenhouse gas emissions in the atmosphere are crucially dependent on our behaviour and policy choices, for example, whether or not we continue to depend on fossil fuels or switch to renewable energy sources, hence, the models are created to simulate climate under a range of emission scenarios. Each scenario represents a plausible future. The IPCC Special Report on Emissions Scenarios describes four possible 'story lines' (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 & Swart 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 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 AR5 (IPCC 2013), 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. There are four pathways – RCP2.6, RCP4.5, RCP6.0 and RCP8.5. 'Radiative forcing' is a measure of the energy absorbed and retained in the lower atmosphere (IPCC 2007. Whilst RCPs have replaced the SRES emission scenarios in current assessments, the outputs of older SRES GCM simulations

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

and associated downscaled models remain valid, even if they describe a different subset of possible future climates. In this chapter we therefore present the outputs resulting from both SRES and RCP simulations.

Box 1

Dealing with (un)certainty in climate change projections

The degree of certainty in each finding in this chapter is based on the consistency of evidence such as data, mechanistic understanding, models, theory and expert judgement and the degree of agreement between the different models and approaches to downscaling. By summarising the areas of agreement between the different models and approaches the chapter is able to present key messages of future changes in climate that can be used in decision-making. 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.

Choosing the single 'best' GCM or downscaling technique 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. The suitable approach taken is to use the largest number of GCMs (excluding those that can be shown to be unsuitable) possible 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.

Determining regional climate change

Global circulation models 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: 28). Two main types of downscaling methodologies may be employed, namely statistical (empirical) and dynamical downscaling. For further explanations of these methodologies, see Tadross et al. (2011: 30).

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. A key limitation of all downscaling techniques is that their performance is highly dependent on the quality of the input data, and that downscaled data may inherit assumptions and errors in the GCM simulations. Therefore, in order to consider the range of climate change projections, a suite of GCM and downscaled regional climate model (RCM) projections should be used in any impact and adaptation assessment. 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 (Tadross et al. 2011: 30).

Key messages from regional climate projections

Climate Risk and Vulnerability: A Handbook for Southern Africa

The first edition of *Climate Risk and Vulnerability: A Handbook for Southern Africa* (Davis 2011) considered three main sources of climate change projections for southern Africa: GCMs, statistical downscaling (Hewitson & Crane 2006) and dynamical downscaling (Engelbrecht et al. 2009, 2013). All the models assumed an A2 SRES emissions scenario and are for the 2036–2065 period relative to the 1961–2000 period. The approach taken in the handbook concentrated on finding areas of agreement between the three sources of climate change projections for the southern African region, and thus focusing the findings that may form the basis for robust decision-making. Overall, there is greater confidence in the magnitude of changes in temperature than in the magnitude of changes in rainfall. This is because projected precipitation changes vary more between models, due in part to differences in the models' ability to replicate observed rainfall patterns and simulate rainfall producing processes (IPCC 2013).

Box 2, taken in part from Tadross et al. (2011: 50), shows key areas of agreement, as well as important metadata for the three projection sets, including findings on areas of agreement around extreme weather events (assuming an A2 SRES scenario). GCMs, statistical downscaling and dynamical downscaling all show an increase in projected temperatures, particularly for the interior of the subcontinent. The ensemble of statistically downscaled GCMs indicate an increase in temperature of between 0.8 and 3.6 °C per annum. Similarly, the ensemble of dynamically downscaled GCMs

Box 2

Summary and comparison of climate change projections from the GCMs and the two downscaling techniques (Tadross et al. 2011: 50)

	GCM	Statistical downscaling	Dynamical downscaling
Time scale	1960–2000 2030–2060	1961–2000 2036–2065	1961–2000 2036–2065
Rainfall	Decreases over central and western southern Africa during summer (December-January-February) and autumn (March-April-May). Increases further north over east Africa. Decreases over most of southern Africa during spring (September-October-November) and south-west Africa during winter (June-July-August).	Increases over Angola, northern Mozambique and south-east South Africa during summer (December-January-February) and autumn (March-April-May). Decreases over Zimbabwe, Zambia, western Mozambique and parts of the south western coastline during summer (December-January-February) and spring (September-October-November).	Increases over East Africa and south-east South Africa during summer (December-January-February). Decrease in rainfall projected for western southern Africa in winter (June-July-August).
Temperature	Increase in mean, minimum and maximum temperature		
	1–3°C	0.8–3.6°C	0.4–3.2 °C
Extreme weather events	Increase in the amount of very hot days and heatwaves	Increase in the amount of very hot days and heatwaves	More extreme rainfall events over eastern southern Africa Increase in the amount of very hot days – above 35 °C

indicates an increase in temperature of between 0.4 and 3.2 °C per annum. In addition, all models show increases in very hot days and in heatwaves. This finding is supported in the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (hereafter referred to as AR4) (IPCC 2007), which states that under the A1B and A2 emission scenarios the mean annual temperatures are expected to exceed 2 °C over large areas of southern Africa. Under high RCP, projections indicate that mean annual temperatures could reach between 3 and 6 °C over the region by the end of the century (IPCC 2013).

Despite the differences between the projected change in rainfall derived from the statistical and dynamical downscaling methods presented in the handbook, there are still regions where the ensembles agree. These include increases in annual rainfall over south-east South Africa, decreases in rainfall over southern Zambia and Zimbabwe during summer (December-January-February), and a decrease in rainfall over central Zambia during spring (September-October-November). The finding based on the dynamically downscaled models that rainfall over the south-western region of southern Africa is expected to decline is replicated in the AR5 (IPCC 2013). The difference in rainfall projections between the statistical and dynamical downscaling methods may be attributed to the manner in which they relate surface rainfall to physical rainfall producing mechanisms, including the land surface and associated feedbacks.

South Africa's Long-Term Adaptation Scenarios

The Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa is a policy-relevant research programme led by the DEA in South Africa in collaboration with the SANBI. It aims to respond to the South African NCCRP White Paper by investigating the socio-economic and environmental impacts of climate variability and change and by developing suitable adaptation scenarios under plausible climate futures for key sectors in South Africa (DEA 2013).

The LTAS Technical Working Group on Climate Scenarios developed four climate change scenarios for South Africa, namely:

1. Warmer and wetter
2. Warmer and drier
3. Hotter and wetter
4. Hotter and drier (DEA 2013: 18)

'Warmer' is considered to be less than 3 °C above the 1961–2000 baseline average; while 'hotter' is defined as more than 3 °C above the 1961–2000 baseline average. In terms of rainfall, 'drier' considers a future with an increased frequency of drought events and slightly greater frequency of extreme rainfall events. In contrast, 'wetter' defines a future with significantly greater frequency of extreme rainfall events (DEA 2013). These four scenarios provide a substantial contribution to the working messages on projected climate change for South Africa.

Dynamically downscaled projections

The Climate Studies, Modelling and Environmental Health Research Group of the CSIR in South Africa performed a set of six climate simulations. In these experiments, a variable-resolution atmospheric global circulation model (AGCM) was applied as a RCM to simulate both present-day and future climate over southern Africa and its surrounding oceans. The AGCM used to perform the downscaling is the Conformal-Cubic Atmospheric Model (CCAM) of the Commonwealth Scientific and Industrial Research Council (CSIRO) in Australia (McGregor 2005). Earlier climate projection studies using CCAM over southern Africa, including verification of the model's ability to simulate present-day southern African climate, are described by Engelbrecht et al. (2009, 2013) and Malherbe et al. (2013).

The following section presents projections of temperature and rainfall for southern Africa obtained from dynamical downscaling techniques. The change is expressed as an anomaly: the difference between the average climate over a period of the last several decades (1971–2000) and the projected climate (near-future 2015–2035, mid-future 2040–2060 and far-future 2080–2100). For temperature, the 10th, 50th (median) and 90th percentiles are shown for each time period in order to present the ensemble of projected changes. For rainfall, the focus is on the spatial patterns of change, which are identified in the median (50th percentile) downscaled GCM response in order to identify regions where change is most consistently simulated by the ensemble of six dynamically downscaled GCMs. The projected changes are based on outputs from IPCC AR4 (A2 SRES emissions scenario) and IPCC AR5 (RCP8.5 and RCP4.5 Wm^{-2} pathways). The A2 emissions scenario assumes that society will continue to use fossil fuels at a moderate growth rate, that there will be less economic integration and that populations will continue to expand (Nakicenovic & Swart 2000). RCP 4.5 describes a future with relatively ambitious emission reductions whereas RCP 8.5 describes a future with no reductions in emissions. Emissions in RCP 4.5 peak around 2040, and then decline. In RCP8.5, emissions continue to rise throughout the 21st century (Meinshausen et al. 2011; IPCC 2013).

Temperature

Temperatures over southern African are expected to increase most notably over the central interior of the region, with smaller increases over coastal areas. Under the A2 emission scenario, temperature increases of 1 to 2 °C are projected for the near-future. For the far future, increases of more than 4 °C are plausible for the over central interior of southern Africa (Figure 3.1). In general, winter and summer show the greatest increase in temperature (Figure 3.2). Substantially smaller increases in temperature are projected for RCP4.5 compared to the A2 and RCP8.5 scenarios. The most drastic rise in temperature is projected for the RCP8.5 scenario with increases of 5 to 7 °C across the interior and more than 3 °C for the coastal areas by the end of the century (2080–2100).

Rainfall

Under the A2 emission scenario, a drying signal is observed over Namibia and Angola extending south-eastwards to Zambia, Zimbabwe, Botswana, the southern region of Mozambique and the Limpopo province of South Africa (Figure 3.3). The amplitudes of the projected changes differ somewhat for the far and mid-future compared with the near-future. These decreases in rainfall are projected to occur most strongly in summer, which is the main rainfall season in these regions (Figure 3.4). This drying trend is expected to increase over time as a result of increases in the occurrence of mid-level highs over the eastern parts of southern Africa, a strengthening of the Indian Ocean high-pressure system to the south-east of the subcontinent, and an associated northward displacement of tropical lows and cyclones (Engelbrecht et al. 2009; Malherbe et al. 2013). Significantly drier winters are projected for the south-western Cape of South Africa and are consistent with the projected poleward shift of the westerlies and mid-latitude cyclones (Tennant & Reason 2005; Stager et al. 2012). This drying trend is also projected under the RCP4.5 and RCP8.5 scenarios.

Despite predictions of general drying over most of southern Africa, slight to moderate rainfall increases are projected over the central interior and south-eastern parts of South Africa, west coast of Madagascar, Tanzania, eastern DRC and the northern region of Mozambique for the near and mid-future time period. These increases in rainfall are projected to occur in spring and summer. Engelbrecht et al. (2009) attribute these changes to deepening of the heat low over the western interior during spring and summer seasons. A heat low is a shallow low-pressure system that develops in response to strong heating of the earth's surface and which is conducive to thunderstorm formation. There is also a tendency towards an increase in intensity of rainfall (extreme events), which is also linked to the strong heating of the earth's surface.

Extreme weather events

A general increase in the frequency of extreme rainfall events (20 mm of rain falling within 24 hours) is likely over the eastern parts of the continent and the western parts of Madagascar (Figures 3.5 and 3.6). The increasing signal amplifies towards

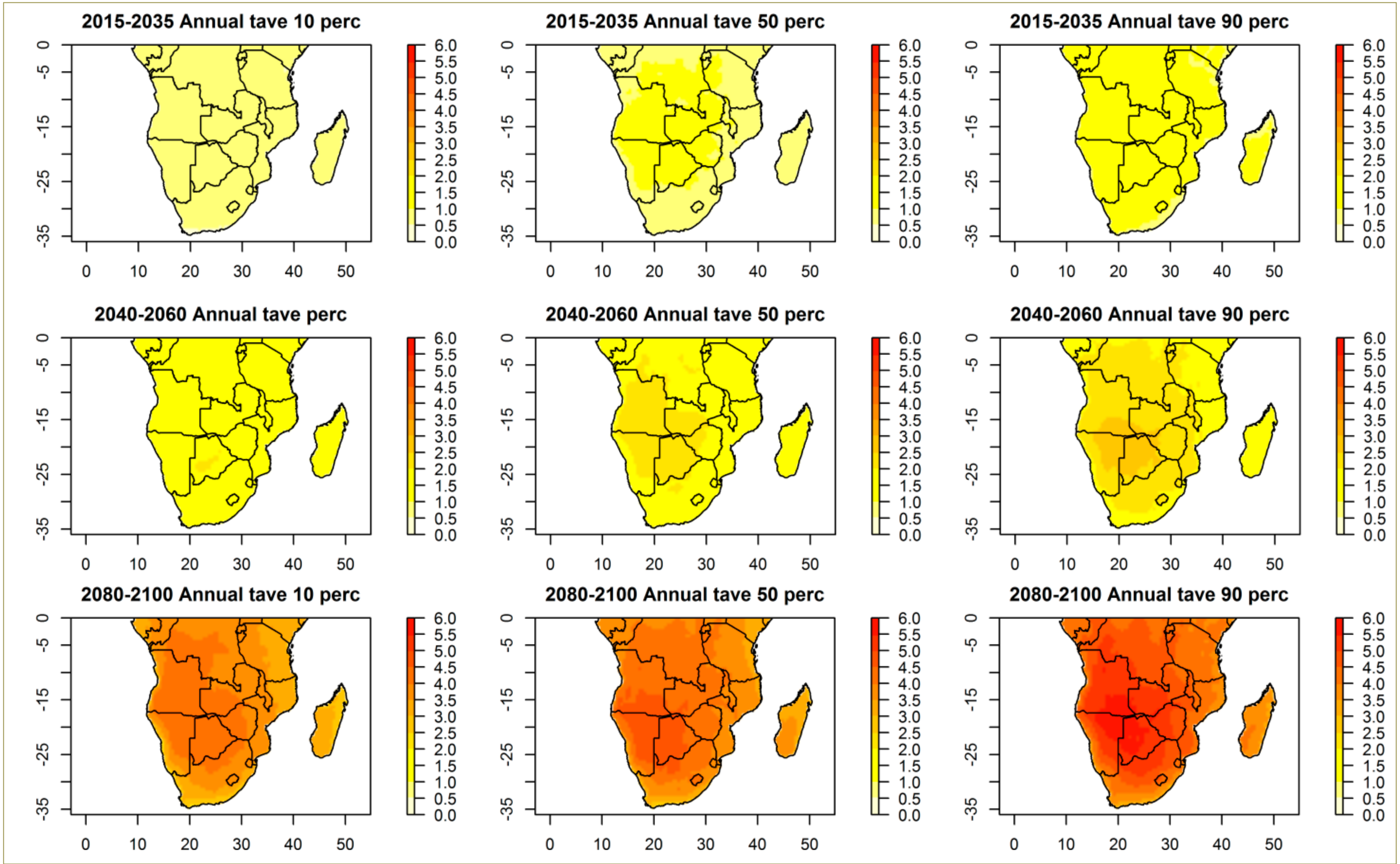

Figure 3.1 Projected change in average temperature over southern Africa for the time periods 2015–2035, 2040–2060 and 2080–2100, relative to 1970–2000. Units are the change in the temperature (°C) per grid point per year based on the 10th percentile (left), median (middle), and 90th percentile (right) of six CCAM downscalings for the A2 emission scenario.

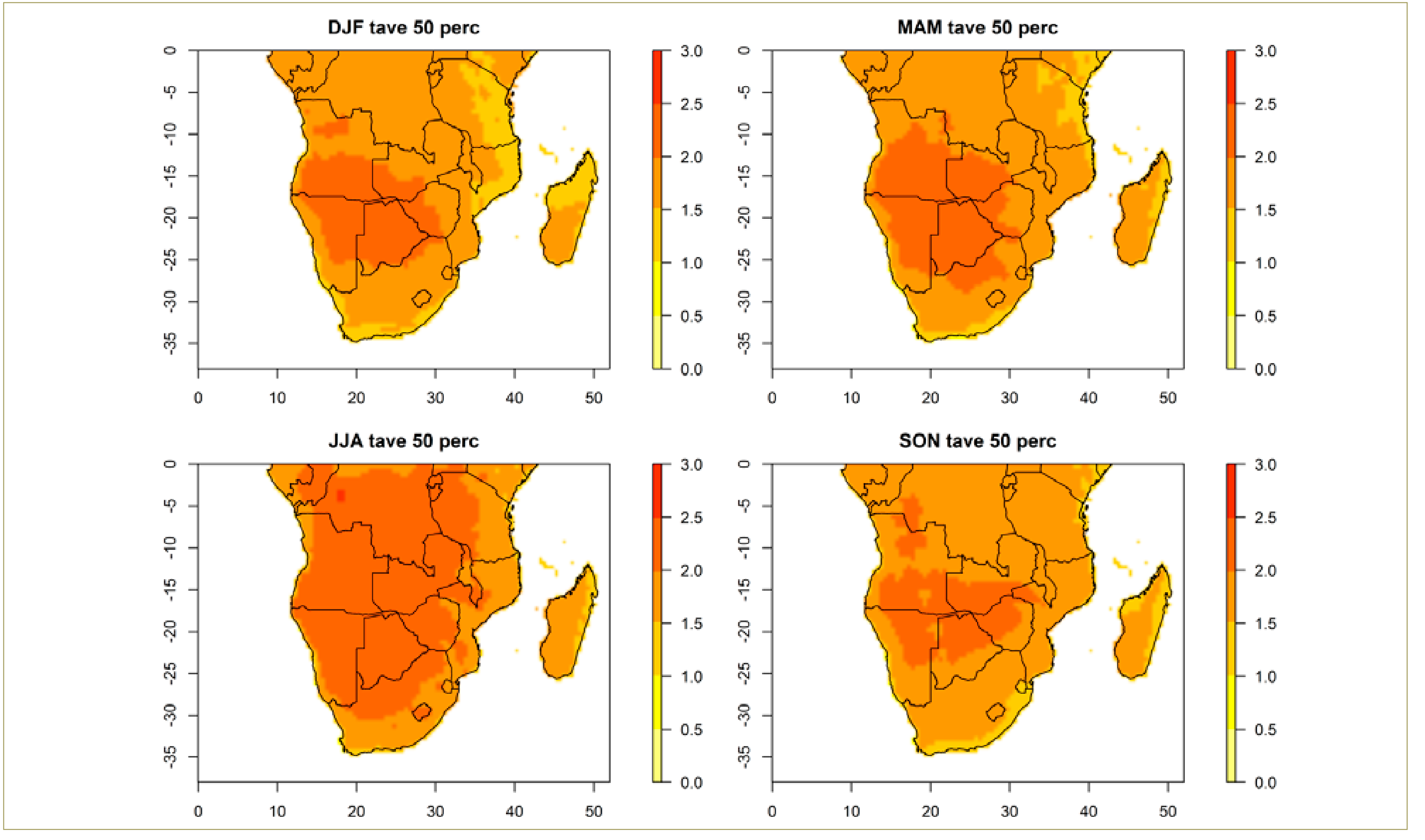

Figure 3.2 Projected change in average seasonal temperatures over southern Africa for (December-January-February), autumn (March-April-May), winter (June-July-August) and spring (September-October-November) for the period 2040–2060 relative to 1970–2000. Units are the change in the temperature (°C) per grid point per year based on the 10th percentile (left), median (middle), and 90th percentile (right) of six CCAM downscalings for the A2 emission scenario.

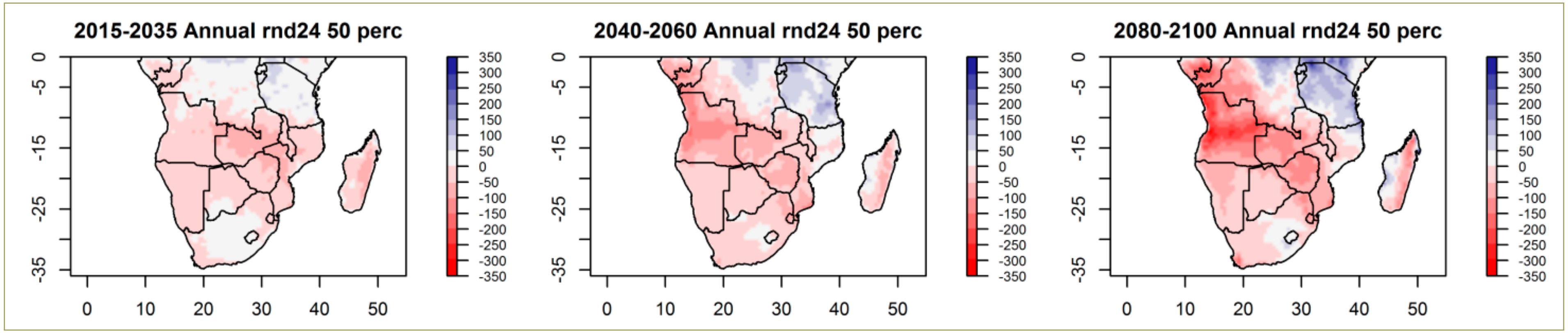

Figure 3.3 Projected change in the average annual rainfall (mm) over southern Africa, for the time periods 2015–2035, 2040–2060 and 2080–2100, relative to 1970–2000. Units are the change in the amount of rainfall (mm) per grid point per year based on the median of six CCAM downscalings for the A2 scenario.

the end of the century (2080–2100). This increase is partially driven by changes in the landfall of tropical cyclones originating in the Indian Ocean. Over the rest of the region the future trend in extreme rainfall is inconsistent with reductions expected over the interior of the continent and most notably over the eastern half of South Africa. Changes in thunderstorms (including hail and lightning) are difficult to detect due to insufficient studies and data issues and there is low confidence in the observed trends and future projections (IPCC 2013).

There is little evidence to suggest long-term changes in tropical cyclones (intensity, frequency, and duration) (IPCC 2012, 2013). 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 suggest an increase in tropical storms and cyclones over the southwest Indian Ocean. Further research is needed in order to better project changes in the characteristics of tropical cyclones occurring over the south-west Indian Ocean (Tadross et al. 2011; Malherbe et al. 2013).

Coastal storm surges are expected to increase due to sea level rise and an increase in the frequency and intensity of sea storms, accompanied by increases in wave heights (IPCC 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).

South Africa is projected to become warmer and the increase in average temperature is projected to occur in association with an increase in the increase in very hot days (number of days when the maximum temperature exceeds 35 °C) and heatwave events. The occurrence of fires is closely linked with climate and increases in temperature combined with an increase in dry spells in some areas may result in wildfires affecting larger areas and fires of increased intensity and severity (IPCC 2012). Low temperatures, including the number of frost days, have decreased in frequency and are expected to become less frequent in the future (DEA 2013).

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

The following results are taken from a study to assess the spread of possible future climates simulated by a multi-model and multi-method hyper-ensemble (Hewitson et al. 2014). The simulated climates are taken from an ensemble of 16 GCMs, an ensemble of statistical downscaling of ten of these GCMs, and an ensemble of a single RCM downscaling of eight GCMs generated through the Coordinated Regional Climate Downscaling Experiment (CORDEX) framework. All simulations utilised both the RCP4.5 and RCP8.5 scenarios. Although some of the GCMs used in the RCM downscalings were not included in the GCM ensemble, these model future climates remain valid.

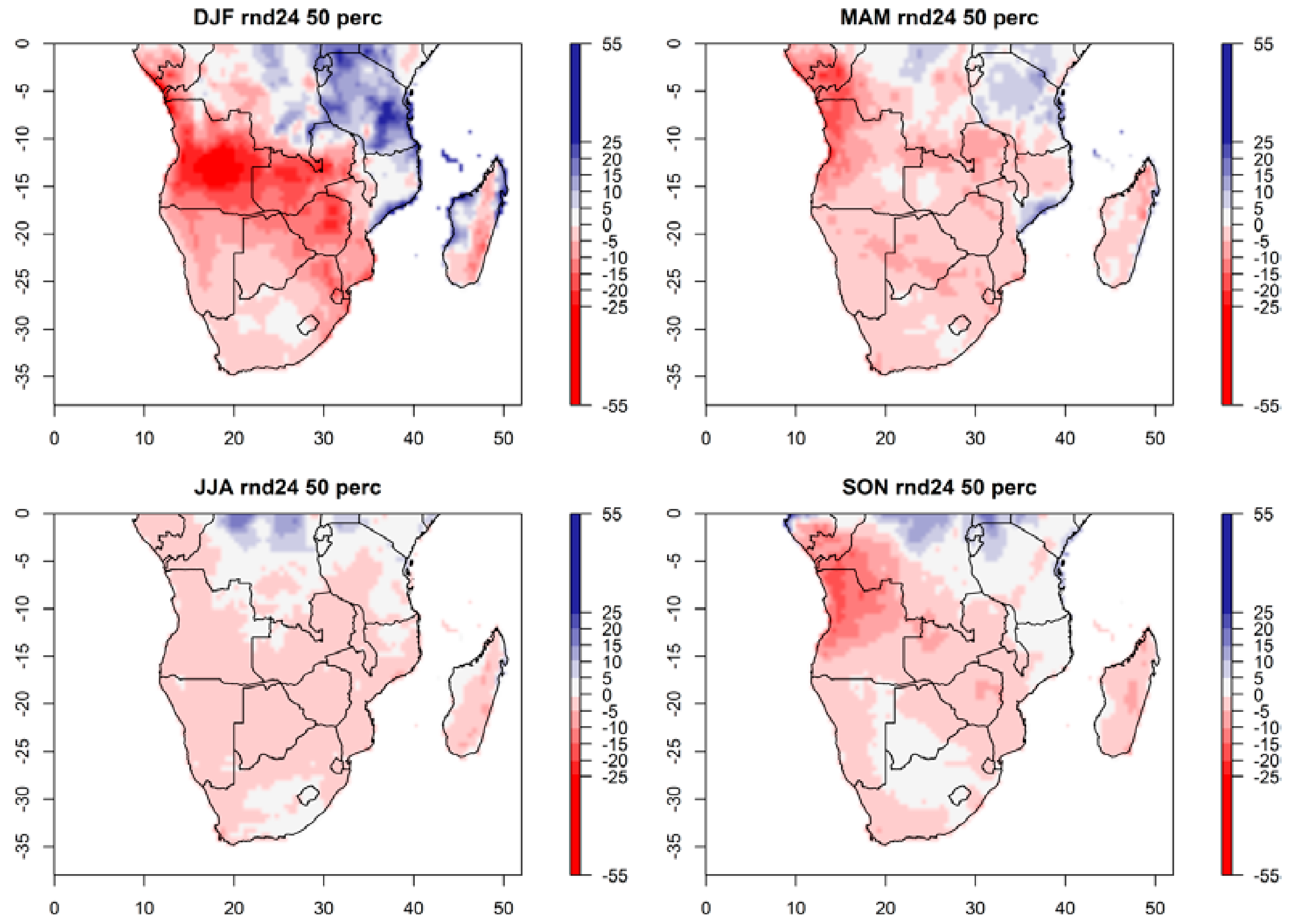

Figure 3.4 Projected changes in the average seasonal rainfall (mm) over southern Africa for (December-January-February), autumn (March-April-May), winter (June-July-August) and spring (September-October-November) for the period 2040–2060, relative to 1970–2000. Units are the change in the amount of rainfall (mm) per grid point per year based on the median of six CCAM downscalings for the A2 SRES scenario.

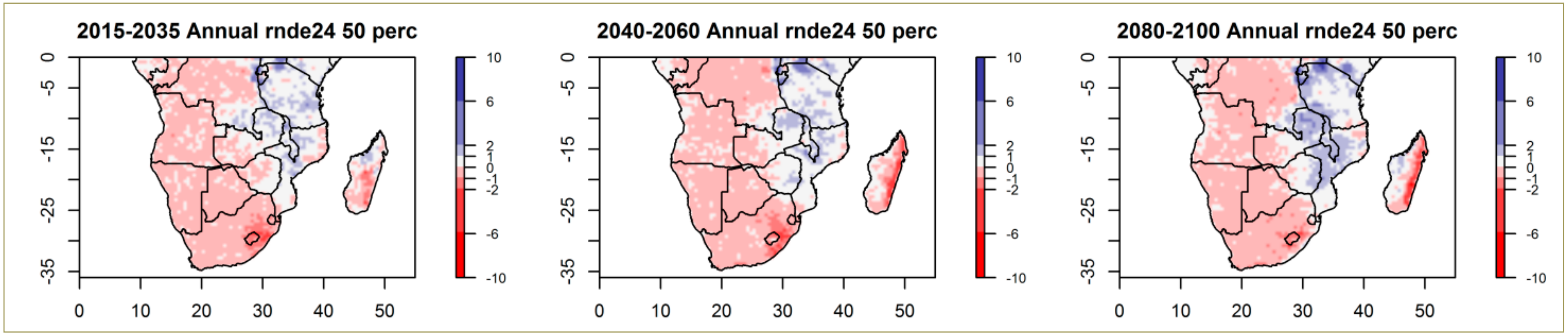

Figure 3.5 Projected change in the number extreme rainfall days (20 mm of rain falling within 24 hours) over southern Africa, for the time periods 2015–2035, 2040–2060 and 2080–2100, relative to 1970–2005. Units are the change in the amount of rainfall (mm) per grid point per year based on the median of six CCAM downscalings for the RCP4.5 scenario.

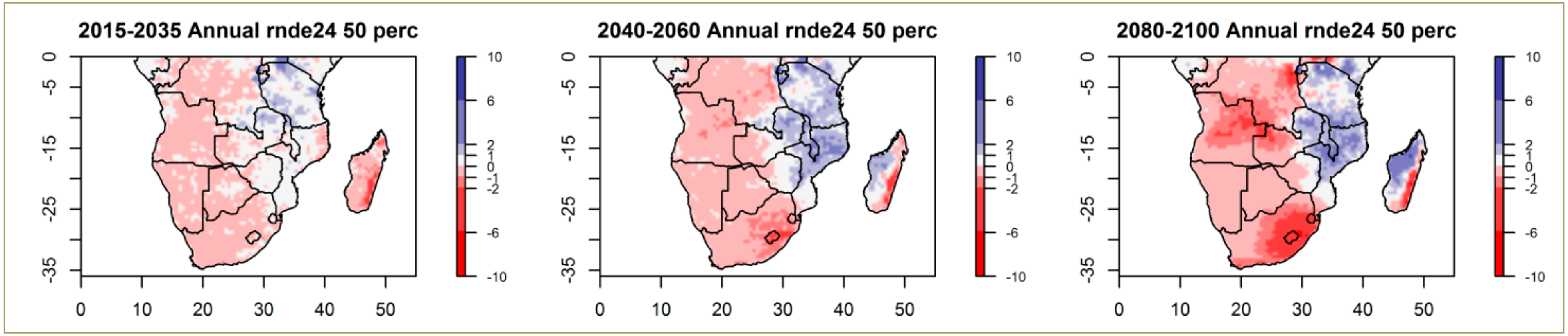

Figure 3.6 Projected change in the number extreme rainfall days (20 mm of rain falling within 24 hours) over southern Africa, for the time periods 2015–2035, 2040–2060 and 2080–2100, relative to 1970–2005. Units are the change in the amount of rainfall (mm) per grid point per year based on the median of six CCAM downscalings for the RCP8.5 scenario.

Figure 3.7 indicates the future changes (the 2041–2070 period relative to the 1976–2005 period) in December to February (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 can be seen 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 regional 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 ranges 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. 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 RCP4.5 scenario. Nevertheless, taking the interquartile ranges, the hyper-ensemble suggests increases in maximum temperatures of between 1 and 3 °C.

Figure 3.8 shows maps of median simulated changes in seasonal (DJF) rainfall in each of the three ensembles for the RCP8.5 scenario. The GCM ensemble change is shown for the same 10 GCMs used for the statistical downscaling. Whilst 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 the latitude 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 under an assumed A2 scenario, suggesting the simulated changes are robust under a wide range of modelling approaches. Differences between the three ensembles shown, 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.

Conclusion

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 method or model used. The difference in rainfall projections between statistical and dynamical downscaling ensembles may be attributed to the way in which surface rainfall is related to the physical processes that 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). This suggests that convergence may be enhanced through the use of more GCMs and through refinement and development of modelling approaches and downscaling tools.

Assuming that emissions of anthropogenic greenhouse gases continue to rise at current or higher levels, central southern Africa is highlighted as a region likely to be drier in the future during mid-summer, with parts of Tanzania likely to be wetter. As a robust finding, temperatures are projected to further 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. Decreases in mid-summer rainfall, together with higher temperatures, will have critical implications for water availability and impact a number of sectors, particularly agriculture and hydrology in what are already vulnerable regions.

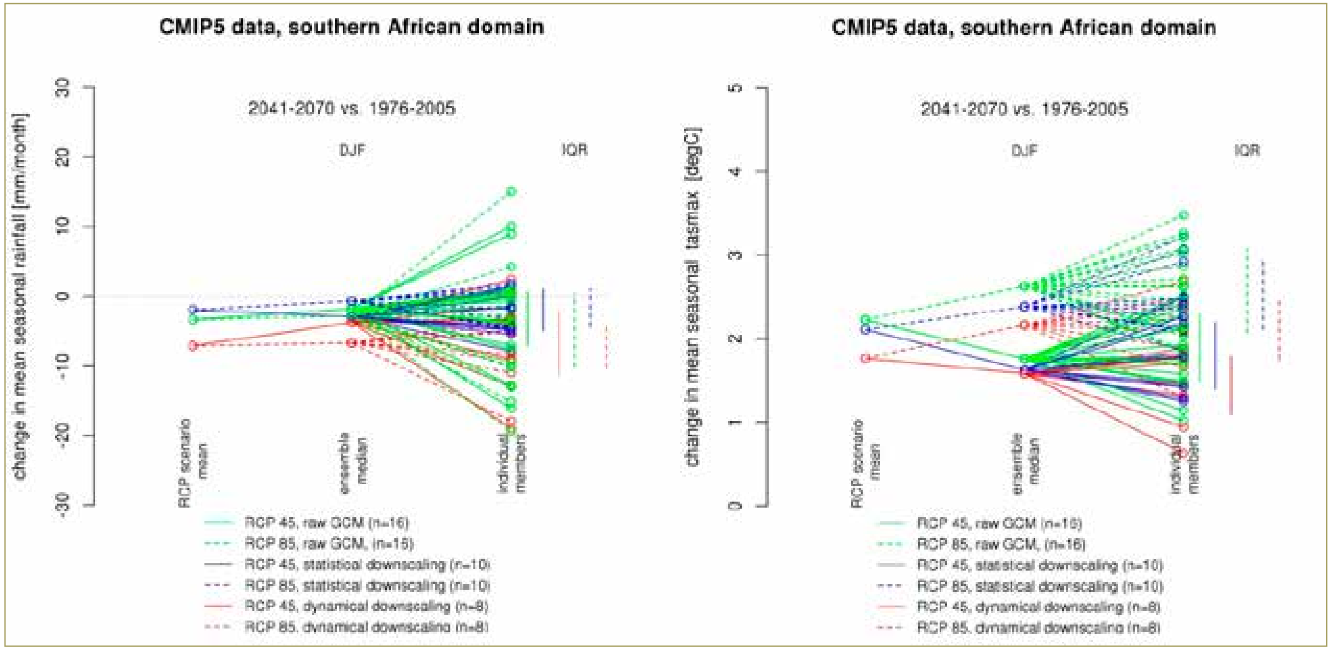

Figure 3.7 Change in mean monthly rainfall (left) and maximum temperature (right) for DJF for two RCP scenarios: 16 GCMs, the statistical downscaling realisations and eight RCM realisations averaged over the domain covering the land body of southern Africa (35°–-20°S, 10°–40°E). Bars on the right-hand side of the graphs mark the interquartile range for each ensemble/RCP combination.

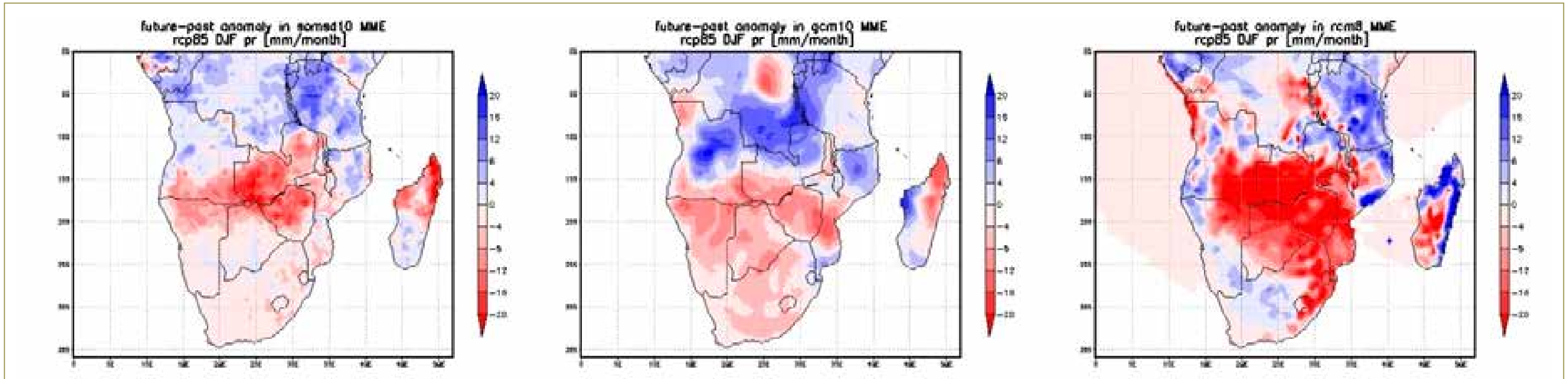

Figure 3.8 Maps of ensemble median of change in rainfall (2041-2070 period relative to 1976-2005 period), in statistically downscaled ensemble (left), GCM ensemble (middle), and dynamically downscaled ensemble (right), for DJF under RCP4.5

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CHAPTER 4

Profiling the vulnerabilities and risks of South African settlements

Alize le Roux,[1] Gerbrand Mans,[1] Elsona van Huyssteen[1] and Willemien van Niekerk[1]

Introduction

Cities, towns and settlements provide housing and livelihoods for a growing global population. Estimates indicate that in 2014, 54% of the world's population and 40% of the population on the African continent were considered urban. African city growth rates are amongst the highest in the world and it is estimated that by 2050, 56% of the population in Africa will be living in urban settlements (UN 2014). Aside from hosting the majority of the world's population, urban settlements generally provide a wide range of livelihoods and services for their residents and its surrounding areas, provide economies of scale in production, ease of information flow, large markets for goods and labour, and offer greater opportunities for education, healthcare, social cohesion and trade. It is, however, becoming increasingly difficult for people to find

1 Council for Scientific and Industrial Research (CSIR) – Built Environment

safe shelter, sustainable livelihoods and adequate services in many African cities. There is evidence of increasing social conflicts and environmental strains in African cities as a consequence of the inherent vulnerabilities associated with urbanism combined with political and institutional failures to plan effectively (UN-Habitat 2014). Thus, cities and towns are burdened with rising service delivery backlogs, poverty levels and unemployment. Yet anticipated migration, urbanisation and natural population growth will limit their ability even further to effectively respond to and mitigate risks associated with global change.

This chapter builds on the first *South African Risk and Vulnerability Atlas* (SARVA) and extends the work by examining some of the multi-stressors[1] associated with global change that are affecting the vulnerability of urban settlements in South Africa. Some of the analyses have also featured in recently published articles that explore the methods and techniques used in this chapter (van Huyssteen et al. 2013; le Roux et al. 2015). The chapter also serves as a plea to decision makers, officials and practitioners to have earnest consideration for spaces with high (and increasing) concentrations of socio-economic vulnerability combined with exposure to unique and complex environmental and human induced hazards, since they have critical implications for large numbers of the South African population, their livelihoods, and the infrastructure and networks supporting the country's economy.

The chapter is structured as follows: The first section provides an overview of the importance of South African cities and towns and highlights some of the most critical settlement dynamics with regards to its demography and economy. In the second section the analysis of a number of multi-layered indicators provides an indication of the highly concentrated nature of socio-economic vulnerability, largely clustered within cities, towns and settlements. The third section illustrates first level attempts of identifying settlements at risk if exposed to hazards associated with global change. The chapter concludes by highlighting some implications of the findings and responses required.

1 Considering a range of indicators and proxy indicators such as population density, levels of dependency, GVA per capita, etc. in order to provide an indication of social and economic vulnerability, in relation to exposure to a range of potential natural hazards, e.g. extreme rainfall events.

The socio-economic landscape of South African cities

The average annual population growth rate in South Africa between 1996 and 2011 is calculated at approximately 1.85%. This growth includes natural population growth as well as in-migration. Cities and towns are the places with the highest population growth: The national average population growth rate for metropolitan areas between 1996 and 2011 is estimated at approximately 3%, for cities and towns at 2.87%, 1.81% for small towns, and only 0.58% for areas outside of towns. Thus, although cities, towns and settlements[2] cover a surface area of less than 7%, they currently host 78% of the country's population (van Huyssteen et al. 2013b; van Huyssteen et al. 2015). While natural growth will continue to have an impact on the increase of the urban population, recent migration studies (see Maritz 2010, 2015; Mans et al. 2014) suggest a continuing urbanisation rate, concentration of population in cities and towns across South Africa, and strong flows not only between the major centres, but also from the eastern and northern parts of the country to major metropolitan areas. The latter contributes to a dynamic, diverse and increasingly young and mobile urban population.

Recent studies (see van Huyssteen et al. 2014; van Huyssteen et al. 2015) confirm that the network of cities, towns and settlements[2] may be considered the backbone of the South African economy, generating 86% of all economic activity. The major metropolitan areas function as innovation, logistic and intellectual hubs on the forefront of generating knowledge and ideas, and provide significant gateways to global markets and economies (van Huyssteen et al. 2014). However, cities, some city centres, and towns are becoming locations of choice for increasing numbers of urban poor and youth, and are thus challenged with the largest concentrations of poverty, deprivation, unemployment, pollution, crime and, in South Africa's case, with the highest levels of income inequality and service delivery backlogs (SACN et al. 2009). It is estimated that 14% of the 14.45 million households in South Africa are informal (including informal settlements and backyard shacks), of which a staggering 57% of these informal and vulnerable households are located within the eight metropolitan municipalities[3] (Stats SA 2011). These figures prove that any attempt at national

2 CSIR/SACN Settlement Typology. Included in analyses are City Regions, Cities, Regional Service Centres, Service Towns and Local and Niche Towns.

3 The eight metropolitan municipalities are the City of Johannesburg, City of Cape Town, City of eThekwini, City of Tshwane, Nelson Mandela Bay, Ekurhuleni, Mangaung and Buffalo City.

development – including job creation, increasing the quality of life, and resource efficiency as set out by the NPC (2011), any effort to understand risks and vulnerabilities, and any endeavour to improve community resilience – will need to place a significant emphasis on the fact that cities and settlements are networks of complex, interdependent and constantly shifting systems.

Figure 4.1 provides an overview of the spatial distribution of South African cities and towns, and how they differ in geographical size, location, connectivity and concentration of population. It also gives an indication of the total size of economic activity produced in the various settlements. In terms of economic activity, service functions, population size and connectivity, the South African settlement landscape is clearly dominated by the Gauteng global city region, followed by the city region areas of Cape Town, eThekwini and Nelson Mandela Bay, which together host more than 42% of the population and generate 59% of all economic activity on less than 2% of South Africa's land area. The functional reach of these city region areas are far beyond that of the respective municipal boundaries.

Figure 4.2 provides an overview of the current distribution and density of the country's population. The figure clearly indicates that the majority of the population resides within South Africa's metropolitan municipalities as well as in the densely populated rural areas of the Eastern Cape, KwaZulu-Natal and Limpopo provinces. The latest census data (Stats SA 2011) confirms that almost 40% of the country's population are currently living within the eight metropolitan municipality boundaries. The significant role that cities such as Mbombela, Polokwane, East London, Pietermaritzburg and the Mangaung metropolitan areas play, is also evident in Figures 4.1 and 4.2. These cities host 7.5% of the South African population and are responsible for generating just more than 8% of the country's economic activity (van Huyssteen et al. 2015).

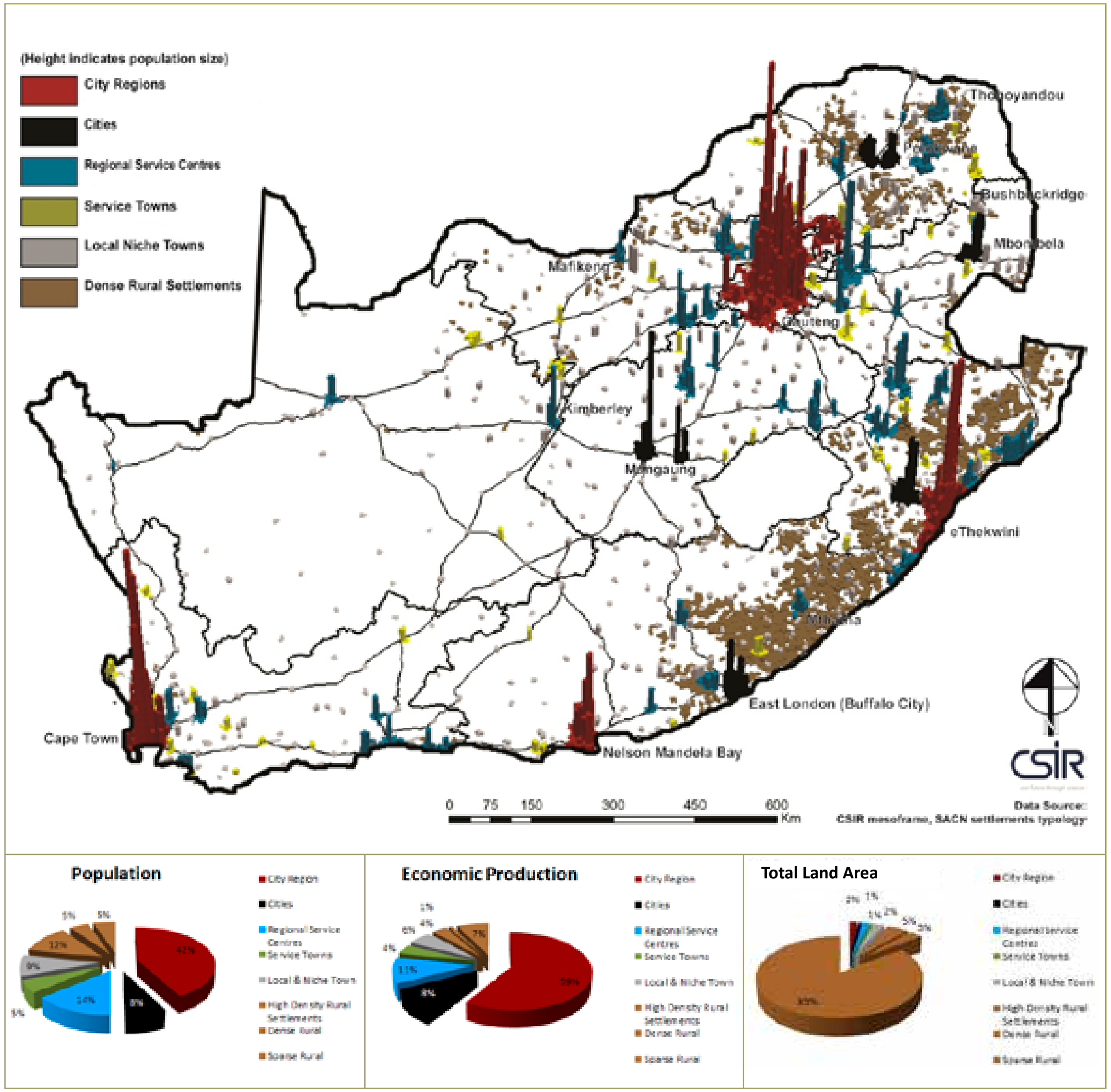

Figure 4.1 Distribution and significance of South African settlements (Data source: CSIR/SACN 2014)

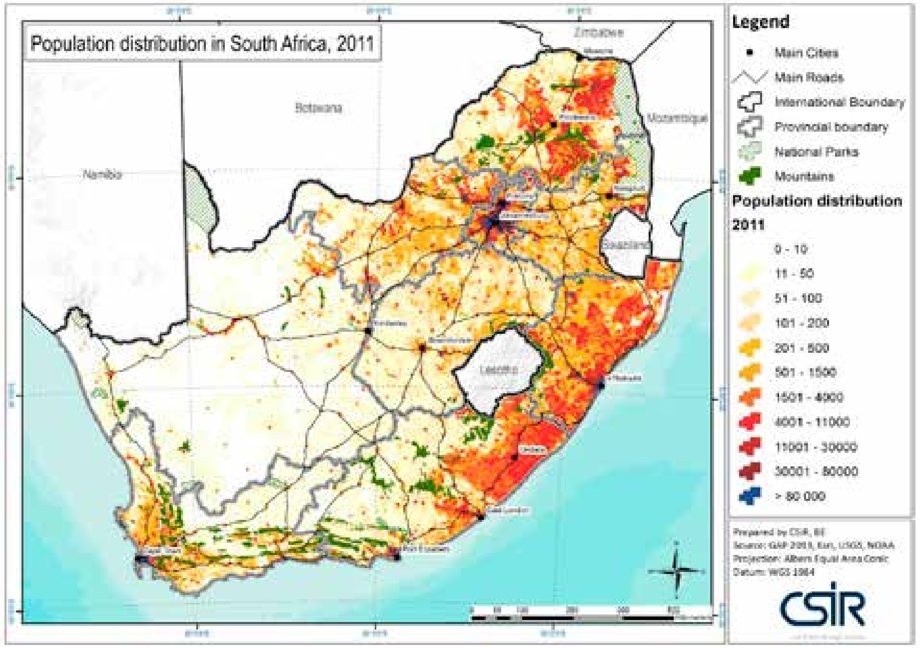

Figure 4.2 Distribution of the South African population (Data source: CSIR GAP 2013)

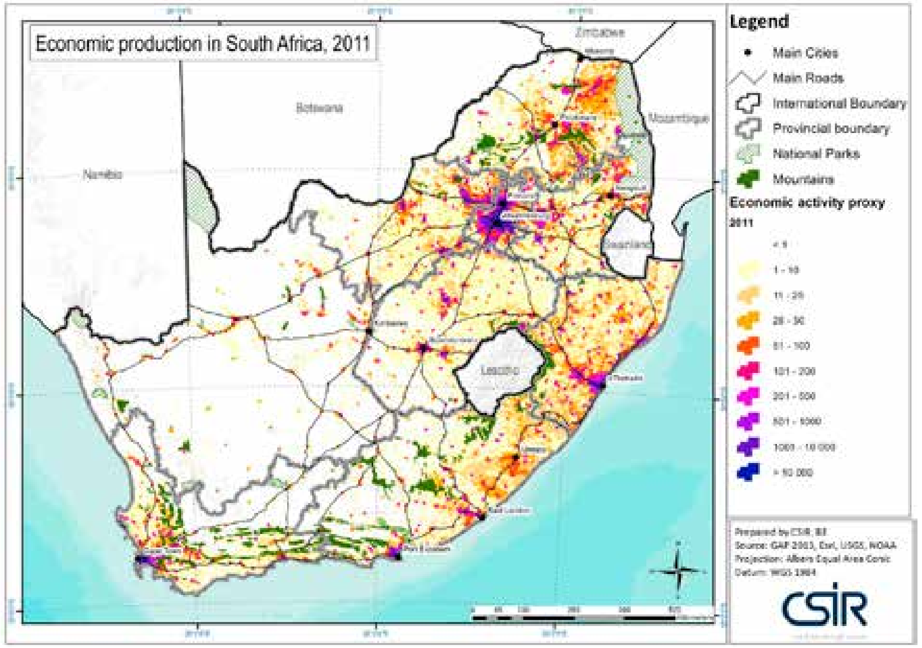

Figure 4.3 Distribution of economic activity in South Africa (Data source: CSIR GAP 2013).

Figure 4.3 provides an overview of the geographical distribution of South Africa's economic activity by representing the proxy gross value added (GVA) product. Population size and GVA often correlate and determine most city and town hierarchies across the world. When comparing the population and economic distribution of South African settlements, a definite correlation is found between the population densities in the metropolitan areas and these areas' high economic production figures. This is also true for a number of regional service centres (large towns) such as Rustenburg (Bojanala Municipality), Richards Bay, and Phalaborwa which are often associated with large resource-based economies. However, this is not the case for many large, medium and small towns in South Africa. The spatial legacy of apartheid produced numerous large and medium-sized towns (such as Mthatha, Thohoyandou, New Castle, Queenstown and Ulundi) that are characterised by population sizes of over 150 000, but have relatively low levels of economic activity and service functions (CSIR and DRDLR 2013). This is also the prevailing trend in the former homeland areas (Bantustans) in the Eastern Cape, KwaZulu-Natal and Limpopo, where an estimated 12% of the South African population resides in densely populated rural settlements, but only produce 3.7% of the country's economic activity (van Huyssteen et al. 2015). These disparities tend to manifest in very low levels of economic activity per capita and high unemployment ratios (coupled with high population densities), pointing toward the socio-economic vulnerability of settlements as well as the severely hampered coping capacity of communities due to a lack of resources.

The socio-economic vulnerability of South African communities

Given the complex landscape as set out above, two indicators were developed to provide an indication of social and economic vulnerability across the South African landscape.

Social vulnerability

The first indicator, a social vulnerability index, quantifies the varying degrees of social vulnerability in order to determine the location of the most vulnerable communities. Social vulnerability refers to "the state of individuals, groups, or communities defined in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being" (Adger 1999). Vulnerability is much more than mere access to economic resources and also includes the loss of social capital, the fragmentation of social networks, and the breakdown of family and friendship ties that form an informal safety net for many poor households. Aspects such as access to resources (social and economic) and networks, health and income thus all influence the coping or adaptive capacity of households, communities and neighbourhoods in towns and cities (van Huyssteen et al. 2013a). Social vulnerability can typically be identified in communities where there are high illiteracy rates, high proportions of age dependent populations, pressures associated with in-migration, ethnic minorities, female headed households, informality, violent crime, and growing backlogs in terms of access to basic services (le Roux & van Huyssteen 2010; van Huyssteen et al. 2013a). A single variable may not render an individual vulnerable, but a combination of above-mentioned variables (or a relationship between these variables) may render a person vulnerable (Dwyer et al. 2004; le Roux et al. 2015).

The social vulnerability index is a composite indicator, created statistically through a principal components analysis (PCA). The index makes use of verified, routinely available public data, and was designed for the purpose of tracking and monitoring change brought about by policy intervention and investments (le Roux et al. 2015). The PCA uses 2011 national census data on ward level and was constructed from fourteen variables (household size average, age dependency ratio, percentage unemployed, percentage people below poverty line, percentage rural population, percentage shacks, percentage education, percentage disabled people, percentage female-headed households, percentage population without electricity, percentage households without telephone lines, percentage people without a car, percentage people without public water, percentage immigrants), each representing an aspect of social vulnerability within a community as identified through national and international research (le Roux et al. 2015).

Figure 4.4 shows the areas in South Africa which are home to the most socially vulnerable communities. The most vulnerable communities correlate strongly with the former homeland areas in the Eastern Cape, KwaZulu-Natal, Limpopo and North West provinces. In addition to these, highly vulnerable communities are also found in the local municipalities of Musina, Blouberg, Lephalale and Molemole in Limpopo; Nkomazi, Mkhondo, Msukaligwa, Pixley Ka Seme in Mpumalanga; Ditsobotla, Ventersdorp and Kagisano in North West; Emadlangeni, Abaqulusi and Emnambithi in KwaZulu-Natal; Ga-Segonyana, !Kheis and Sol Plaatjie in the Northern Cape; and isolated areas in the Western Cape, such as Knysna and the Breede Valley (le Roux et al. 2015).

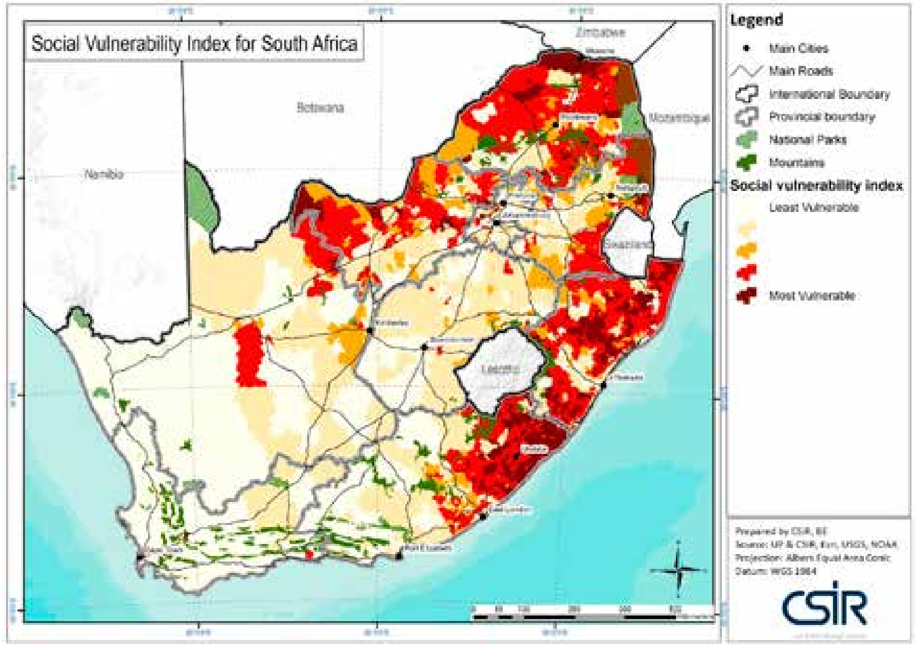

Figure 4.4 Areas with high social vulnerability (Data source: UP and CSIR 2013)

There are also pockets of severe social vulnerability located within the metropolitan municipalities (Figure 4.5), which correlate strongly with the locations of informal settlements and highlights the spatial inequality of South African settlements.

Economic vulnerability

The second indicator, an economic pressure index, quantifies a number of economic indicators to determine the location of the most vulnerable communities in terms of a place's economic health. Economic vulnerability can typically be identified in communities where there are a low GDP per capita, economic decline, and dependency on a single economic activity (van Huyssteen et al. 2013a). It is important for risk analyses to understand the economic landscape; for positive economic growth and development equip places to better manage, and possibly avoid, any adverse events, e.g. severe weather. Conversely, any adverse event can diminish development gains and set back social and economic growth and development prospects for an area.

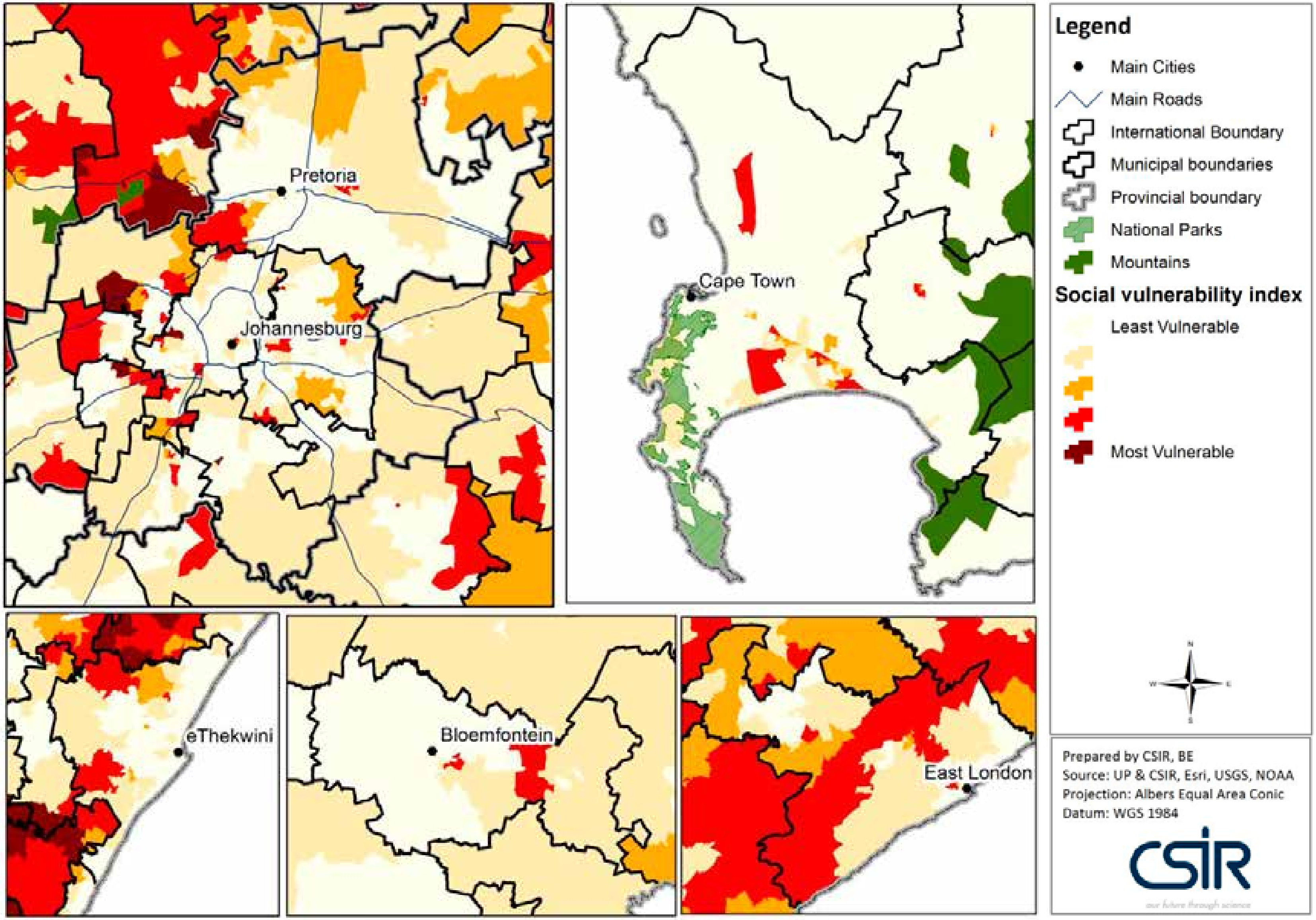

Figure 4.5 Areas with high social vulnerability within seven of the metropolitan municipalities (Data source: CSIR 2013)

If vulnerable, any severe event can damage infrastructure, remove livelihoods, and increase health risks, amongst others. Resources that would have otherwise been spent on poverty reduction and job creation are instead diverted to rebuild what was lost. If a place is not able to reduce its economic vulnerability, its long-term growth potential can be affected, which, in turn, will impact negatively on its long-term development goals. This is particularly true for non-diversified economies if the output and factors of production are repeatedly affected (Stern 2007; Collins 2009).

The economic pressure index is a composite indicator, compiled in a first round multi-criteria analysis that makes use of proxies such as GDP per capita (CSIR GAP 2007), diversity of the economy (Quantec 2010 data), and economic decline (Quantec 2010 data). These proxies have been shown to reflect the economic health and trends in an area. Figure 4.6 indicates the results, namely areas and settlements with high concentrations of economic vulnerabilities (on household, settlement or municipal scale). High levels of poverty, low levels of economic activity, high dependency rates – both in terms of household dependency on state grants and single sector economic dependency often in decline – are the main characteristics found in the identified areas (van Huyssteen et al. 2013a).

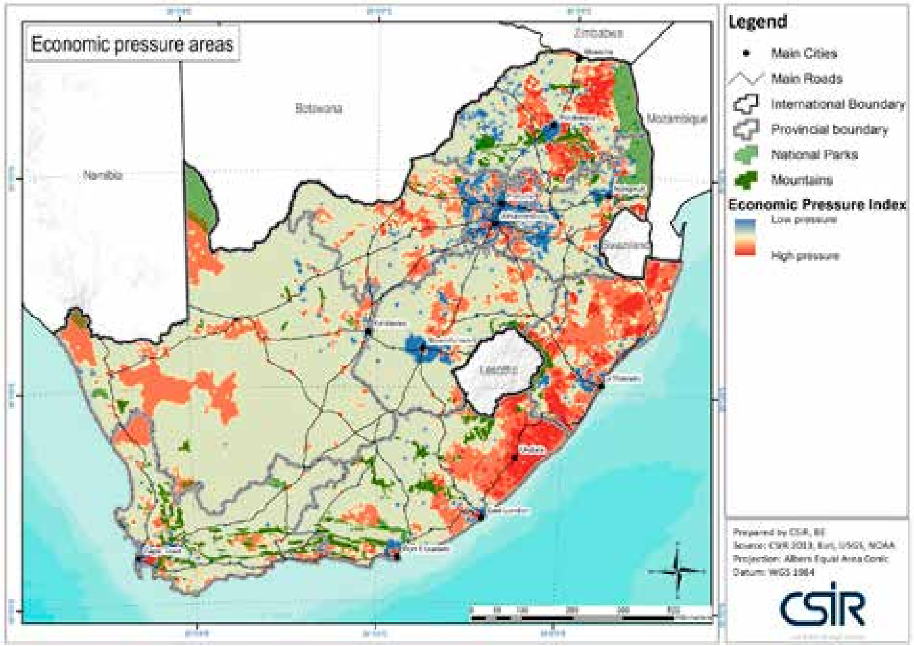

Figure 4.6 Areas marked by economic pressure (decline and vulnerability) (Data source: CSIR 2013)

On a broad regional level, the areas under the biggest pressure are:

- The densely settled former homelands along the eastern coast and in the northern parts of the country;
- Areas surrounding the metropolitan areas and major towns – illustrating settlement-specific dynamics (especially if more zoomed in views are created);
- Resource-dependent and former mining towns, often marked by high unemployment levels despite some economic activity;
- Secondary cities as well as their surrounding areas, located in the central and northern parts of the country and marked by a declining industrial sector and high unemployment; and
- Coastal towns along the southern and eastern coastlines, characterised by high in-migration and unemployment (van Huyssteen et al. 2013a).

Settlement exposure to risks associated with global change

It is evident from the previous section that understanding composite socio-economic vulnerability within settlements is a critical foundation in building resilient communities capable of mitigating and managing the risks associated with global change. This section provides examples of some attempts at exploring settlement exposure to risks associated with global change. The purpose of the section is not so much to identify critical areas of exposure, since these analyses are constantly updated as more current information becomes available. It is rather to provide an indication of the type of exposure cities are facing, and the value of following an integrated approach toward risk analysis. While the impact of global change, specifically climate change, is often quite an abstract topic of discussion, recent progress with sub-regional global change models and projections made by SARVA as part of its Weather and Climate theme (Engelbrecht & Landman 2010), are increasingly enabling a much more tangible illustration of the possible impact of, for example, the projected extreme rainfall events in South Africa. See Figure 4.7 and Figure 4.8 for examples of such analyses.

"The vulnerability of settlements or communities may be described as the extent to which a settlement system is exposed and sensitive to negative implications of change, and the degree to which the subject community is able to anticipate, resist, cope with, adapt or recover... The vulnerability of settlement systems thus includes not only susceptibility to physical changes but, more importantly, the impact such changes may have on social, economic and ecological subsystems and processes on which communities are dependent" (DPCD 2008).

Two examples of risk analysis

Example of settlements exposed to projected extreme rainfall events (2013)

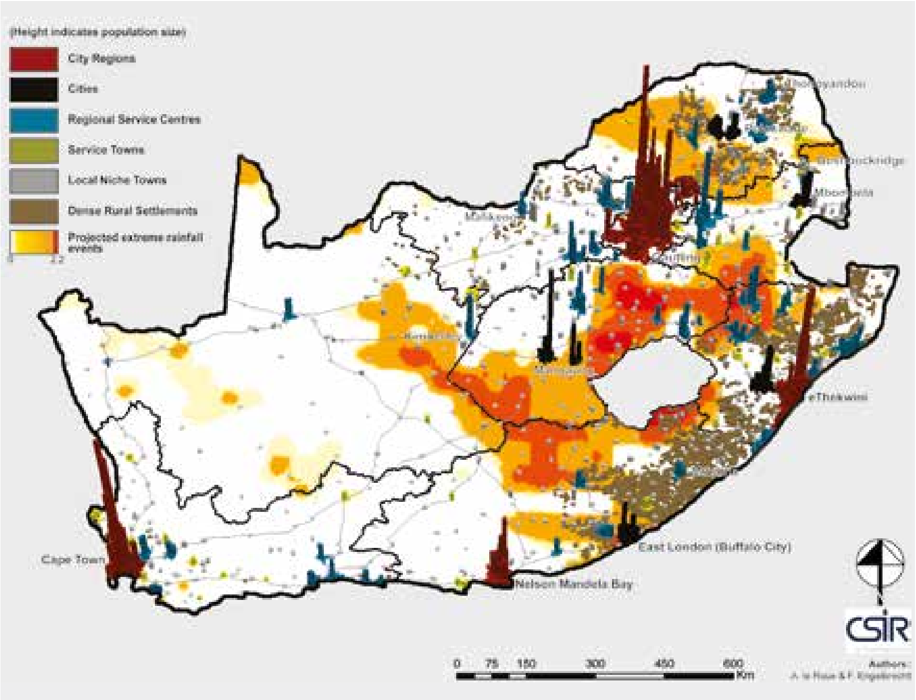

Figure 4.7 Projected extreme rainfall events (2011-2040) in relation to settlement concentrations in South Africa (Data source: CSIR GAP 2013)

The map indicates the regions and towns most likely to experience an increase in extreme rainfall events in the future (2011-2040), highlighting the importance of timeously identifying communities and areas that are at the risk of being exposed to hazards. The analyses points out that dense rural settlements and smaller towns are expected to experience the highest risk of extreme rainfall events. In addition to harsh local and household level socio-economic conditions that obstruct coping capacity, numerous of these areas are located within the jurisdiction of resource- and capacity-strapped municipalities with limited capabilities to timeously mitigate or respond to potential disasters (van Huyssteen et al. 2013a).

Example of coastal vulnerability and settlement patterns

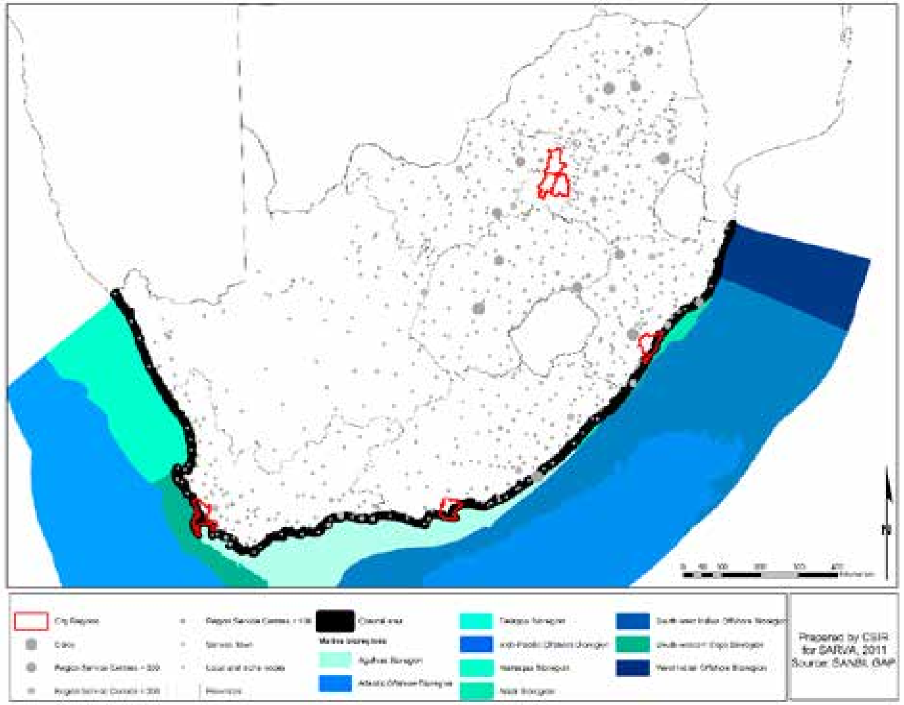

Figure 4.8 Cities and their coastal proximity (Data source: CSIR GAP 2011)

Another critical aspect of global change is the often discussed impact on coastal areas, including sea level rise and the occurrence of storms. One of the biggest concerns with regard to exposure to such hazards and the associated risks, is the number of people and assets that could possibly be affected. An analyses conducted in 2008 estimated that more than 1.2 billion people world-wide live within 100 km of the coast and less than 100 m above sea level (Purvis et al. 2008), and that over 3 000 cities across the world are within low-lying coastal areas (64% of these are within developing countries). These cities face various risks associated with sea level rise, such as storm surges, flooding, wetland displacement, altered tidal range, sedimentation changes, and coastal erosion which tend to threaten infrastructure, ecosystems, tourism facilities, housing and other buildings (Blanco et al. 2009).

A South African analysis conducted by the CSIR in 2013 (see SARVA: CSIR GAP 2013) indicated that an estimated 3.5 million people resided within the first 5-7 km along its coastline (CSIR, GAP 2011). (This number grew by approximately 1.8 million people in coastal municipalities between 2001 and 2011.) Of these, an estimated 40% were considered to live below the minimum living level, and 60% were located in dense metropolitan areas. Furthermore, it was estimated that coastal areas contributed 12% of the total South African economy[4], indicating the potential risk to the economy and infrastructure in case of a disaster. The analyses identified areas that are potentially at risk of sea level rise, storm surges and flooding, as well as areas where local and regional economies are closely intertwined with coastal areas, resources and ports. These include the metropolitan areas of eThekwini, Cape Town and Nelson Mandela Bay, where the population exceeds 1 million, city areas such as Richards Bay and East London with population sizes exceeding 400 000, as well as major coastal towns and approximately 45 smaller towns.

Implications and responses

Settlements are increasingly becoming vulnerable to risks through the accumulation of poverty, lack of basic services and human rights, and their extension into unsafe land. It is highly likely that such vulnerability will increase due to the pressures associated with the existing and growing backlogs of basic services, high levels of informal housing, and the lack of efficient management of these growth areas.

For some towns and cities, the risks of exposure to possible environmental hazards (as identified in this chapter) may seem insignificant – for others, and especially those with substantial levels of socio-economic vulnerability, such risks will most likely pose severe implications for households, as well as government and civil society.

Given the vulnerability of many settlements, their increasing sizes, and their significance within regional and local economies, their preparedness to deal with risks are critical. More integrated analyses and projections are crucial to timeously support governance and inform integrated management and planning instruments, such as local economic development (LED) plans, integrated development plans (IDPs), spatial development frameworks (SDFs), disaster plans and land use management plans.

An enhanced understanding of the impacts associated with the exposure of vulnerable communities and settlements (in cities, towns and rural areas) to environmental and climate change, as well as increased socio-economic risks could significantly increase the ability of key role players, such as the National Disaster Management Centre (NDMC), provinces and local municipalities, the private sector, as well as various research institutes and civil society to consider possible risks and appropriate mitigation options and resource requirements.

Whilst this chapter does not attempt to provide an overview of the wide range of multi-stressor risks and vulnerabilities associated with South African settlements it highlights the need for a concerted focus on cities and towns on the agenda to mitigate climate change related risks and vulnerabilities in South Africa. In addition, it clearly illustrates how innovations in spatial specific profiling and modelling increase opportunities for integrative profiling in order to bridge disciplinary and science-praxis gaps and find innovative opportunities to improve resilience of cities and towns, and the communities residing in them.

4 Calculated by using a crude indicator of GVA as proxy for economic activity. GVA figures obtained from Quantec 2009 Regional Indicators.

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CHAPTER 5

Air quality

Tirusha Thambiran[1,2] and
Yerdashin Padayachi[1]

Introduction

Since the industrial revolution, episodes of poor air quality and pollution have become common phenomena in many cities across the world. These air pollution events are primarily associated with the combustion of fossil fuels which release air pollutants such as sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and particulate matter (PM). These air pollutants are known to have negative impacts on human health and often result in respiratory ailments, exacerbate existing illnesses and, in severe cases, even lead to mortality (Brunekreef & Holgate 2002). Populations of society that are particularly vulnerable to air pollution include children, the elderly and people who are predisposed to chronic cardiac and respiratory illnesses (Patz et al. 2004).

Today, air pollution is a great concern in many regions of the world, especially within developing countries that still rely heavily on fossil fuel consumption and have insufficient or poorly regulated air quality legislation (Fenger 2009). These countries often contain areas with large populations of people who are at greater risk or more vulnerable to being impacted by poor air quality due to their socio-economic status, the existing prevalence of diseases, and the lack of access to adequate medical care.

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In South Africa, the combustion of fossil fuels in the industrial, transport and domestic sectors is a major source of air pollution. Ambient (outdoor) air quality in the country is also influenced by transboundary air pollution, biomass burning, industrial processes and waste management practises (Thompson et al. 1996; Scorgie et al. 2004; Sowden et al. 2008). Planning methods used during the apartheid era resulted in a number of human settlements being located close to large industrial sites. The combination of poor planning and ineffective air quality legislation (see the Atmospheric Pollution Prevention Act No. 45 of 1965) have resulted in poor air quality in many areas of country, with negative impacts on human health (Mathee & von Schirnding 2003; Naidoo et al. 2006; Norman et al. 2007) and ecosystems (Zunckel et al. 2000; van Tienhoven et al. 2005) being reported.

During the past decade, South Africa has entered into a new era with regard to air quality management. The National Environmental Management: Air Quality Act (No.39 of 2004) (the AQA) came into full effect in 2010, and signalled a paradigm shift in air quality management from a source-based toward a receiving environment approach (RSA 2005). In order to give effect to this act, significant measures have been implemented to tackle the air pollution challenges that the country faces.

This chapter provides an overview of the latest developments in air quality management and air pollution trends in South Africa. The critical issues of managing air quality in the context of climate change and risk and vulnerability, are also discussed.

Air quality management in South Africa

South African air quality legislation tasks the government with regulating air pollution emissions, and monitoring and managing ambient air quality in the country. The goal of air quality legislation is to reduce atmospheric emissions which may have a detrimental effect on the environment so as to avoid harmful effects on the health or well-being of people (RSA 2005).

In order to assist in this process, eight compounds, namely PM with diameters of less than 2.5 and 10 micrometres ($PM_{2.5}$ and PM_{10}), SO_2, ozone (O_3), CO, benzene (C_6H_6), lead (Pb) and NO_2, have been identified as priority pollutants for air quality management, with ambient air quality standards gazetted for these pollutants. With the introduction of ambient air quality standards in the country, there is a greater recognition of the importance of managing atmospheric emissions from the key polluting sectors and of the need to monitor, characterise and manage air quality (Naiker et al. 2012).

Emissions from key air polluting sectors in the country

While there is currently no official national emissions inventory, regional and local inventories indicate that industrial, road transport and domestic fuel combustion are significant sources of air pollution (Scorgie et al. 2004). Various forms of legislation and interventions have been implemented to reduce atmospheric emissions from these sectors.

Under the AQA, government is provided with sufficient tools to regulate emissions from the large point sources of emissions, namely industrial sources. Specifically, minimum emission standards are included for the priority pollutants and industries are prescribed emission standards that are dependent on the activity, type of operation, and whether or not it is a new or existing source of emission. Affected industries are required to apply for atmospheric emission licenses (AELs). AELs allow government to regulate and ensure that industries are indeed compliant with national minimum emission standards for air pollution (RSA 2010). It is expected that once emissions from this sector are well managed, more resources will be placed on regulating other sources of emission.

The road transportation sector is increasingly recognised as a significant source of air pollution in the country, requiring greater attention (Thambiran & Diab 2011a). In 2012, the second phase of the Clean Fuels Programme was implemented, which is aimed at reducing road transport-related emissions. This legislation requires that petroleum products used in motor vehicles in South Africa contain less harmful air pollutants, which are more suitable for use in motor vehicles with advanced pollution control technologies (RSA 2012). Fuel quality is, however, just one of the factors that determines the characteristics and levels of emissions from motor vehicles. Other important factors include the quantity of fossil fuel consumed by the motor vehicle, the vehicle technology, and transportation land-use planning. The combination of the age of motor vehicles in the national fleet, inefficiencies in public transport, and the legacy of poor spatial planning during the apartheid era, all contribute toward the challenge of effectively managing emissions from this sector.

The indoor and outdoor combustion of fossil fuels in residential areas is also a concern. Despite the mass electrification programme (Spalding-Fecher & Matibe 2003) and the roll-out of programmes to support the uptake of solar panels, a large proportion of residents in rural households and informal settlements still rely on biomass fuels, coal and kerosene (paraffin) as their primary energy sources for cooking and heating needs (Barnes 2009).

Ambient (outdoor) air quality management

In order to facilitate the management of emissions from the sectors mentioned above and to ensure that ambient air quality levels are compliant with the specified national ambient air quality standards, the AQA requires that all spheres of government develop an air quality management plan (AQMP). However, given the diverse challenges and priorities faced in different areas of the country, the National Framework for Air Quality Management, which was developed in 2007 (DEAT 2007), has defined 'cities' as areas under the AQA that either have acceptable, poor, or potentially poor air quality. 'Poor' indicates that ambient air quality standards are generally exceeded, whereas 'potentially poor' refers to areas where air quality is at times poor or even deteriorating (Figure 5.1). These ratings were revised in 2010 (Scott 2010), and provide a useful initial assessment of air quality in the country as well as give an indication of where air quality management needs to be prioritised.

To date, AQMPs have been developed for eight provinces as well as for several of the district municipalities that are rated as having areas of poor or potentially poor air quality. In addition to these AQMPs, the AQA also allows for the declaration of priority areas for air quality management. These are areas where the ambient air quality standards are currently not achieved, and/or areas that are expected to, in the future, face developmental growth that may have a significant negative impact on air quality in the specific areas. As yet, the Vaal Triangle Air-Shed, the Highveld, and the Waterberg-Bojanala have been declared as priority areas for air quality management (Figure 5.2). The development of the AQMPs for the Vaal and Highveld has been facilitated by the national government in consultation with interested and affected stakeholders and officials from the local and provincial governments. In 2015, the draft AQMP for the Waterberg-Bojanala Priority Area was published for public comment. Many of the local municipalities within this priority area are currently rated as having 'acceptable' air quality. However, it is anticipated that future developments in the area, that include new coal-fired power stations, are likely to impact on its air quality. The development of the Waterberg-Bojanala Priority Area AQMP is, therefore, a prime example of the value of the AQA and its supporting tools, with government being pro-active in initiating an AQMP for this area.

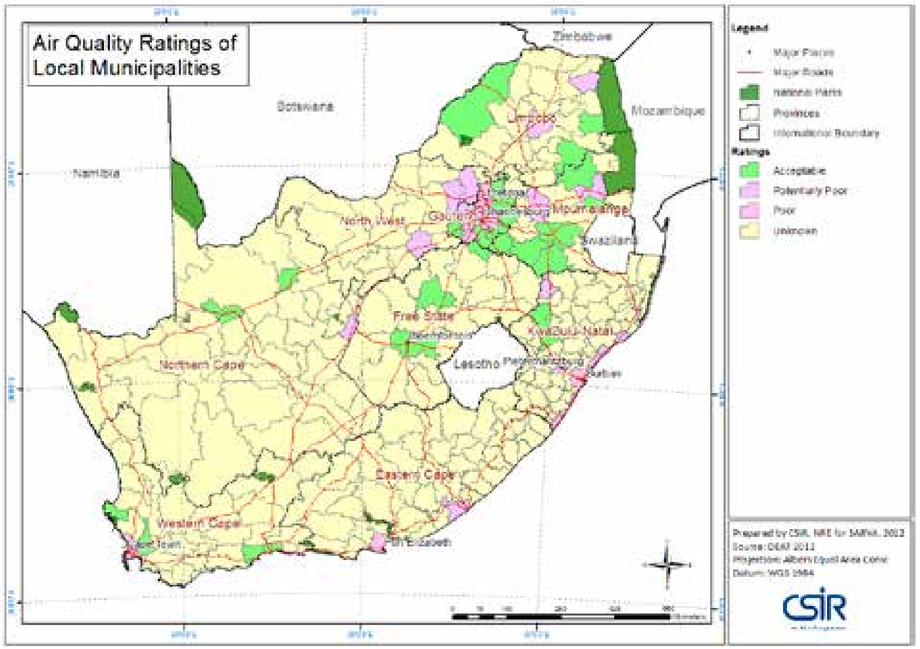

Figure 5.1 Air quality ratings in South Africa (Source: Adapted from Scott 2010)

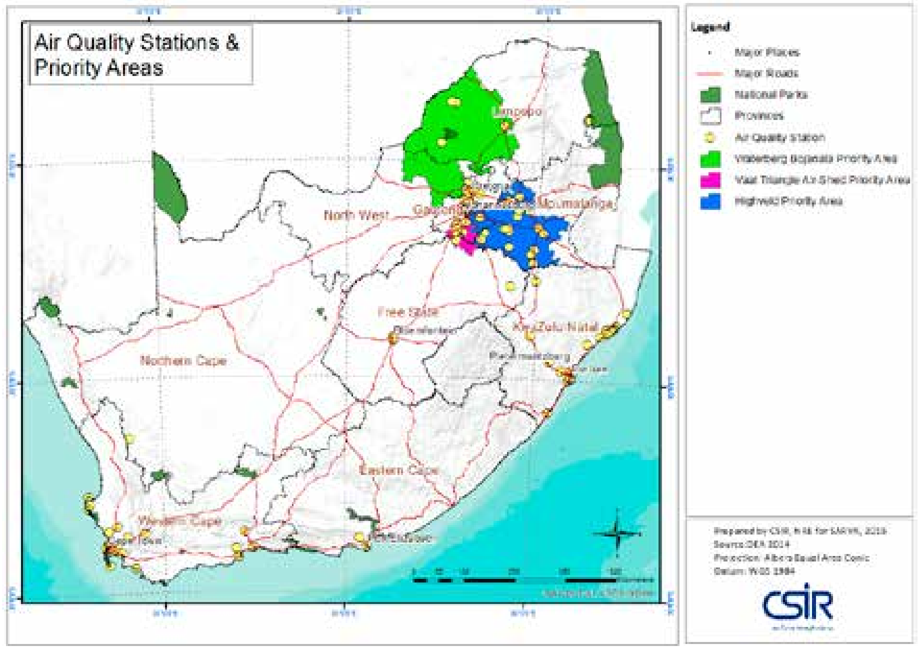

Figure 5.2 The location of ambient air quality monitoring stations and priority areas for air quality management in South Africa (Source: DEA 2014)

Ambient air quality monitoring

Ambient air quality monitoring is critical to allow for a comparison against ambient air quality standards and to evaluate the progress of an AQMP. Government departments currently own and operate 48 air quality monitoring stations, as shown in Figure 5.2. Continuous air quality monitoring in some of the major industrial areas of the country indicates improvements in air quality due to reduced emissions from industrial sources (Thambiran & Diab 2011b). Specifically, some progress has been made in limiting SO_2 concentrations. However, the high levels of PM_{10} remains a growing cause for concern (Mahema & Gwaze 2011), as PM_{10} is linked to numerous health impacts, such as alveolar inflammation, and respiratory-tract infections, such as pneumonia (Tiwary et al. 2009).

Ambient air quality data for the eThekwini Municipality, for example, show that over the 2005–2013 period the PM_{10} levels, although high (Figure 5.3), were still below the prevailing ambient air quality limit (50 ug/m³). However, in the City of Johannesburg, many of the ambient air quality stations recorded exceedances of this limit, and the lack of more recent data from these stations prevents a characterisation of PM_{10} in the city within the context of the 2015 limit of 40 ug/m³ (Figure 5.4).

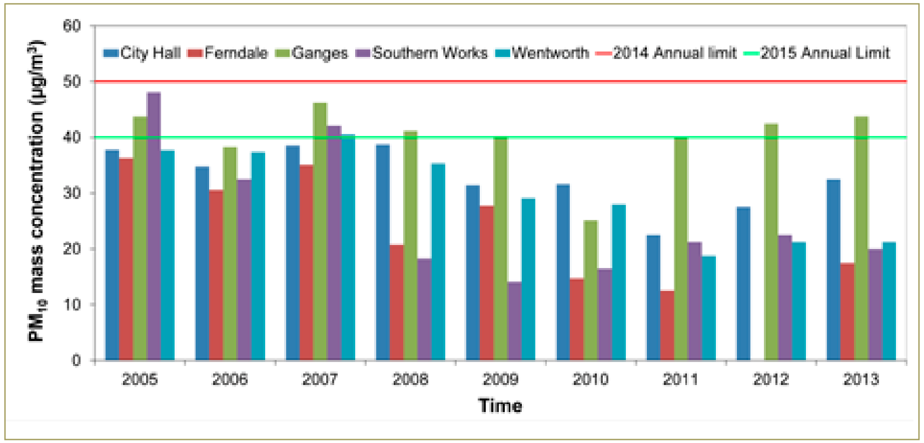

Figure 5.3 PM_{10} levels at monitoring stations in the eThekwini Municipality (Source: Adapted from DEA 2014)

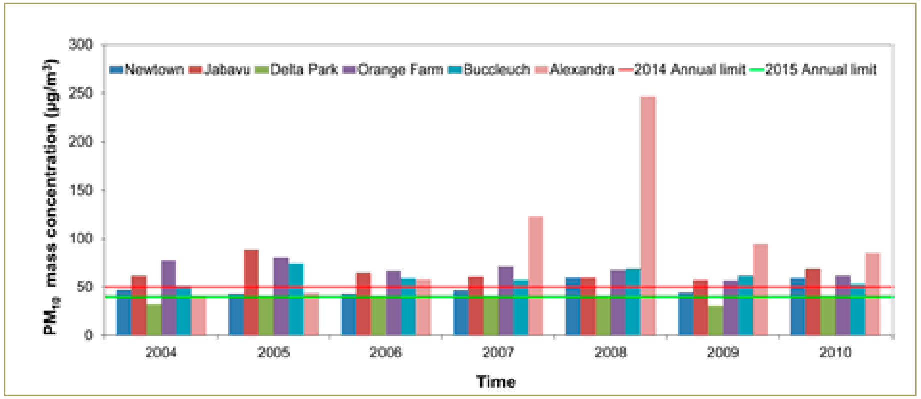

Figure 5.4 PM_{10} levels at monitoring stations in the City of Johannesburg (Source: Adapted from DEA 2011)

Critical issues for the effective management of air quality in South Africa

The challenges experienced within the energy sector around the deficit of electricity supply, reliance on imported fuel, and contributions to greenhouse gas (GHG) emissions, have resulted in key planning and policy imperatives to increase energy efficiency and the use of renewable energy sources. A significant determining factor in reducing air pollution from fossil fuel combustion will thus depend on how successful the country is toward achieving its goals for increasing energy efficiency, and the use of more energy efficient technologies and renewable sources of energy.

The reduction of emissions from key polluting sources has to be supported by adequate air quality governance. Since the inception of the AQA, significant progress has been made with respect to developing air quality legislation and supporting policies. However, numerous challenges still exist to effectively manage air quality in the country. While progress has specifically been made in regulating industrial emissions, significant challenges still exist with respect to the road transport and domestic sectors. Furthermore, insufficient continuous air quality monitoring prevents a more robust characterisation of the state of air quality across the entire country and of the impact of current interventions within the key polluting sectors. There is also a need to determine whether there are new emerging 'hot spot' air pollution areas within the country, and to identify the reasons for the deterioration in air quality. These issues are likely, to some extent, to be met with further development of the South African Air Quality Information System (SAAQIS) and other supporting projects. Greater investment of resources in terms of monitoring and evaluating the effectiveness of AQMPs in meeting the objectives of the AQA, which is to protect every citizen's right to an environment that is not harmful to their health and well-being, is needed. Further challenges to air quality management in terms of risk, vulnerability and climate change are discussed below.

Implementation of air quality management to reduce human health and ecosystem risks

In South Africa, outdoor air pollution is regarded as a risk factor that contributes to the burden of disease in the country (Norman et al. 2007; MRC 2008). Numerous studies, reviewed in detail in Wright et al. (2011), have described the human health impacts associated with poor air quality in South Africa. The existing ambient air quality standards in South Africa have been developed from the perspective of providing the widest protection for the largest proportion of the human population. As such, these standards do not consider the existing vulnerabilities of communities, or the cumulative impact of multiple air pollutants on human health.

These national standards further do not consider the critical loads with respect to acid deposition, eutrophication, and the resultant impacts on ecosystems. This means that even in instances where an ambient air quality exceedance does not occur, air pollution could still pose a risk to human and ecosystem health. Therefore, concurrent to improvements in air quality management practises, is the need for improved collection and access to environmental health data in order to fully understand the risks and vulnerability of different communities and ecosystems to air pollution. The availability of such data will be key in ensuring that appropriate air management interventions are implemented to reduce the burden of air pollution in the country.

Air quality management linkages to climate change

Air quality and climate change have many complex linkages and interactions, as shown in Figure 5.5. As air quality and climate change share common sources of emissions, there is likely to be trade-offs to separate policies and significant co-benefits to dealing with both of these issues at the same time. Interventions that will simultaneously reduce air pollutants and greenhouse gas (GHG) emissions within these sectors will provide cost-effective options. However, at present, air quality management systems in South Africa do not mandate that air quality interventions have co-benefits for climate change mitigation. As such, opportunities to simultaneously deal with both these issues are being overlooked. In addition to this, air quality management systems in South Africa also do not currently include any linkage to projected future regional meteorology. As shown in Figure 5.5, a changing climate is likely to impact the emissions and dispersion of air pollutants. This is expected to, in turn, influence the duration and the extent of air pollution episodes or exceedances of ambient air quality standards.

It is, therefore, anticipated that air quality risks to human health and ecosystems are likely to be exacerbated within the context of climate change. As such, especially in a changing climate, the emission reductions planned for in AQMPs may be insufficient to ensure compliance with ambient air quality standards in the country, and may further not adequately provide protection for vulnerable communities.

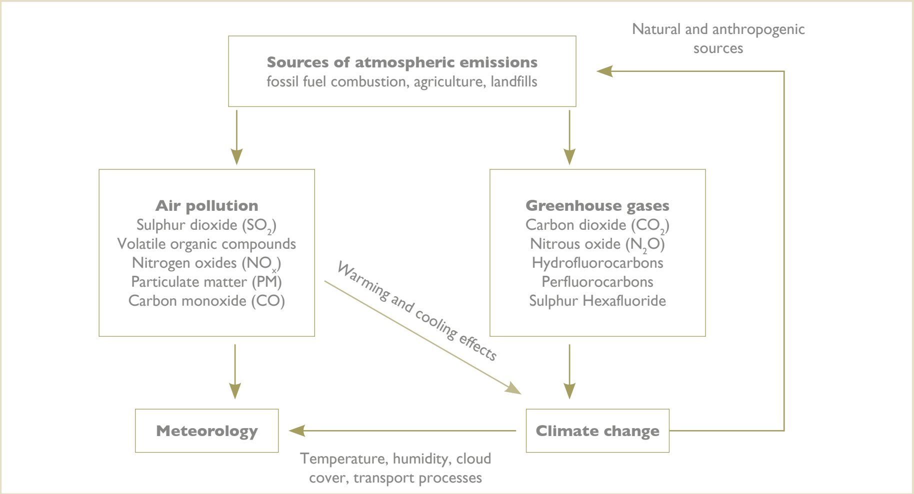

Figure 5.5 Linkages and interactions between climate change and air quality (Source: Thambiran & Diab 2011c)

The challenges mentioned in the previous paragraphs imply that the generic framework for air quality management as contemplated in the National Framework for Air Quality Management (DEAT 2007) need to be revised to include considerations of climate change, risk and vulnerability.

Case study

Air quality management and climate change mitigation in the road transportation sector

Research shows that implementing a co-benefits approach to tackling air quality management and climate change mitigation in the road transportation sector, would offer authorities a means to simultaneously reduce air pollution and GHG emissions (McKinley et al. 2005; Woodcock et al. 2007). This is especially relevant within the context of developing countries that face urgent air quality management challenges but do not have the resources to prioritise climate change mitigation.

In South Africa, petrol and diesel consumption in motor vehicles are known to result in significant emissions of CO, NO_x and PM (Wicking-Baird et al. 1997; Scorgie et al. 2004; Thambiran & Diab 2011a), and in the year 2000 was responsible for over 8% of the total carbon dioxide (CO_2-eq) emissions in the country (DEAT 2009). Recent data suggests that despite increasing fuel prices and the introduction of a CO_2 tax on new motor vehicles, fuel consumption for road transportation has not significantly declined (DoE 2012) (Figure 1).

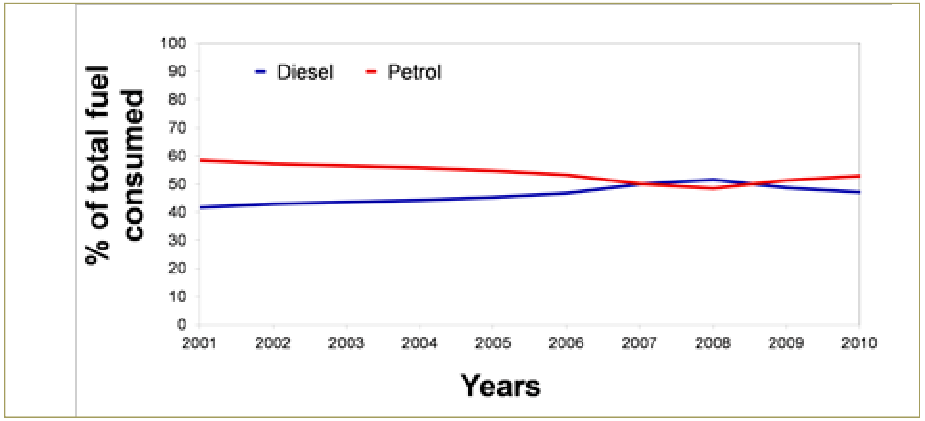

Figure 1 Diesel and petrol consumption for road transportation (2001–2010) (Source: DoE 2012)

As shown in Figure 2, CO_2 emissions vary by province, with significant increases in emissions noted in 2010 for the Free State and Mpumalanga when compared to 2001 (Padayachi & Thambiran 2012). While there are no specific legislated provincial GHG mitigation targets, due to the potential for air quality impacts from this sector, opportunities to innovatively use local and provincial AQMPs to contribute toward creating low carbon road transport should to be explored.

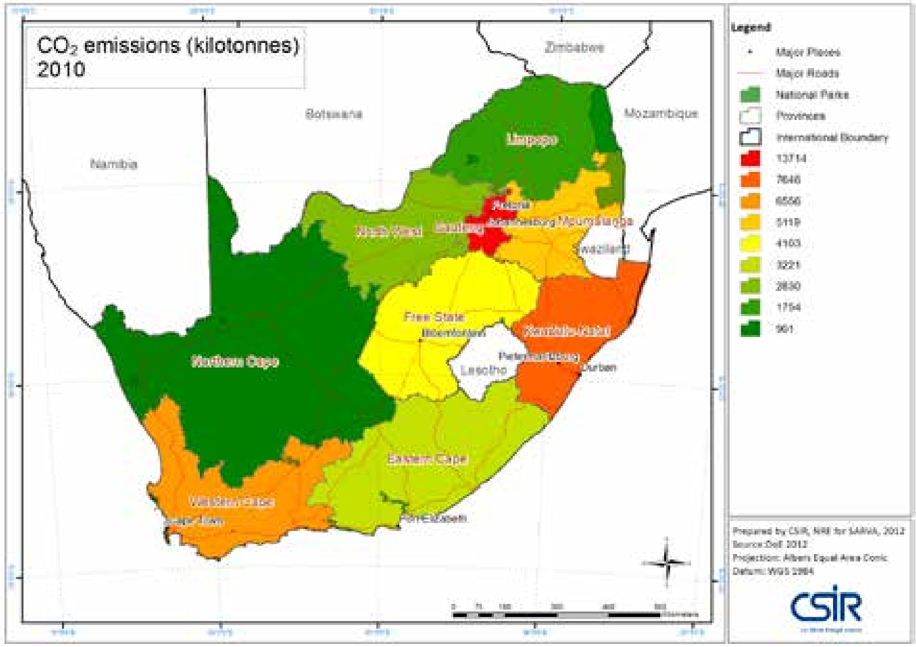

Figure 2 Provincial CO_2 emissions from road transportation for 2010 (Source: DoE 2012)

A case study of the opportunities for co-benefits in the road transportation sector in South Africa, found that many of the measures that are typically proposed to tackle air pollution within road transportation have the potential to simultaneously impact on fossil fuel consumption and thus reduce CO_2 emissions (Thambiran & Diab 2011a). It was found that AQMPs can play an important role in ensuring that air pollution interventions with co-benefits are selected by supporting and influencing interventions that target the types of vehicle technologies, fuel changes and road transportation management measures that are implemented (Thambiran & Diab 2011c).

The case study further illustrated that while there are significant opportunities for using air quality interventions to influence GHG emissions within the sector, there are also challenges.

For example, with strategies such as fleet renewal campaigns, the impacts of inter-city travelling, distances travelled by local motor vehicles, and road freight transport may prevent significant improvements from being made. Furthermore, while measures such as congestion charging have been shown to be successful internationally, it may not be justifiable in South Africa, and would have to be considered against other socio-economic issues.

Additionally, unlike the industrial sector, air quality regulations for the road transportation sector are not as well developed within the country. As such, existing legislation has a limited role to play in ensuring that AQMPs prioritise reducing air pollution from this sector. Considering the opportunities for co-benefits, it is critical that as air quality legislation around road transportation is developed, cognisance of national GHG mitigation targets are borne in mind. A co-benefits approach may help to bridge the gap between the implementation of climate change mitigation and road transportation-related air quality policies, and allow for more integrative policy development in the country. Ultimately, provinces with significant CO_2 emissions will be able to more cost-effectively improve air quality while simultaneously tackling GHG emissions from this sector.

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CHAPTER 6

Groundwater

Julian Conrad[1] and Marilie Carstens[1]

Introduction

As part of the water cycle, groundwater is fundamentally linked to other water resources and plays a critical role in our water-scarce country. Rain and surface water contribute to the recharging of groundwater, which, in turn, supports springs, rivers, wetlands and other ecosystems. Although groundwater is hidden, it is too important to simply be ignored.

The important role of ground water is well-embraced within the framework of Integrated Water Resources Management (IWRM). IWRM itself is highlighted in both the *National Water Act (No. 36 of 1998)* (NWA) (RSA 1998) and the Department of Water Affairs (DWA) National Water Resource Strategy (NWRS) (DWA 2013). A developing awareness of water scarcity, water quality deterioration, and the impacts of climate change in South Africa have placed emphasis on groundwater due to the potential contribution it can make to future water security. Whilst South Africa is a relatively dry country with low average rainfall and the majority of the country underlain by rock with limited porosity, groundwater can still contribute significantly to the water used for rural, domestic, industrial, agricultural and mining purposes. In most of the smaller towns in the arid areas of the country, groundwater is the main and often sole source of water.

1 Geo-hydrological and Spatial Solutions International Pty Limited (GEOSS)

Groundwater quantity

According to the Department of Water Affairs and Forestry (DWAF) the total volume of available groundwater in South Africa is estimated at 10 343 Mm^3/a (DWAF 2005). This total available volume is called the Utilisable Groundwater Exploitation Potential (UGEP). According to the DWA, the UGEP volume reduces to 7 500 Mm^3/a in conditions of drought (DWA 2010). The latter figure has been suggested as the sustainable potential yield that may be used for planning purposes in the rural, domestic, municipal, industrial and agricultural sectors (DWA 2012). Although the volumes of existing groundwater use are uncertain, the DWA estimates that only between 3 000 and 4 000 Mm^3/a of groundwater is currently used, thus allowing the possibility to potentially expand groundwater use. Potential expansion should be conducted carefully and subject to proper planning, siting, management and resource protection (DWA 2012). The distribution of utilisable groundwater available in drought conditions is shown in Figure 6.1. The values used in this map were derived as part of the Groundwater Resource Assessment Phase 2 (DWAF 2005).

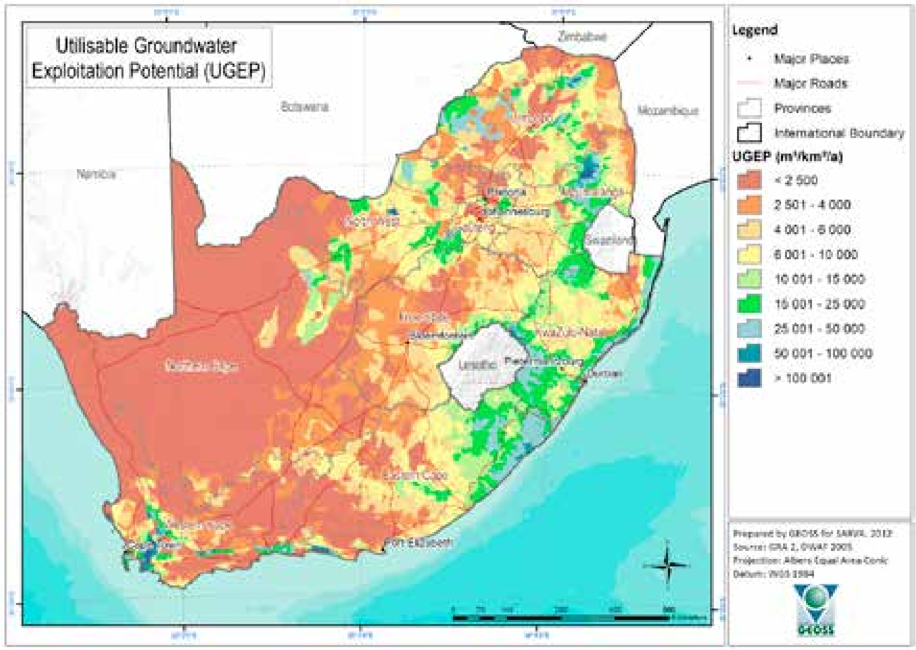

Figure 6.1 Utilisable Groundwater Exploitation Potential (UGEP) for South Africa. (Source: DWAF 2005)

Groundwater quality

Groundwater can naturally contain many different dissolved minerals. Many factors influence groundwater quality, including the amount of rainfall and associated amount of recharge, the topography, the soil conditions, the geological setting, and, of course, anthropogenic activities. Groundwater contamination may result from many anthropogenic activities such as industries (spills and inappropriate disposal of waste products), mining (notably acid mine drainage), agriculture (excessive use of fertilisers and pesticides), and also urban and rural developments (notably pit latrines). Groundwater is not restricted to visible channels – dispersion of pollutants may occur slowly, and, therefore, without regular comprehensive monitoring the effects of pollution may not be immediately detectable (NWRS 2004).

Groundwater vulnerability

Groundwater vulnerability, in terms of pollution, can be defined as the '[The] tendency for contaminants to reach a specified position in the groundwater system after introduction at some location' (Vrba & Zaporozec 1994). A national scale map of groundwater vulnerability, that was completed for South Africa (DWAF 2005) and is based on the DRASTIC method, is shown in Figure 6.2.

Key physical parameters which determine groundwater vulnerability include lithology, thickness, effective porosity, groundwater flow direction, age, and residence time of water. Generally, the residence time of a contaminant in groundwater and the distance that it travels in the aquifer, are considered important measures of vulnerability.

The DRASTIC method of Aller et al. (1987) uses the typical overlay technique often applied in subjective rating methods and is appropriate for nonpoint source pollution.

The **DRASTIC** method takes the following factors into account:

D	=	depth to groundwater	(5)
R	=	recharge	(4)
A	=	aquifer media	(3)
S	=	soil type	(2)
T	=	topography	(1)
I	=	impact of the vadose zone	(5)
C	=	conductivity (hydraulic)	(3)

The number indicated in parenthesis at the end of each factor description, is the weighting or relative importance of that factor.

As part of the Groundwater Resources Assessment Project (DWAF 2005), numerous data sets were produced, enabling the mapping of groundwater vulnerability at a national scale. The value of this national scale map is that it indicates the relative vulnerability of groundwater resources throughout the country.

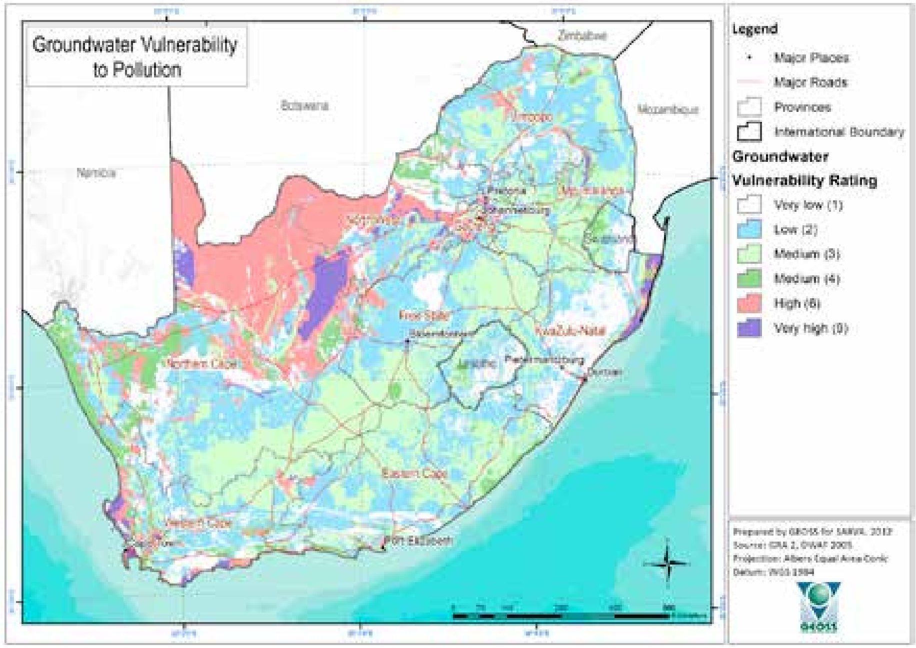

Figure 6.2 Groundwater vulnerability to surface-based pollution (Source: DWAF 2005)

Groundwater management

In order for groundwater to be considered a reliable water source, it is essential that correct management practices be implemented. Ongoing, appropriately designed monitoring is a vital component of sustainable groundwater management. Risks such as over-abstraction and pollution of groundwater must be prevented, particularly in areas of high vulnerability, as rehabilitation is difficult and costly. For example, the high porosity of dolomite makes dolomitic aquifers particularly susceptible to pollution. Furthermore, over-abstraction of these aquifers may lead to collapse, whereas the over-abstraction of a coastal aquifer may lead to irreversible salt water intrusion.

In June 2015, the South African government approved the final regulations for shale gas exploration and production – thus enabling government to start processing applications. It is essential that such regulations be adhered to and appropriately revised as new findings and technologies present themselves so as to prevent contamination of groundwater.

Climate variability and groundwater

In the short term, groundwater is less directly affected by climate change than surface water. In comparison to surface water, its evaporation rates are significantly lower, and groundwater levels decline slower in drought years. This is due to the fact that there is far more undergroundwater, and groundwater moves far slower. As a result of these characteristics, groundwater should play a key role in strategies to help adapt to climate change (DWA 2010).

Climate change may affect the recharge of groundwater, groundwater levels, and the contribution of groundwater to the base flow of rivers. Rainfall is the main source of groundwater recharge, and changes in rainfall will, therefore, also influence groundwater levels. Rainfall characteristics, such as the volume, intensity and duration of rainfall events, together with factors such as temperature, vegetation cover, topography, soil type and geology, influence recharge rates. Higher annual temperatures will result in increased evapotranspiration, thus reducing recharge. In addition, more intense storms may cause destruction of small alluvial aquifers (DWA 2010).

Beaufort West, for example, experienced a severe drought in 2010. This was mainly due to three years of gentle rainfall. During this time, the rainfall was 84%, 96% and 74% of the long-term average (260 mm) for the region respectively, and importantly the rainfall in these years was more scattered geographically with the rainfall events having far lower volumes of rain (in 2010 the rainfall was less than 15 mm for 83% of the rainfall events). This resulted in very little runoff and very little groundwater recharge (see the Beaufort West case study). A reduction in recharge may also lead to decreases in groundwater quality as there will be less dilution, and flooding may lead to the mobilisation of pollutants. In addition, sea level rise may result in the salinisation of coastal aquifers.

Responses to climate change

Sustainable groundwater use and management is advised so as to maintain groundwater quantity and quality. Suggested strategies for meeting climate change include artificial recharge, groundwater data collection, and increased groundwater research (DWA 2010).

The concept of artificially recharging groundwater is gaining momentum in South Africa. Artificial recharge, a process by which surface water is transferred underground, can be used to replenish aquifers that have been over-utilised, act as a mechanism to store surface water, as well as serve as a means of storing and reusing water. The storage of water underground is an exciting prospect in an arid climate where evaporation rates are high. In addition, water stored below ground is less likely to be exposed to certain types of pollution. The DWA published an Artificial Recharge Strategy in 2007. Potential areas suitable for artificial recharge have been identified and implementation has begun (DWA 2012). You may access the official Artificial Recharge website at www.artificialrecharge.co.za.

Although a great deal research has been conducted on the effects of climate change on surface water resources in South Africa, the effects of climate change on groundwater is a relatively new avenue of research. As a first step toward the assessment of climate change on groundwater, a vulnerability indicator that can be used to highlight areas in South Africa where groundwater is vulnerable to climate change has recently been developed, namely, the DART index (Dennis & Dennis 2012). The DART index considers the following parameters:

- Depth to the groundwater level
- Aquifer type (storativity)
- Recharge
- Transmissivity

The index is used as a regional screening tool to identify areas that could experience possible changes in their groundwater resources as a result of climate change. The monthly DART index calculations indicate a strong spatial and temporal dependency of the index with a maximum negative index change of 6 and a maximum positive index change of 2 over the simulated hydrological year. A negative index change represents areas which will experience more stress on their groundwater resources with respect to their current groundwater conditions. The temporal nature of the DART index is also scale-dependent. This is evident from the average change in the DART index. On average, the majority of the country will maintain its current DART index. Note that, due to the selected recharge model, large portions of western South Africa do not experience a change in recharge, which in turn implies no change in water level. These low-precipitation areas are prone to episodic recharge events. Areas subject to average degradation of their current DART index are mainly situated in the Western Cape. Two scenarios manifest themselves in areas which are subject to the same negative change in the DART index:

- Areas not experiencing stress in their current groundwater resources might experience possible stress in their future groundwater resources for certain months of the year.
- Areas currently experiencing stress in their groundwater resources might experience failure of their groundwater resources in future for certain months of the year.

The question is how effectively these possible changes can be managed and will people be able to adapt? Detailed local-scale studies should be conducted to quantify the actual impacts in areas highlighted by the DART index. The current DART index does not account for adaptation and migration occurrences.

Conclusion

This chapter provides a rapid overview of groundwater in South Africa. Groundwater plays a vital role in socio-economic development as well as in sustaining certain ecosystems. It is a hidden resource, difficult to grasp and understand, and the theory is often not matched by reality. However, it does conform to physical laws and dynamics. With a greater understanding of groundwater comes an increasing awareness of its importance – an importance that is being stated in constitutional acts and environmental laws. Groundwater is a resource that is finite and should be well protected. Once damaged, groundwater resources may take decades to recover or, in some situations, not recover at all.

Further work is required in improving the scale of mapping our country's groundwater resources in terms of its importance and vulnerability. The vulnerability is to be considered both in terms of ease of contamination and ease of over-depletion. Both quality and quantity are important aspects of groundwater. Various studies have shown that there is still sufficient additional groundwater to use and available for use. However groundwater exploration is occurring at an accelerated rate in South Africa and numerous new boreholes are drilled on a daily basis throughout the country. Thus it is essential that the groundwater balance is frequented monitored, assessed and managed. With a reduction in rainfall and associated groundwater recharge, the volume of groundwater available for use will reduce and if the exploration and development of groundwater resources continues at this current rate, over-abstraction of aquifers beyond the safe yield can easily occur with serious consequences, both socio-economically as well as from an ecological perspective.

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Case Study

Beaufort West drought of 2010

Beaufort West is situated in the Western Cape province, South Africa. It is the largest town in the arid Great Karoo region, with roughly 36 687 inhabitants. The town is the centre of an agricultural district of which the income mainly comes from sheep farming. It is also a significant 'stop-over' town on the N1 national road. Close to the town is the Karoo National Park, showcasing fossils from the area.

An average annual rainfall of 270 mm is measured at the De Hoop station, roughly 25 km north-east of the town (GEOSS 2012), with an annual potential evaporation an order of magnitude higher. These conditions – where evaporation rates vastly exceed rainfall – are typical across the biggest part of South Africa, making Beaufort West the perfect example of a town dealing with the same water issues as faced by the country at large.

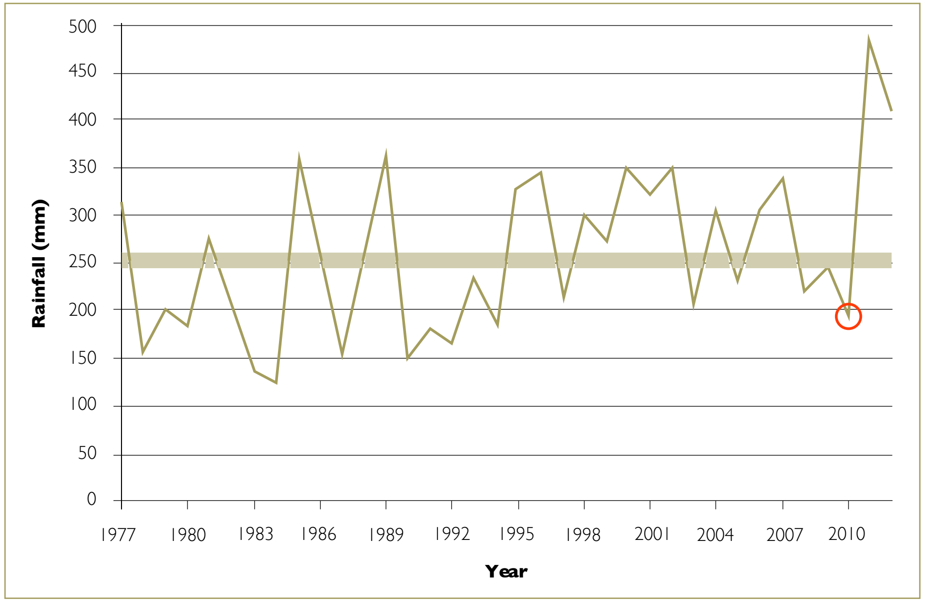

Figure 1 Long-term annual rainfall, Beaufort West (Source: Beaufort West Municipality)

In 2010, Beaufort West experienced a significant and widely publicised drought. Interestingly enough, the rainfall during that and the two previous years was not significantly less than the long-term average rainfall for the region. The 2010 drought was, however, far more severe than the ones experienced in the 1980s and 1990s when the region received, in fact, far less rain. The main factor which resulted in the 2010 drought being the worst one in living memory for this town, was the change in the characteristics of the precipitation. It was far gentler in 2008, 2009 and 2010, with rainfall events often less than 15 mm respectively. Runoff, therefore, became more and more insignificant, which resulted in very little infilling of the Gamka Dam and very low recharge of the aquifers. Under normal conditions, Beaufort West is supplied with water from the Gamka Dam as well as with groundwater from approximately 26 production boreholes. These production boreholes are located in well-fields to the north and north-east of the town, the furthest boreholes being approximately 27 km away.

In 2005/2006, the Beaufort West Municipality became aware of the fact that the water balance (i.e. bulk supply versus water demand) was about to become negative in the near future – even if a dry spell did not occur (Smit & Wright 2011). It was at this time that plans were put in place for the development of a Water Reclamation Plant (WRP) in order to supply portable water (as a sustainable source) from treated sewage effluent and other sources of poor quality water. However, funds were not available for building the WRP. It was only in February 2010 that the Minister of Finance made the necessary funds available for the construction of the WRP, as well as for the extension of the groundwater supply system. In summary, the following occurred with regard to the groundwater, surface water and the reclamation of water:

- Groundwater recharge reduced significantly and production boreholes dried up. Additionally, a drilling programme was introduced and ten new boreholes (drilled mainly to the south of the town) were commissioned in December 2010.
- Gamka Dam, the town's main supply dam, was 100% full in June 2008. By May 2010, the water level dropped to 0% and by 15 September 2010, the dam was said to be 'bone dry'.
- In February 2010, funds were made available for a Water Reclamation Plant (WRP). Construction started in July 2010, and the first water was delivered on 15 January 2011. A very effective awareness campaign resulted in the acceptability of the water by consumers, but, most importantly, the reclaimed water was pumped back into the reservoirs and distributed to *all* consumers.

Besides demand management, the bulk supply of water was also addressed. A multi-pronged approach was implemented once the severity of the water supply situation was clearly evident. The approach included the following components:

- Water tariffs, or 'drought tariffs', were applied in April 2009.
- Water restrictions were also imposed in April 2009, and revised at intervals.
- An awareness campaign was implemented.
- A bottled water campaign was launched by the radio station RSG.
- Water distribution scheduling (involving water cut-offs, mobile water tankers, pressure reducing valves, etc.) was introduced in December 2010, as only 60% of the demand could be met.

The first rains fell in February 2011, and the Gamka Dam was once again 100% full on 31 July 2011. The drought is thus something of the past. However, planning continues and a medium- and long-term drought aversion strategy have been put in place. The groundwater supply is being optimised and a new well-field was recently developed as part of the medium-term strategy. The WRP is modular and will be expanded in 2018. A proper Water Conservation and Water Demand (WC/WDM) Strategy is also being put in place.

Although Beaufort West still remains vulnerable to droughts reoccurring in the future, the risks (i.e. significant consequences) have been reduced. With regard to the Beaufort West 2010 drought, and particularly in the context of risk and vulnerability, valuable lessons have been learned:

- Water balance forecasting is crucial.
- Ongoing resource monitoring and management is crucial.
- Funds must be secured well in advance of a crisis.
- Use different water sources that supplement each other.
- A good awareness campaign is crucial.
- Reduce pressure in the water system and reduce the leakages.
- Drought policy and tariff structure are crucial.

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CHAPTER 7

Surface water

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Introduction

South Africa's surface water resources are naturally limited and unevenly distributed (Schulze et al. 2007; DWAF 2009). Over the years, South Africa's rivers have been highly developed and utilised, and in many instances overexploited. South Africa relies primarily on surface water for water supply, with more than 66% of the country's total mean annual runoff (MAR), of approximately 49 000 million cubic meters per annum, currently being stored in reservoirs (DWA 2013). However, according to Statistics South Africa (Stats SA) *Community Survey 2016,* 10.1% of households still do not have access to piped water (compared to 8.8% in 2011) (Stats SA 2016: 65) and only 60.6% of households in 2016 have access to flush toilets connected to a sewerage system (compared to 57% in 2011) (Stats SA 2016: 68). The remaining opportunities for the development of surface water resources are situated far from centres of demand and in relatively remote areas, which may limit its feasibility due to the high construction and energy costs required to transport water.

According to the DWA National Water Resource Strategy (NWRS), given South Africa's continued population growth, the need to redress past inequalities, the ever-growing urban areas and economic development, as well as the continued degradation of our natural resource base, easily accessible surface water and its remaining development potential will be insufficient in the near future (DWA 2013).

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Water quantity and quality

Natural river flow has been significantly altered – both in quantity and in quality – through the construction of reservoirs, inter-basin transfers, and domestic, industrial and agricultural water use (Claussen et al., 2004; DeFries & Eshleman 2004; DWAF 2009; Warburton et al. 2012; DWA 2013). Additionally, changes from the natural land cover to anthropogenic land uses such as urban areas, commercial forestry and agricultural lands to meet human demands for food, fuel and fibre, have significant impacts on the water resources of the country (see the Mgeni case study). Land use mainly determines the partitioning of rainwater through the vegetation and soil into the critical hydrological components of interception, infiltration, total evaporation, surface runoff and groundwater recharge. Any changes in land use can thus alter the partitioning of rainfall (Falkenmark et al. 1999; Costa et al. 2003; Jewitt 2005). The hydrological response of a catchment is dependent on the land use of the catchment, and is, therefore, sensitive to any changes in such land use. It becomes increasingly clear that land use change, particularly alien invasive plants (van Wilgen et al., 2008) and degradation (Blignaut et al., 2010), poses a risk to South Africa's water resources.

The main contributors to water quality problems are mining, urban development, industries and agriculture. South Africa's water ecosystems are currently threatened, with 60% of river ecosystems and 65% of wetland ecosystems being identified as threatened (DWA 2013). Approximately 25% of the country's MAR is required to support riverine and estuarine ecological functioning. However, in many catchments this requirement has not been fully implemented (DWA 2013). This is of enormous concern, since the poor condition of water ecosystems has negative impacts on human health, on rural communities directly dependent on such water-related ecosystems, and also on the mainstream economy.

The relationship between land use, economic development and hydrological response is complex. It is evident that any land use or economic development decision has direct, and often significant, implications for water resources. Therefore, economic development, land use planning and water resources planning cannot occur in isolation. This issue becomes even more critical when climate change and variability is taken into account.

Climate variability and change

Climate is one of the most important drivers of the hydrological responses of catchments. As the responses of the hydrological system are non-linear and complex, any changes in precipitation are amplified by the hydrological cycle (Schulze 2000). Thus, even relatively small, short-term variations or long-term shifts in climate alter runoff.

According to the IPCC assessment, the frequency of heavy rainfall events (or the proportion of total rainfall from heavy events) will increase under a changing climate, there will be an increased risk of drought, and rainfall variability will also increase (IPCC 2007). These highly likely changes will impact directly on the hydrological responses: As the climate changes, the partitioning of rainfall into the components of stormflow, baseflow and evapotranspiration may change due to changes in the intensity, magnitude, timing and duration of rainfall, as well as different regions responding differently, depending on the physiogeographical and hydrogeological characteristics of the catchment (Schulze 2000; Chiew 2007). Changes in rainfall will not be the only influencing factor for runoff. Changes in temperature, solar radiation, atmospheric humidity and wind speed also affect potential evaporation, and could either offset or reinforce the impact that changes in rainfall have on runoff (Kundzewicz et al. 2007). Furthermore, shifts in the timing of high flow and low flow periods may occur, and the variability of flows may change.

In conclusion, changes in the climate and in climate variability will be an added stressor (Ashton 2002; Arnell et al. 2004; AMCOW 2012), placing further pressures on South Africa's water availability, its accessibility and its demand, particularly given the limited opportunities available for further water resources development and the growing water quality problems in the country. Thus, the impacts of climate change on water resources and the required shifts in water management approaches are likely to be significant.

Water resources management

Given the current pressures on South Africa's water resources, there is a need for sound, integrated and adaptive water management on a catchment and national scale. This need is strengthened further with projected changes in climate change and climate variability likely to occur.

The NWRS, in accordance with the National Water Act, outlines how the country's water resources are to be protected, developed, managed, used, conserved and controlled (RSA 1998; DWAF 2004; DWA 2013). Furthermore, the NWA requires that the entire population be fully supplied with potable water. However, many of the water management, use and protection goals currently outlined in the NWRS, as well as the supply of potable water, are not so easy to achieve. Reasons for this include the complex population distributions, demographic characteristics, and growth patterns with a high degree and rate of urbanisation in South Africa. Compared to the world average water consumption of 173 litres per person per day, South Africa has a high per capita water use of 235 litres, with a large part of this being due to physical losses and commercial losses (McKenzie et al. 2012). Furthermore, a number of the country's major river systems cross or form national boundaries, which makes the collaborative management of these shared water resources challenging. In addition to these difficulties, inadequate finance and the lack of appropriate skills and capacity are critical challenges which water resources management is facing.

In order to meet growing water demands, alternatives need to be explored. Suggestions for such alternatives include water use efficiency and water demand management, rainwater harvesting, reuse of water, groundwater, and desalination. By exploring alternatives, South Africa has the potential to meet its water resources requirements in the future. However, there are numerous challenges related to these alternatives that need to be addressed and overcome.

Climate change will add a further layer of complexity to these management challenges. Therefore, the risks and the potential opportunities that arise from the impacts of a changing climate need to be incorporated into the country's growth and development path. These factors, together with South Africa having a high risk and water limiting natural environment, make water resources management a complex and challenging task (Schulze 2010).

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Case Study

All land use decisions have hydrological consequences

The case of the Mgeni catchment, KwaZulu-Natal

To contextualise the relationship between land use and hydrological response, consider the Mgeni catchment in KwaZulu-Natal, where more than 60% of the catchment has been altered from natural vegetation (Figure 1). In terms of water availability, the Mgeni is a stressed catchment which, as a result, has been closed to all new streamflow reduction activities.

The water-engineered system in the Mgeni catchment is important to four large dams, namely Midmar Dam (237 million m^3 at full supply capacity) which supplies water to Pietermaritzburg and parts of Durban, Albert Falls Dam (289 million m^3), Nagle Dam (23 million m^3) and Inanda Dam (242 million m^3). The latter supplies water to the Durban metropolitan area, one of the largest cities in the country. Additionally, there are approximately 300 farm dams within the middle and upper reaches of the catchment, supplying water for 18 500 ha of irrigation.

As water moves through the Mgeni catchment, the impacts of the various land uses are transmitted through the catchment. In its upper reaches, decreases in mean annual accumulated streamflows of between 15% and 50% are evident (Figure 2). These decreases can be attributed to the high percentage of commercial forestry as well as sugarcane found in the upper reaches (Warburton et al. 2012). Deep-rooted, evergreen commercial forests decrease streamflows by changing the partitioning of rainfall into increased evapotranspiration and reduced stormflows and baseflows (Jewitt et al. 2009). Similarly, sugarcane has higher biomass than natural vegetation, consequently using more water and reducing streamflows. The increases in streamflow in the middle reaches of the catchment (Figure 2) can be attributed to the high percentage of urban and residential areas such as Pietermaritzburg (Warburton et al. 2012). The increases in streamflow from urbanised areas are mainly caused by the increase areas covered by impervious surfaces, such as tar and concrete, and drainage systems designed to convey stormwater as quickly as possible away from urban areas. Thus, urban areas can cause increased stormflows and resultant peak discharges downstream, with shorter lag times and often deteriorating water quality (Schulze 2003).

Overall, along the main river stem to the catchment outlet, decreases in streamflow are evident due to the accumulative effects of land use change and the regulating effects of the reservoirs in the catchment. The reservoirs in the Mgeni catchment have a significant regulating effect on the streamflow in the catchment. Flows in the wet months are decreased and dampened, while flow reversals are evident between the dry and wet months for the reduced median flows. However, the high flows, especially in the wet months (January to March), are only marginally reduced due to the overriding effect of the increased high flows caused by urbanisation in upstream areas (Warburton et al. 2012).

Furthermore, these anthropogenic land uses have drastically altered the water quality of the Mgeni catchment, and it is only in the upper reaches of the catchment that water quality is near pristine conditions. Urban, industrial and residential areas have had significant negative impacts on the water quality, for example, where stormwater is contaminated by pollutants that are deposited on to roads, or where industries discharge their untreated wastewater illegally into nearby streams. Similarly, non-point source pollutants from agriculture and sediments from degraded lands have also affected the water quality negatively.

An imminent risk of serious concern to the water quality of the Mgeni catchment, in particular Midmar Dam, is the planned development of a second low-cost housing scheme, 300 m from the edge of the dam. This new development will exacerbate the water quality issues caused by the first development which is situated further from the dam. Research has shown that 51% of the *E. coli* loads found in Midmar Dam originate from this first development. A deterioration of the water quality of Midmar Dam will not only harm downstream environments, but will also jeopardise the water supply to cities in KwaZulu-Natal. This example serves to illustrate why it is important to integrate land use planning and water resources planning. In this case, very little thought went into the serious potential impacts of the planned development on Midmar Dam due to, amongst other reasons, the separation of water resources planning and management from land use planning in the catchment.

It is essential that decisions related to water resources management take into consideration, now and in the future, the complex interactions between land use

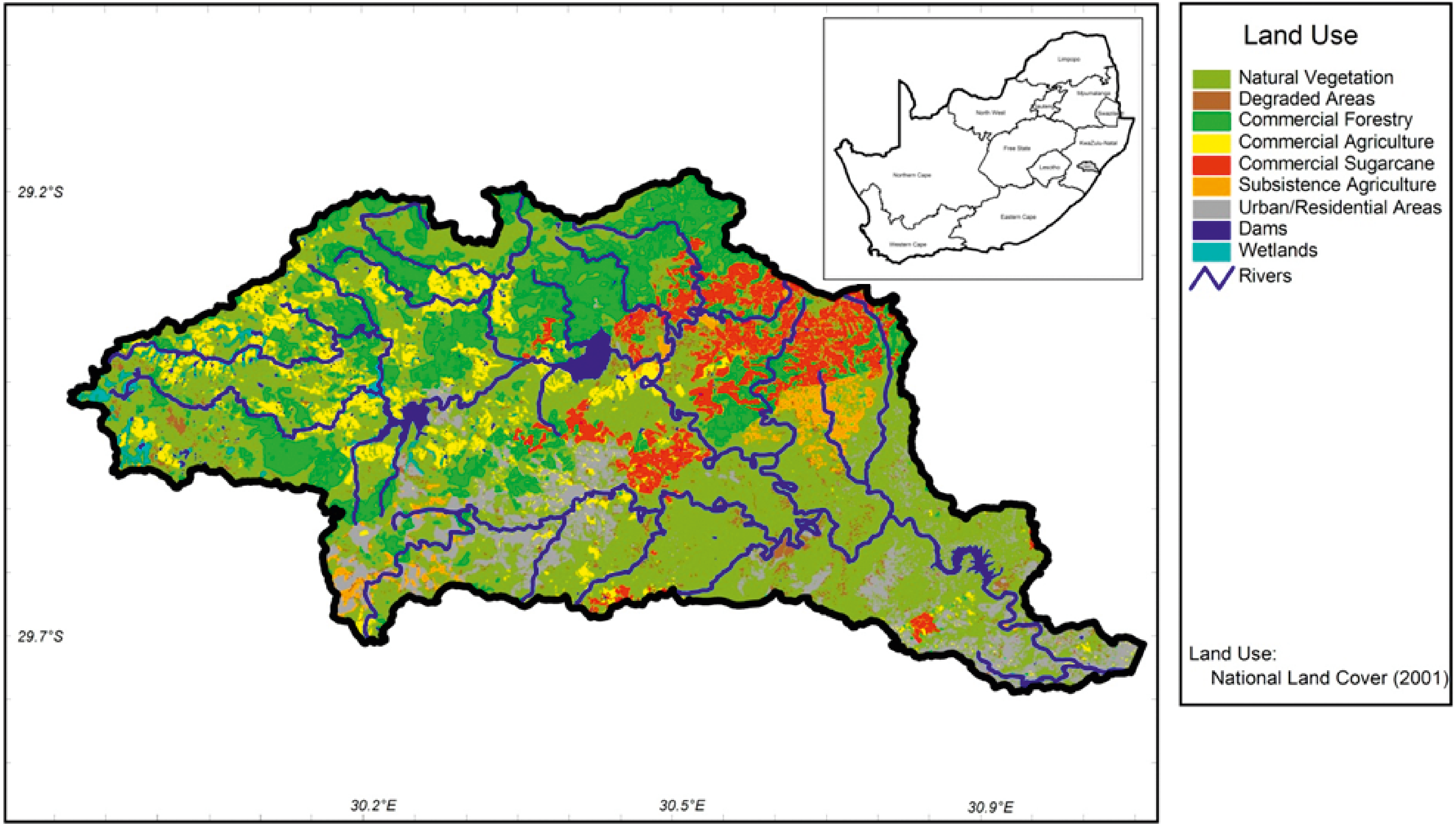

Figure 1 The Mgeni catchment, KwaZulu-Natal, including its land use and large dams (Source: Warburton et al. 2012)

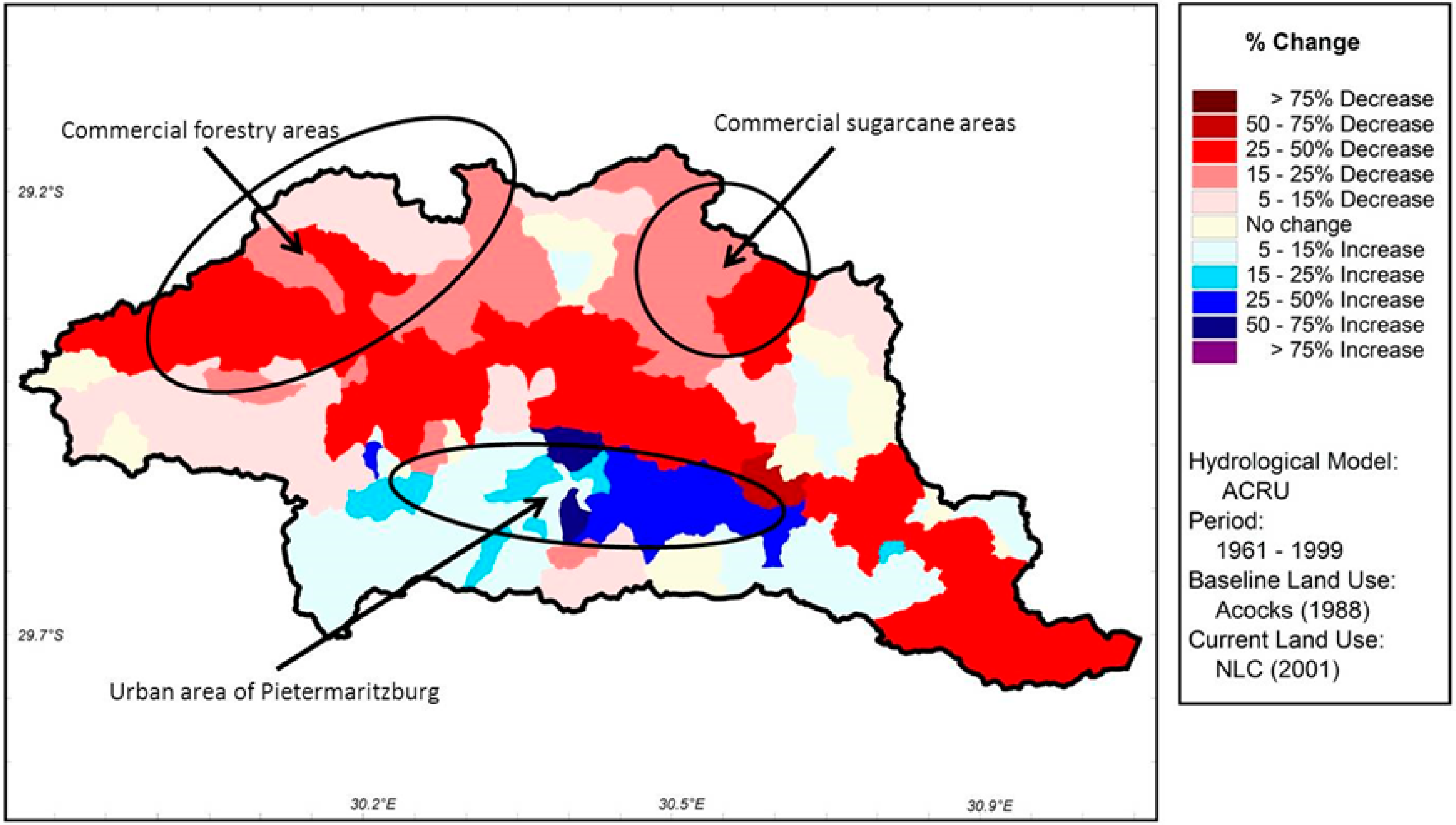

Figure 2 Impacts of current land uses on mean annual accumulated streamflows in the Mgeni catchment, relative to the streamflows under baseline land cover conditions (Source: Adapted from Warburton et al. 2012)

change and hydrological responses, for the effective management of water resources such as the Mgeni catchment. This becomes more important in the light of climate change, which will eventually be an additional stressor on the availability, accessibility and demand for water resources.

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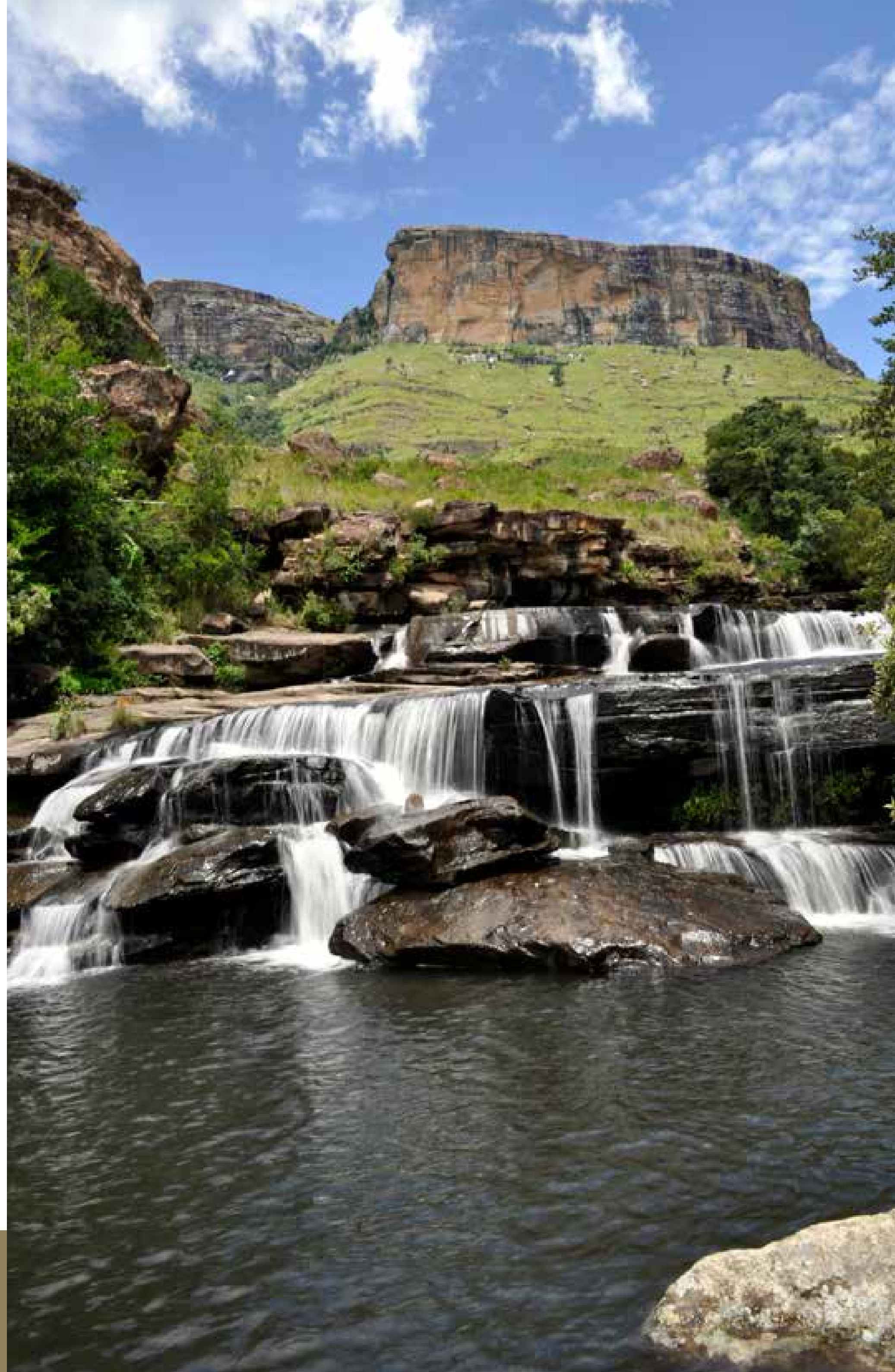

CHAPTER 8

Human health

Rebecca Garland[1,2]

Global change impacts on human health

Health can be impacted by many factors, including genetics, demographics, socio-economic factors, and environmental factors. Many of these factors can be sensitive to climate, though sometimes indirectly, and may thus be impacted by a changing climate.

Currently, public health in South Africa is in a unique situation with a quadruple burden of disease, with HIV/Aids, communicable diseases, non-communicable diseases, and injuries all contributing greatly toward this burden. This quadruple burden not only highlights the high HIV/Aids rate, but also the fact that South Africa's burden of disease is impacted by those illnesses mainly found in both developing countries (i.e. communicable diseases) and developed countries (i.e. non-communicable diseases, also known as lifestyle diseases) (Econex 2009). This quadruple burden also puts a stress on the public health sector and climate change could add an additional stressor to this sector.

The Millennium Development Goals (MDGs) are a set of eight goals with measureable targets that countries committed to in order to improve the lives and livelihood of their people. Table 8.1 highlights a selection of the MDGs and the potential impact that climate change may have on these (Rao et al. 2010). These listed MDGs are the ones that are directly related to health; however, climate change has the potential to impact other MDGs, too. From Table 8.1 it becomes clear that climate change has the potential to affect these goals in various, mostly negative, ways in South Africa.

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Table 8.1 Selected MDG and potential impacts of climate change in South Africa (Source: Adapted from Rao et al. 2010)

MDG	Potential impacts of climate change
Goal 4 Reduce child mortality	Morbidity and mortality are likely to increase due to climate change related population migration or displacement, food insecurity, and increased risks of water-borne and vector-borne diseases
Goal 5 Improve maternal health	Morbidity and mortality are likely to increase due to climate change related population migration or displacement, food insecurity, and increased risks of water-borne and vector-borne diseases
Goal 6 Combat HIV/Aids, malaria and other diseases	Increased vulnerability due to increased water contamination, air pollution, increased malnutrition, and changing patterns of vector-borne diseases

How climate change may impact health

In general, the impacts of climate change on human health are complex, with multiple pathways, interactions and linkages. As discussed in the 'Global Change and Human Health' chapter (Olwoch & Wright 2011), climate change has the potential to affect people's exposure to climate variables in multiple ways, which, in turn, can affect their health (Wright et al., 2014). These potential health impacts may result from direct exposures (including impacts such as increases in temperature and extreme weather events), or from indirect exposures (including impacts such as changes in air quality and impacts on agriculture). Additionally, climate change may lead to social and economic disruption, which may affect health (Confalonieri et al. 2007; Smith et al. 2014).

Figure 8.1 highlights these potential pathways as well as the effects that 'modifying factors' (the dotted lines in Figure 8.1) may have on the potential health impact (Confalonieri et al. 2007). These modifying factors can either ease or worsen the health outcome. For example, increasing temperatures could lead to people being exposed to higher temperatures (direct exposure in Figure 8.1). If the health sector has an early warning system and heat-health action plan in place that could help people to respond quickly in setting up preventative and response measures, the health impacts from exposure to high temperatures may be decreased. However, if health systems are not prepared for high temperature events and the systems become overwhelmed, the health impacts may be worsened.

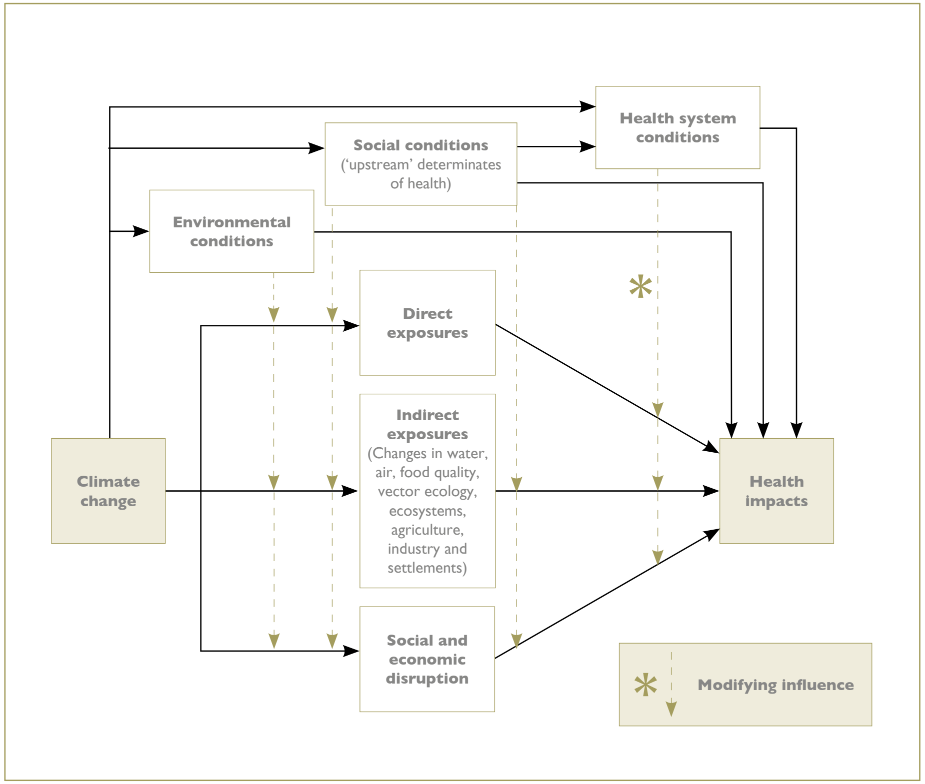

Figure 8.1 Schematic drawing to indicate how health could be impacted by climate change. The dotted lines highlight the potential for modifying influences. (Source: Confalonieri et al. 2007)

Another example of a modifying factor is the continuous supply of clean water that is safe to drink. Climate change may affect water availability or quality (indirect exposure, as seen in Figure 8.1), which, in turn, can have various impacts on health. If every person in South Africa has continuous access to water that is clean and safe to drink and in the quantities needed, the health impacts from water-borne diseases, such as cholera, can be greatly minimised. However, the opposite is also true: If people do not have access to water that is clean and safe to drink, the health impact from deteriorating water quality due to climate change will be worsened.

Modelling climate change impacts on health

Southern Africa – in fact, the entire continent – is highly vulnerable to the consequences of climate change. In 2000, the World Health Organization (WHO) conducted a study that measured the impact of climate change on worldwide human health (McMichael et al. 2004; Patz et al. 2005). In this study, the health impact of four climate-sensitive health effects (diarrhoea, malaria, health effects due to inland and coastal flooding, and malnutrition) in 2000 were modelled and compared to figures taken from 1990. Southern Africa was found to be the region with the highest mortality rates due to climate change in the period studied. This study only looked at a partial list of health impacts, making the results merely a conservative indication of health effects from climate change. However, the high impact of climate change on southern Africa still indicates a potentially serious public health problem – a fact that could add additional pressures to public health services within the region. Since many of the potential health impacts are not new issues to the area, but rather issues that the region has been struggling with for quite some time, it is important to start developing plans and systems that will effectively protect the public's health from these health impacts.

Figure 8.2 highlights projected change in heatwave days and maximum temperature in 2080–2100 compared to 1961–1990 over Africa under the A2 SRES scenario. These projections are from the Conformal-Cubic Atmospheric Model (CCAM), which is a regional climate model that was used to project future climate over Africa at high spatial resolution through the dynamic downscaling of six global climate model (GCM) simulations (McGregor 2005; McGregor & Dix 2008; Engelbrecht et al. 2015). In Figure 8.2, the 90th, 50th and 10th percentile from the ensemble of the CCAM downscalings of the six GCM projections, are highlighted. In this analysis a heatwave is defined as an event of at least three days where the maximum temperature at a specific location exceeds the average maximum temperature of the warmest month of the year by at least 5 °C.

These projections highlight that sub-tropical northern and sub-tropical southern Africa are expected to see the largest increases in maximum temperature, and are 'hot spots' for increases in heatwave days (Engelbrecht et al. 2015). The case study in this chapter highlights the potential health risks from increasing temperatures and heatwave occurrences, as well as a discussion on heat-health plans. Such plans have been identified as key adaptation measures to protect public health from the negative health effects of increasing temperatures (Matthies et al. 2008; WHO 2009; Berry et al. 2014).

Vulnerability and adaptation strategies

As discussed earlier, modifying factors (see Figure 8.1) are very important factors in determining the effects of a changing climate on human health. Due to this large potential impact, vulnerability assessments of communities in South Africa are key – not only in order to understand *who* is vulnerable to what health impacts, but also *what* is making them vulnerable and what role modifying factors play in this vulnerability (e.g. is vulnerability mostly due to a lack of clean water supply, etc.). By understanding the latter, it will be possible to develop appropriate adaptation policy options and interventions to lessen health impacts. For example, in a study conducted in KwaZulu-Natal, Craig et al. (2004a; 2004b) found that the number of cases of malaria was more strongly related to the level of drug resistance (e.g. chloroquine) and HIV infection than to climate variables. In fact, the climate variables could not explain the number of cases, although they did appear to be significant drivers in the inter-annual variability of incidences. These studies once again highlight the importance of modifying factors (e.g. physical and health infrastructure, health status, and poverty) on the health outcomes of an area, and also highlight areas of potential management options to mitigate the potential health risk from malaria in those areas.

Climate change and health adaptation plans are key factors when it comes to decreasing health impacts – now as well as in the future – and must account for cross-sectoral modifying factors. The South African Department of Health (DoH) has developed a National Climate Change and Health Adaptation Plan: 2014–2019 that '…provide(s) a broad framework for health sector action toward adaptation to climate change' (DoH 2012). The plan has identified the following health and environmental risks that might be impacted by climate change in South Africa: Heat stress, natural disasters, housing and settlements, communicable diseases, exposure to air pollution and respiratory diseases, non-communicable diseases, vector and rodent-borne diseases, food insecurity, hunger and malnutrition, and mental illness. The list focuses on public health, although occupational health (e.g. heat stress in outdoor workers, mine workers, agricultural workers, etc.) may also be impacted by a changing climate, making it another important consideration.

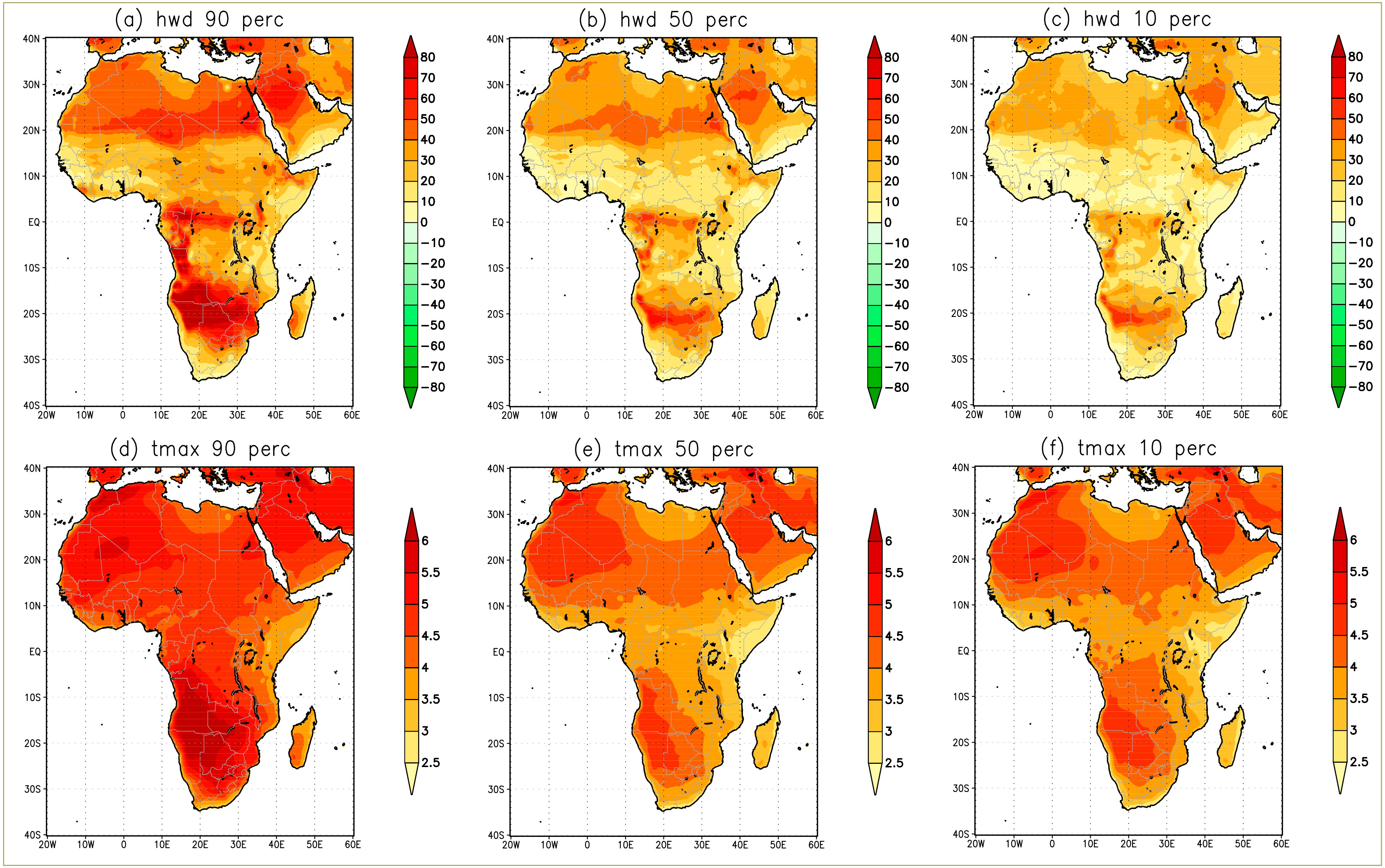

Figure 8.2 Projected change in heatwave days (number of days per grid point per year) over Africa, for the time period 2080–2100 relative to 1961–1990. The 10th percentile (a), median (b) and 90th percentile (c) are shown for the ensemble of CCAM downscalings of six GCM projections under the A2 SRES scenario. Panels d to f are the same, but for projected change in annual maximum temperature (°C) over Africa for the time period 2071–2100 relative to 1961–1990.

The most recent IPCC assessment report highlights that the largest health risks due to climate change exist in those populations that are currently impacted most by climate-related diseases (Smith et al. 2014). The health risks that may be impacted by climate change are not new issues to the area; however it is difficult to quantify the climate-health linkages in South Africa due to a lack of data. Current programmes and policies can thus be supported or simply modified and strengthened through robust data capturing and monitoring and evaluation systems, in order to provide for flexible systems that can take on current as well as future health issues (Garland 2014; Wright et al. 2014).

Case study: Health impacts caused by increasing temperatures

Exposure to high ambient temperatures, including those experienced during heatwaves, has been associated with increases in mortality from heatstroke, cardiovascular, cerebrovascular and/or respiratory diseases (Smoyer-Tomic & Rainham 2001; Diaz et al. 2002; Medina-Ramón & Schwartz 2007; Baccini et al. 2008; Ballester et al. 2011; Rocklöv et al. 2011). Africa has already seen warming, and it is likely that temperature increases over this continent will increase at a rate faster than the projected increase of global temperatures (Collins 2011; Niang et al. 2014). These increasing temperatures have the potential to negatively affect human health in the future (Garland et al. 2015). Thus, it is critical for decision-makers and health stakeholders to understand the health risks involved and to start develop appropriate planning, managing and easing efforts in order to lessen the future health impacts brought on by increasing temperatures.

Many countries have implemented planning measures, such as heat warnings and heat-health plans, to help prevent increases in morbidity and mortality due to high temperature events (e.g. Kalkstein et al. 1996; Smoyer-Tomic & Rainham 2001; Sheridan & Kalkstein 2004; Tan et al. 2004; Pascal et al. 2006; Berry et al. 2014). Some weather bureaus call for a heat warning when temperatures are forecasted to reach above a certain threshold temperature. Some cities have more elaborate intervention plans that are activated by such warnings. For example, in Philadelphia, Pennsylvania, USA, there are ten activities that are enacted once a warning has been issued by the US National Weather Service, including media announcements, halting suspensions of utility services, and increasing in emergency medical service staffing (Kalkstein et al. 1996; Sheridan & Kalkstein 2004). An evaluation of Philadelphia's heat watch/warning system concluded that for 1995–1998, issuing a warning saved 2.6 lives on average, with high benefits and low costs (Ebi et al. 2004).

The South African NCCRP of 2011 calls for the development and implementation of 'Heat-Health' actions plans, including plans in respect of emergency medical services, improved climate-sensitive disease surveillance and control, safe water, and improved sanitation These plans must be tailored according to local conditions and take into account factors such as the communities' vulnerability and ability to cope (RSA 2011).

The WHO has developed an eight-step guideline to develop heat-health plans (Table 8.2). This was developed in a project specifically for Europe, but the steps, and the development and implementation thereof, can be tailored to local conditions. For example, Step 2 needs to take into consideration both the threshold temperature at which South Africans' health begins to be impacted by heat, as well as the ability of local weather models to accurately forecast high temperatures (Pascal et al. 2006; Lazenby et al. 2014). This is currently an area where research is ongoing in order to attempt to clarify both these factors.

Even though research is ongoing, in order to protect human health, key stakeholders can still develop draft heat-health action plans. For example, government and local authorities can still develop plans to educate the public and businesses on what to do when temperatures are high (e.g. reduce physical activity, especially in the middle of the day, drink plenty of fluids, etc.), and medical services can develop plans to ensure the increased provision of services when hot temperatures are forecasted. The WHO (2008) highlighted that it is not necessary to develop new systems or structures to implement a heat-health action plan – building upon and linking existing systems (i.e. meteorological forecasting and monitoring from national weather bureaus) as far as possible, will be sufficient.

This case study highlighted the need for cross-sectoral collaboration in order to develop appropriate and effective plans, policies, strategies and interventions that will help protect health in a changing climate. Teamwork and collaboration are critical in this regard in order to develop plans and strategies that could impact on and help protect human health in South Africa – now as well as in the future.

Table 8.2 The WHO's eight steps to develop a heat-health action plan (Source: Adapted from WHO 2009)

Steps to build a heat-health action plan	Description
1. Collaboration between bodies and institutions, and identification of a lead body to coordinate response	This includes the definition of roles and responsibilities for stakeholders on national/regional level
2. Availability of accurate and timely alert systems	Heat-health warning systems (HHWS) should be developed in collaboration with meteorological services to trigger warnings, determine the threshold for action, and communicate the risks. A HHWS can use various methods for forecasting, and an effective system, that is accurate and timely, is targeted toward local needs
3. Heat-related health information developed in advanced	This plan should include advice to people on how to protect themselves and others, how to reduce heat exposure indoors and outdoors, and how to recognise heat-related symptoms. Information targeted at particular groups, such as healthcare institutions and caregivers, should also be provided
4. Avoidance or reduction of heat exposure	As part of the plan, measures to reduce exposure should be taken, such as adaptation of individual behaviour, short-, medium- and long-term measures in buildings to reduce indoor temperatures, and long-term improved urban planning, building design, transport and energy policies. Medium- and short-term options are available for cooling buildings without power consumption (passive cooling), such as cool paints, external shading, radiant barriers, and insulation of buildings. Advice should be given to the public on how best to reduce indoor temperatures, with particular attention to avoiding pollutants. Possible electricity shut-offs or lack of access to electricity, as well as reduced water availability, need to be considered in heat-health action plans and public advice
5. Particular care for vulnerable population groups	It is helpful to identify groups at high risk before the summer and to plan and target interventions (advice, follow-up and care) accordingly. Community organisations, medical practitioners and care providers play important roles
6. Provision of healthcare, social services and infrastructure	This includes summer health workforce planning, health service provision, and training of health personnel and other interest groups. Emergency departments of hospitals could be alerted to heatwaves to better manage an increase in patient admissions
7. Real-time health surveillance incorporated into the planning process	Real-time surveillance is important to detect early impacts of hot weather, to potentially modify interventions, and to inform about abnormal outbreaks or clusters of health impacts. The most useful real-time data are all-cause mortality, emergency calls, emergency department visits, hotlines, and general practitioner records. All these should be available within a maximum of one to two days
8. Monitoring and evaluating components and criteria	At the end of summer, it is crucial to evaluate whether the heat-health action plan has worked according to defined processes and outcome criteria. Monitoring health outcomes over time in relation to heatwaves, is another important component of the plan

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CHAPTER 9

Risk and vulnerability in the South African farming sector

Implications for sustainable agriculture and food security

Daleen Lötter[1]

Introduction

South Africa covers an area of 121.9 million ha, of which over 80% (100 million ha) is used for agriculture (Figure 9.1). This includes commercial timber plantations that cover approximately 1.3 million ha of the country and constitute about 1.1% of South Africa's forest land. Of the 80% land surface area used for agriculture in South Africa, only 12% of the country has arable potential. The remaining 69% is suitable mainly for extensive livestock farming. Areas of moderate to high arable potential occur mostly in the eastern part of the country, in Mpumalanga and Gauteng. Low to marginal potential areas occur in the eastern half of the country and in parts of the Western Cape. Most of the interior and Northern Cape only supports extensive livestock farming. Yet, despite the country having large areas of marginal land and an unpredictable climate, agriculture plays a vital role in food security and social stability. It is estimated that 638 000 people are formally employed (Stats SA 2012,

1 Council for Scientific Research (CSIR) – Natural Resources and the Environment

Q2) in agriculture while around 8.5 million people directly or indirectly depend on agriculture for their employment and income. Agriculture contributes to economic development through food production, providing a market for produced goods, providing employment and as a net exporter of agricultural products.

Risk and vulnerability is however inherent to agriculture owing to both production and price risk. According to Gbetibouo et al. (2010) vulnerability depends on both biophysical conditions of the farming regions and the socio-economic circumstances of the farmers. According to the Department of Agriculture, Forestry and Fisheries (DAFF) an estimated 2.8 million households are involved in subsistence farming, while 225 000 are semi-commercial small farmers and less than 40 000 are commercial farmers (DAFF 2012). South Africa is regarded as a water scarce country with high variability of climatic conditions and limited fertile land. Climate change impact modelling suggests that even relatively small mean temperature and rainfall changes may amplify existing water scarcity. The challenge to agriculture is therefore to remain productive and contribute to food security amidst limited natural resources and looming climate change.

Our finite natural resources

It is estimated that close to 18% of South Africa's natural land cover is transformed, mainly by cultivation (10.46%), degradation (4.47%), urban areas (1.51%) and forestry (1.41%). Land transformation through degradation and desertification pose a serious threat to food security. Water availability and quality are a further major restriction for sustainable agricultural production since as much as 90% of the country is considered sub-arid, semi-arid, or sub-humid (Schulze 2008).

Soil

Intensive agricultural production in South Africa is limited by the extent of fertile arable soils available. More than 80% of South Africa is dominated by very shallow soils or less fertile sandy soils with less than 3% of South Africa which is considered as high-potential land (GCIS n.d.). The moderate to high-potential soils in South Africa are found in the higher rainfall, humid to sub-humid areas in the east of the country (Figure 9.2). Soil quality has typically been equated with soil organic matter, where adequate organic matter levels are vital to soil health and productivity. South Africa, however, is characterised by topsoils with very low organic matter levels, with about 58% of the soils containing less than 0.5% organic carbon (Du Preez et al. 2011).

Inappropriate land-use practices have led to a definite decline in the organic matter content of soils. For example, as a result of intensive tillage over long periods, many of South Africa's arable soils are in poor shape through losses of organic matter and accompanying soil structural decline. The consequences being reduced water infiltration, low water retention and increased soil density. Overgrazing in rangelands also results in significant losses of soil organic matter, whereas the use of fire in rangeland management decreases soil organic matter by reducing/removing plant litter, which is the primary source of organic matter.

Changing land management practices such as intensive mechanised cultivation, increased use of heavy machinery and overuse of synthetic fertilizers have increasingly contributed to soil compaction and human-induced soil acidification. South African soils are especially prone to soil compaction which causes reduced rate of both water infiltration and drainage rendering crops vulnerable to drought and nutrient stress.

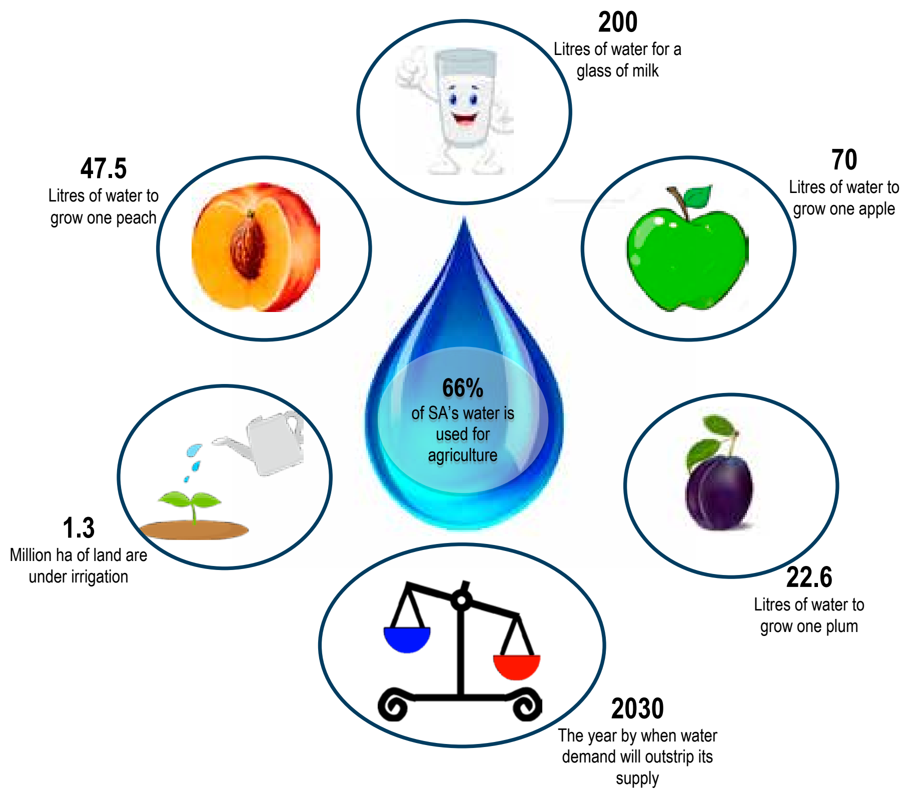
Water erosion is another mechanism causing serious soil degradation in South Africa. Potential soil loss is predicted to be most severe on the limited amount of high potential agricultural land (Figure 9.3). It has been estimated that 25 % of topsoil has been lost during the 20th century. According to the *South African Yearbook, 2008/9*, South Africa has the highest per capita soil loss in the world, losing an estimated 400 million tons of soil per year (GCIS n.d). This is due to the combination of inappropriate farming practices and cultivation of highly erodible non-arable soils. In some areas nearly all erodible material has been removed and there is little or nothing left to be eroded. Soil is essentially a non-renewable resource and hence critically important to protect and manage sustainably.

Water

The scarcity of South Africa's freshwater resources contributes to the country's agricultural vulnerability. South Africa is generally a semi-arid, water stressed country with an average rainfall of about 450 mm, which is approximately 60% of the world average. Its precipitation is highly variable, with an uneven spatial distribution and seasonality of rainfall (43% of the rain falls on 13% of the land). The subsequent availability for water supply is highly variable, with the eastern and southern parts of the country receiving significantly more rain than the northern and western regions.

Agriculture is inextricably linked to rainfall since water availability is a restricting factor in plant development, dictating the physiological and chemical processes in the plant. It is especially the characteristics of rainfall that are of fundamental importance: How much does it rain? How often does it rain? Where does it rain? When does it rain and what are the duration and intensity of rainfall events? (LTAS 2015).

Agriculture is the largest water-user sector in the country, consuming almost 60% of the entire surface water resource available (Stats SA 2010). Irrigated farming operations involve about 20 000 medium- to large-scale and 150 000 small-scale farmers practising irrigation, making South Africa the largest 'irrigation country' in the southern African region (WRC 2000). In addition, the country's water resources are already highly developed and utilised with 98% of the available water resources already allocated (Stats SA 2009). There is, however, a large potential for water saving in this sector given that 30 to 40% of the irrigated water is lost through leaks and evaporation.



In South Africa 90% of fruit production is dependent on irrigation. The Western Cape and the Eastern Cape Provinces are the largest apple growing regions, producing 95% of all apples in South Africa. In recent years productivity of orchards has increased significantly from 60 to 80 tonnes of fruit per hectare per season to a yield of up to 120 tonnes/ha/season (Gush et al 2015). These high-yielding orchards may therefore require much more water to sustain the exceptional high yields. More accurate information on water use in orchards is therefore important for the sustainability of South Africa's deciduous fruit industry given the increasing pressure on the limited water resources.

Facts about water use in the agricultural sector

Groundwater use increased rapidly until 2000 and usage at that stage was about 41% of the potential (GCIS n.d.). The surplus is thus dwindling fast and few exploitable aquifers exist. Climate change through increased rainfall intensity in some parts of the country, or longer and extreme drought periods in other areas, is likely to exacerbate water availability issues. Given these supply constraints, it will be a huge challenge to produce more food with the same or less water.

Rangelands

Livestock farming is by far the largest agricultural sector in South Africa, with the area involved in cattle, sheep and goat farming covering approximately 590 000 km^2. The country's rangelands provide the main fodder resource to sustain these commercial and informal livestock systems. Rangelands also provide us with high quality water and habitat for our flora and fauna. South African rangelands stretch mainly across low rainfall areas and include a diverse group of ecosystems comprising savanna, grasslands, Nama and succulent Karoo biomes.

Due to inappropriate land management practices, large areas of South Africa's rangelands are also in a moderate to severely degraded condition, with the arid areas being most severely affected (DEA 2011). Productivity of all the rangelands has been put at risk of deteriorating as a result of, amongst others, bush encroachment, desertification and overgrazing. The dry savanna and sweetveld grasslands have been severely affected by bush encroachment and densification resulting in a serious decline in grazing capacity. Uncontrolled and frequent fires are also regarded as a major problem in rangeland degradation in South Africa. Fires taking place with high frequency inhibit the regeneration of palatable grasses, which are then replaced by unpalatable thorny scrub bush. Climate change can act as an additional pressure or stressor that may complicate the existing problems associated with rangeland degradation (DEA 2011). In areas under pressure from overgrazing or inappropriate water use, a higher frequency of drier spells or a lower critical rainfall season can further affect vegetation cover and amplify desertification. However, according to du Preez et al. (2011), preventing overgrazing and restricted burning may increase soil organic matter and contribute to the restoration of degraded rangelands.

Biological diversity

South Africa is regarded as one of the most biologically diverse countries in the world. Terrestrial ecosystems provide essential agricultural services, such as the regulation of water and climate, which is crucial for national food security. The conversion of natural habitat is the biggest cause of biodiversity loss and decline in ecosystem functioning. Land transformation by cultivation (10.5%) make up the largest component of the nearly 18% of South Africa's land cover which is currently transformed (DEAT 2006). Thirty-four percent of South Africa's terrestrial ecosystems and 82% of main river ecosystems are threatened, while an estimated 50% of wetlands have been destroyed (DEAT 2006). Poor farm management through the use of pesticides and herbicides and the use of limited monoculture species further reduces ecosystem functioning. This, in turn, seriously inhibits and decreases the country's agricultural capacity.

Is it natural climate variability or climate change?

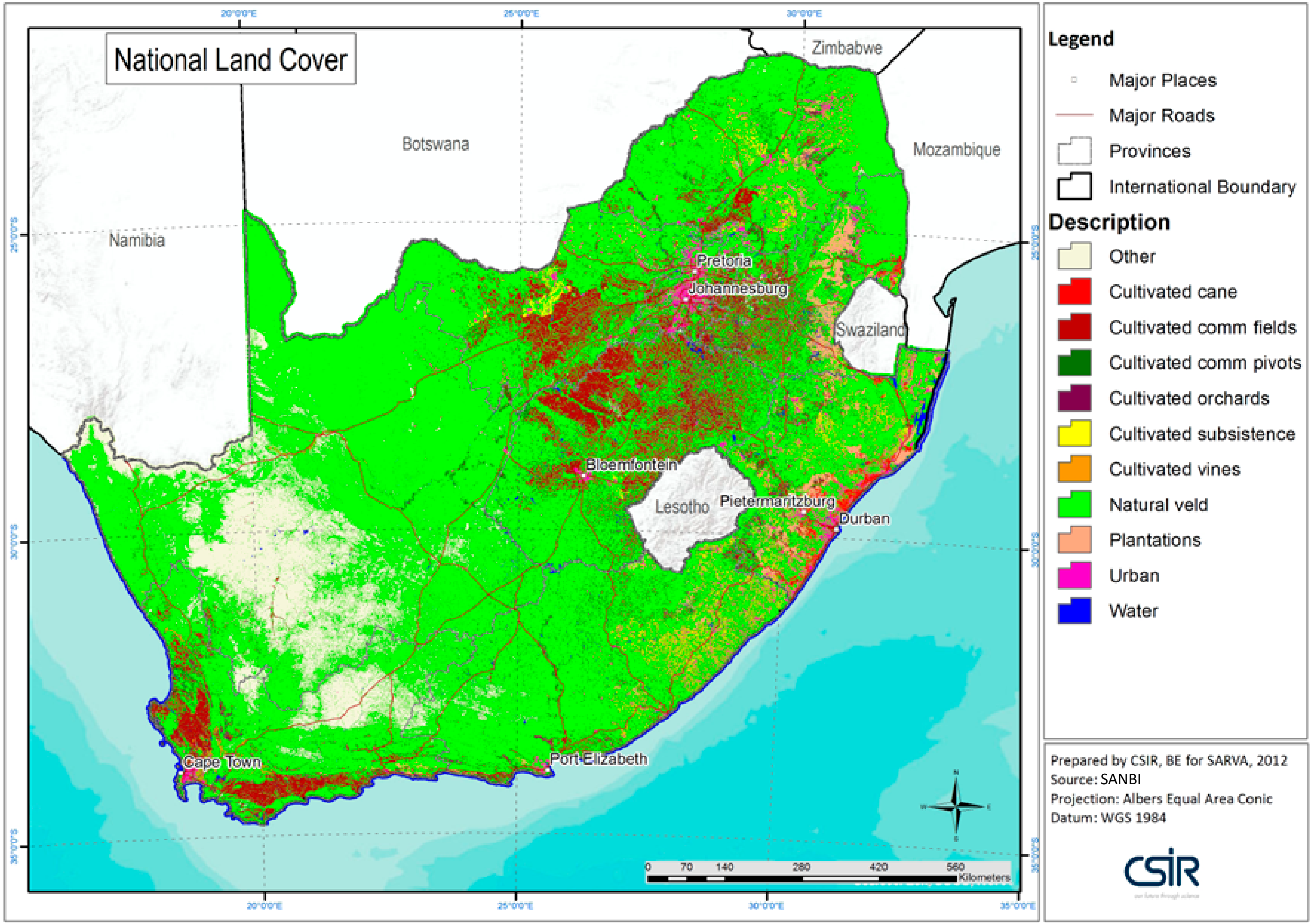
Rainfall is fundamentally important for agricultural production and farmers need to consider how variable the rainfall is from year to year and how frequently droughts of a certain level of severity are likely to recur (Schulze 2008). Climate variability refers to the way climate fluctuates yearly above or below a long-term average value. This is a natural phenomenon and is caused by external factors (e.g. variations in solar radiation) as well as internal processes (e.g. the interaction between ocean and atmosphere). This means that South Africa from time to time experiences years that are unusually wet/dry and cool/hot compared to the long-term average. One specific recurring natural event, which affects South Africa's climate, is the El Niño phenomenon. It takes place every two to seven years and appears when large parts of the eastern and central Pacific Ocean experience above normal sea-surface temperatures. In 2015, one of the strongest El Niño events ever observed settled over the Pacific Ocean causing intense drought conditions over South Africa.

Whereas climate variability generally refers to the natural fluctuations of the climate system, global warming is caused by human activities through burning of fossil fuels. This has altered the Earth's climate system, causing a long-term trend of rising global temperatures. Climate change may influence the intensities and frequencies at which natural cycles occur, exacerbate existing climate variability and further increase the frequency of climate extremes such as droughts and heavy rainfall events.

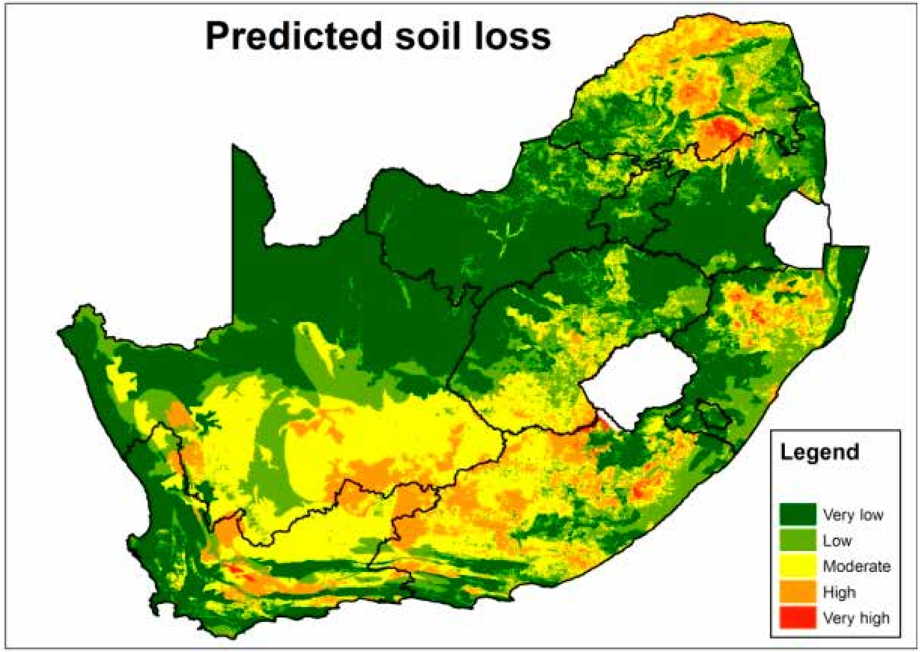
The drought crisis in South Africa

The strong El Niño event that took place during 2015/2016 contributed to South Africa experiencing the lowest rainfall since the recording of rainfall began in 1904 (SA Weather Services 2015). The below-normal rainfall was also associated with above-normal temperatures, which has had a devastating effect on South African agriculture. The impacts of the drought were felt across the farming spectrum with significant secondary effects on other sectors of the economy dependent on agricultural production. The drought associated impacts experienced in the 2015/2016 season is a good indication of what can be expected in future under similar scenarios of increased temperature and severe drought. AgriSA indicated some of the most important consequences of the drought as:

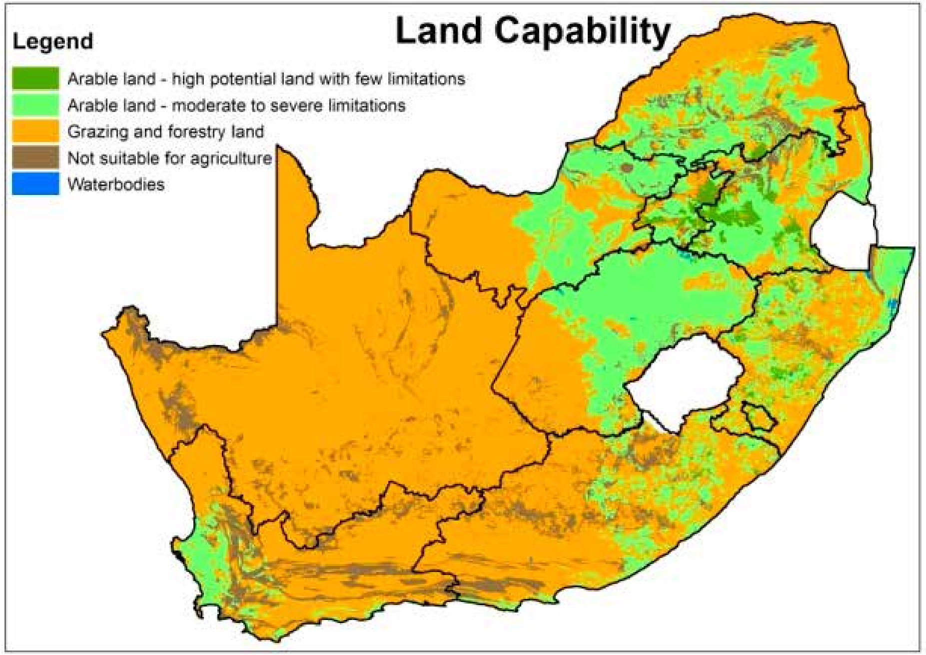
- A serious depletion in natural grazing leading to the forced slaughtering of livestock and further livestock deaths due to fodder unavailability.
- Reduced plantings of summer crops, or if planted, crops were severely damaged by heat and drought. South Africa is particularly vulnerable to the effects of drought since most of its crops are produced under dryland conditions. According to Dr Belinda Janse van Rensburg, a researcher at the ARC-Grain Crops Institute, 'A soil moisture deficit of just four days can reduce maize yield by up to 50%.' (Janse van Rensburg 2015).
- Above normal temperatures affecting pollination of crops in several areas. Maize pollen viability decreases with exposure to temperatures above 36 °C causing reduced pollination rate, grain fill and yield ' (Janse van Rensburg 2015).



Map 1 National land cover map indicating cultivated and plantation areas (Source: Department of Environmental Affairs. South African National Land Cover Dataset (2013/2014))



Map 2 Potential soil loss or erodibility map for South Africa (Source: Pretorius 1998)



Map 3 Land capability map for South Africa (Source: ARC-ISCW)

- A looming grain deficit, which will require maize imports of 3 to 5 million tons by mid-2016.
- Reduced purchasing power of the agricultural sector affecting its ability to support industries producing seeds, fertilizers, chemicals and insecticides (AgriSA 2016:5).

Ecological farming

Global environmental change concomitant with pressure to increase productivity of agricultural systems to meet domestic and international demands has the potential to permanently damage our natural resources and threaten food security. Agriculture and conservation can, however, be mutually inclusive. Climate Smart Agriculture (CSA) is an initiative of the Food and Agricultural Organisation (FAO) and recognises that while agricultural production will have to increase substantially in the future, it will also need to transform itself to accomplish this within a changing climate and without depletion of the natural resource base. This requires a major shift in the way land, water, soil nutrients and genetic resources are managed, which will in return require considerable changes in national and local governance, legislation, policies and financial mechanisms. CSA aim to address both food security and climate challenges based on three concepts: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions (FAO 2013). Several CSA programmes and projects (such as LandCare, the Comprehensive Agricultural Support Programme (CASP), the Green Economy, and Climate Action Now) are being implemented in South Africa through national government departments, research institutions as well as farmer and civil society organisations.

These initiatives aim to address natural resource management through both ecological and socio-economic dimensions. Specific ecological issues are being targeted, for example: conservation tillage which helps to prevent soil erosion and loss of nutrients; maintenance of natural corridors within cultivated land to provide travel and dispersal routes for wildlife and plants; restoration of riparian vegetation, wetlands and floodplains to regulate floods and protect water quality and wind-breaks to increase resilience of rangelands. Most importantly, training and capacity building of emerging farmers through existing extension facilities and services is critically important to ensure long-term sustainability and economic viability of rural communities.

Conclusion and critical messages

Agricultural activities in South Africa are subjected to many risks and uncertainties, such as climatic variability, economic and price-related risks, environmental degradation, water scarcity and pests and diseases. When climate change issues are superimposed upon the existing vulnerabilities, the effects thereof are exacerbated. For example, over-exploitation of resources and resultant land degradation will aggravate the effects of natural occurring droughts and floods, which in turn may be further intensified by projected climate change.

According to the DEA (2013), subsistence dryland farmers are more vulnerable to climate change than commercial farmers, while large-scale irrigation production is probably least vulnerable to climate change. This is due in part to the fact that small-scale producers typically have limited resources and a lower capacity to cope with shocks. Large- and small-scale farmers will, therefore, adapt to climate changes using very different strategies.

Driving forces, such as land use change and land management practices, define the way in which climate change will affect agriculture and food security. The challenge is to increase food production and sustain a growing population and economy, as well as to protect our limited natural resources. Integrated adaptation planning will help insure South Africa's food security, without compromising the resource base. Agricultural systems that contribute to biodiversity and ecosystem health will be better able to withstand climate change. These systems will be less vulnerable, more cost-effective and also able to mitigate the climate change effects.

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Case Study

Rainfall and drought risk in the Northern Cape (1920-2000)

Daleen Lötter and Andries Jordaan

Climate change often carries the blame for the increased incidence and negative impacts of drought and other natural disasters which occur in South Africa. However, droughts and water shortages are normal cyclic events and inherent to any climate system. A healthy environment (both socio-economically and ecologically) will be able to absorb and recover from such events. Nevertheless, in transformed or degraded environments climate change may interact with increased pressures such as population growth and land degradation, and worsen the effects of dry periods and other disaster events. However, is climate change the only factor to consider and, if not, what are the other variables contributing to the increase in natural disasters?

Drought is the disaster with the largest impact on people in southern Africa. It is normally closely associated with the Northern Cape province – the most arid region in South Africa – with an annual precipitation that varies from 500 mm in the eastern to as little as 40 mm in the western parts of the province. The province recently commissioned a provincial drought risk assessment (Jordaan, 2011; Jordaan et al. 2013) in preparation for a provincial drought management plan (see Chapter 1 for a detailed explanation of technical terms). This risk assessment considers all elements of a disaster, including hazard, vulnerability, adaptation, coping capacity, and resilience of the local people.

The drought risk indexing was based on the following equation (Jordaan 2011; Jordaan et al. 2013):

$$R = \left(\frac{H}{C_H}\right) x \left[\frac{\sum(V_{econ} V_{env} V_{Soc})}{\sum(C_{econ} C_{env} C_{soc})}\right]$$

Where: R = Drought risk

H = Probability of drought with a certain intensity and severity

C_H = Capacity or factors that impact on probability and/or the magnitude of drought

V_{econ} = Economic vulnerability

V_{env} = Environmental vulnerability

V_{soc} = Social vulnerability

C_{econ} = Capacity to deal with economic vulnerability

C_{env} = Capacity to mitigate and limit environmental vulnerability

C_{soc} = Capacity to mitigate and limit social vulnerability

The unit of measurement was the secondary and tertiary catchments due to the availability of meteorological data and its homogeneity.

The results for drought hazard (H) showed no statistical significant change in mean annual precipitation, evapotranspiration, or mean minimum and mean maximum temperatures for the period 1920-2000. The mean number of rainy days per annum also did not change significantly. The Standardised Precipitation Index (SPI) for 3, 6, 12 and 24-month periods were also calculated for all of the tertiary catchments, and no statistically significant trends could be detected from the results. In fact, all the results indicated a slightly positive trend toward higher precipitation and fewer droughts, although statistically not significant. The research team, therefore, concluded that there are other factors, not only climate change, which contributed toward increased incidences of drought in the Northern Cape.

An analysis of the vulnerability and resilience factors did indeed provide better insights into the drought phenomenon in the Northern Cape province. Most importantly was the deterioration of the environment – notably land degradation and bush encroachment, especially on communal land where the 'tragedy of the commons' is evidenced. These were more the results of over-utilisation and mismanagement of the natural resources (such as grazing and ground water) than of extreme droughts. The analysis also exposed the vulnerability of small-scale communal farmers to dry periods, as is reflected by the social and economic vulnerability index. This group of farmers perceived normal dry periods (with an SPI of minus 1) as drought and applied for drought relief and support at least once every five years. These farmers thus often experience severe droughts although it is, in fact, merely regular normal dry periods.

Coping capacity, which may include (i) land ownership, (ii) on-farm diversification to provide own feed and fodder during drought, (iii) government support, and (iv) non-agricultural entrepreneurship, is a further determinant of the degree to which farmers, farm workers and rural towns are able to withstand droughts. Finally, a drought risk map was produced for the Northern Cape, incorporating all the mentioned factors. From the map it can be derived that the areas with the highest drought risk are located in the upper north west of the Kgalagadi District Municipality and in the Richtersveld. Vulnerability to the local economy and environment, land degradation, and the lack of coping capacity became the most important determinants for drought risk in these areas.

The research thus concluded that the value of a risk assessment lies not only in the final result, but rather in the analysis of the contributing factors to the disaster. Vulnerability is important in the determination of disaster risk, but the methodology for drought declaration should limit the impact of human mediated vulnerabilities such as over-grazing and poor management. Hence, conservation farming and the long-term advantages thereof should be supported and promoted. This should be undertaken by extension services as well as expanded further at commercial farm level. Drought is not a local phenomenon, and other provinces should also use risk assessment as a basis for the development of disaster management planning.

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Figure 10.1 Community forestry at Ozwatini, KwaZulu-Natal (Photo: Steven Germishuizen)

CHAPTER 10

Commercial forestry

Ilaria Germishuizen[1] and
Thamsanqa Mzinyane[2]

Introduction

Commercial forestry in South Africa consists of highly managed planted blocks of even-aged, single species trees. South African plantation forests occupy an area of approximately 1.3 million ha, of which 80% is found in the provinces of Mpumalanga, KwaZulu-Natal and the Eastern Cape (DAFF 2010). Plantations are dominated by three exotic genera: *Pinus* (52.5%), *Eucalyptus* (39.1%) and *Acacia* (7.6%), and these are mainly grown for the production of pulp (66.7%), saw logs (25.3%) and mining timber (3.1%) (DAFF 2010). Plantation forestry plays a significant role in the country's economy and contributes 0.2% to the total gross domestic product (GDP) from areas where economic alternatives are limited (Chamberlain et al. 2005). Forestry also provides a livelihood for many rural households through the direct employment of low-skilled workers as well as support to small growers schemes (see Figure 10.1) (Chamberlain et al. 2005).

The past two decades saw a growing focus of this sector on environmentally and socially responsible forest management. The sector had to respond to the global demand for timber and non-timber products from responsible sources, and the *National Forest Act (No. 84 of 1998)* set the scene toward the development and implementation of environmentally and socially responsible forestry practices (RSA 1998). Since the late 1990s, the majority of plantations in South Africa have

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achieved certification under the Forest Stewardship Council (FSC) (Godsmark 2010). As an outcome of the National Forest Act, the DAFF has developed and tested a set of principle and criteria indicators (PCIs) toward the sustainable management of natural and plantation forests (see the PCIS case study). Furthermore, the drive toward SFM, led by the DAFF and paired with the growing request from international markets for certified forest products, ensures that the majority of plantation forests in South Africa are managed according to sound and sustainable forest management principles (Dyer 2007). Improved management practices are extending to unplanted areas, and through partnerships with regional conservation authorities, forestry landowners now play an active role in the preservation of areas perceived as being important for biodiversity and ecosystem functioning (see Figure 10.2) (Scotcher 2006). The potential contribution of the forestry sector toward the country's economic growth has been acknowledged (DAFF 2011), and opportunities for expansion have been evaluated. An area of approximately 100 000 ha, mostly in the Eastern Cape, has been identified as suitable for forestry expansion (DAFF 2011). The afforestation of new areas in the Eastern Cape could play a significant role in the much needed creation of employment opportunities in this impoverished area of the country.

The forestry sector is facing many challenges that could threaten its long-term sustainability, including land occupancy, skills shortage, licensing for new afforestation, and climate change (Dyer 2007, DAFF 2009). The GCMs for southern Africa predict warmer temperatures and, particularly in the western and southern parts of the country, reduced rainfall, resulting in a decrease in moisture availability (DEA 2013) An increase in the number of pests and pathogens, frequency and intensity of forest fires, and generally less predictable weather patterns, have already been observed within the areas currently under plantation forestry. These incidents are likely to become more severe (Dyer et al. 2011). The timeous development and implementation of climate change adaptation strategies are, therefore, of utmost importance in reducing the risks that are threatening plantation forests in South Africa. This chapter of the *South African Risk and Vulnerability Atlas* considers the challenges of commercial plantation forestry in a changing climate, with particular focus on:

- forest physiology;
- risk (pests and pathogens, fire, inherent site fertility); and
- management responses to a changing environment.

Commercial plantation forestry and climate change

In South Africa, climate change actually represents an opportunity for the forestry sector to raise awareness and improve the public perception of this type of land use.

However, the interaction between climate change and forestry is considerably complex and multi-faceted, presenting not only opportunities but challenges, too. Mitigation, rather than adaptation, has been the main focus of both the scientific community and policy-makers. This is because of the ability of forests to reduce impacts on climate-sensitive systems by removing carbon dioxide, one of the main greenhouse gases (Smith et al 2014). More recently, however, the scientific community has begun stressing the importance of exploring and understanding the concept of adaptation as a method of reducing the risks associated with climate change, and to take full advantage of certain opportunities that could result from it (Füssel 2007).

Atmospheric carbon and forest physiology

Forests play a mitigating role by removing atmospheric carbon dioxide (CO_2). Although plantation forestry occupies only 1% of South Africa, it was estimated to sink about 4% of the total CO_2 emitted from human activities (Christie & Scholes 1995). However, a system for the estimation of carbon fluxes in South Africa plantation forestry is lacking, and there is an urgent need for a sector's carbon sequestration model.

Carbon is a fundamental element in the metabolism of plants, and climate change has stimulated research into the effects that increased levels of atmospheric CO_2 have on biomass production. Although the effects of increased atmospheric carbon availability on plant growth are complex and species-specific (Sage 1994), there is some evidence that, when other resources, such as soil moisture, temperature and nutrients, are not limiting, raised atmospheric CO_2 levels may in fact enhance growth. Increases in photosynthesis levels have averaged 40% in response to simulated increases in atmospheric CO_2 (Ellsworth et al. 2004), and CO_2-induced growth enhancement has been observed in closed and open-top chambers in a variety of young tree species (Kirilenko & Sedjo 2007). Fast-growing trees have responded strongly to increased levels of atmospheric CO_2 with estimated harvestable wood increases of up to 25% and improved nitrogen-use efficiency (e.g. Calfapietra et al. 2003; Wittig et al. 2005). Mean net primary production was found to be stimulated by raised CO_2 concentrations in young tree stands and not in mature tree stands (Korner et al 2005; Norby et al 2005). However, further studies are required in this field of research, particularly with regard to mature trees.

Figure 10.2 An example of conservation areas within the forestry landscape (Photo: Steven Germishuizen)

Climate change and risk to forestry

A warmer, less stable climate with frequent extreme events can result in physiological stress, stunted growth, and increased mortality in trees. Moreover, according to Davies (2011), increased drought frequency and dryer winters can potentially influence the frequency and intensity of wild fires, and a warmer climate can lead to a more favourable environment for existing as well as new pests and pathogens and alien vegetation species.

Pests and pathogens

Warmer temperatures and more erratic weather patterns can favour existing and new pest and pathogen outbreaks by altering the pest/pathogen – host – environment relationship. Climatic conditions that lead to physiological stress can lower a tree's natural defence mechanism against pests such as the woodwasp, *Sirex noctilio* (Madden 1968). Warm climate conditions have contributed to insect epidemics (Berg et al. 2006; Jepsen et al. 2008) and have led to the expansion of the historical range of some pests and pathogens. Furthermore, tissue damage caused by frost and hail can promote pathogens' infection (Ayres et al. 2009).

Wild fires

Wild fires, forest pests and pathogens are already responsible for an annual loss of approximately 3% of the afforested areas in South Africa (Godsmark 2007). With these climate trends already well established (DEA 2013; IPCC 2013), such threats are likely to increase in the future (Fairbanks &Scholes 1999; Dyer et al. 2011). Stress-inducing climatic conditions may also increase the susceptibility of planted forests to pests and pathogens by altering host defences (Moore & Allard 2008).

Inherent site fertility

A further challenge is posed by the static land base in which the South African forestry industry operates, with limited opportunities for new afforestation and the risk of some currently optimal forestry areas becoming marginal due to climate change. Soil climate interactions affect variable features which characterise a site as well as the site's potential productivity. Carbon dioxide, nitrogen deposition, temperature and rainfall have been identified as climate change drivers affecting soil's physical, chemical and biological processes (French et al. 2009). Efforts have been made to develop simple soil health tests to monitor the effects of climate change on soil. However, controlled environment and long-term research experiments are needed to form a better understanding of the interactions between climate change, soil, land use and management (Allen et al. 2011).

Management responses to climate change in the forestry sector

The development of appropriate management strategies to promote the process of adaptation to climate change is key to the future of the forestry sector. The South African forestry industry is in a favourable position in terms of the ability to act, being based on highly managed, single species, even-aged stands, and relative short rotation (6 to 25 years, depending on genus, site and end use). Furthermore, a long tradition of forestry research provides solid, scientifically sound foundations that can support the development of adaptation strategies. Climate change projections are associated with a certain degree of uncertainty (Keenan 2015), and forest management actions need to be developed from a flexible adaptation framework. The process of developing and implementing adaptation strategies in the forestry context requires time. Opportunities are mainly found in genetics and silvicultural practices (Smith et al 2014).

Genetics

Pure species breeds and clones are likely to see a reduction in their climatically optimal range in favour of more robust hybrids that incorporate traits important for climate change (Fairbanks & Scholes 1999). Although breeding for traits (such as heat stress, drought tolerance and resistance to pests and pathogens) could imply some loss in yield, this will eventually be compensated for through a reduction in the risk of devastating events and, consequently, even reduce financial losses (Christie & Scholes 1995). Species choice should be reviewed frequently and the relatively short rotation length does indeed allow for quick intervention (see Figure 10.3).

Silviculture

Water is the main limiting resource for South African plantation forests, and it is likely to become even more so in certain areas – hence the importance of the adoption of robust silvicultural practices aimed at reducing trees' physiological stress. Planting bigger seedlings has resulted in better survival and growth rate (South et al. 1993), and varying stand density – either at planting or by thinning – has proven

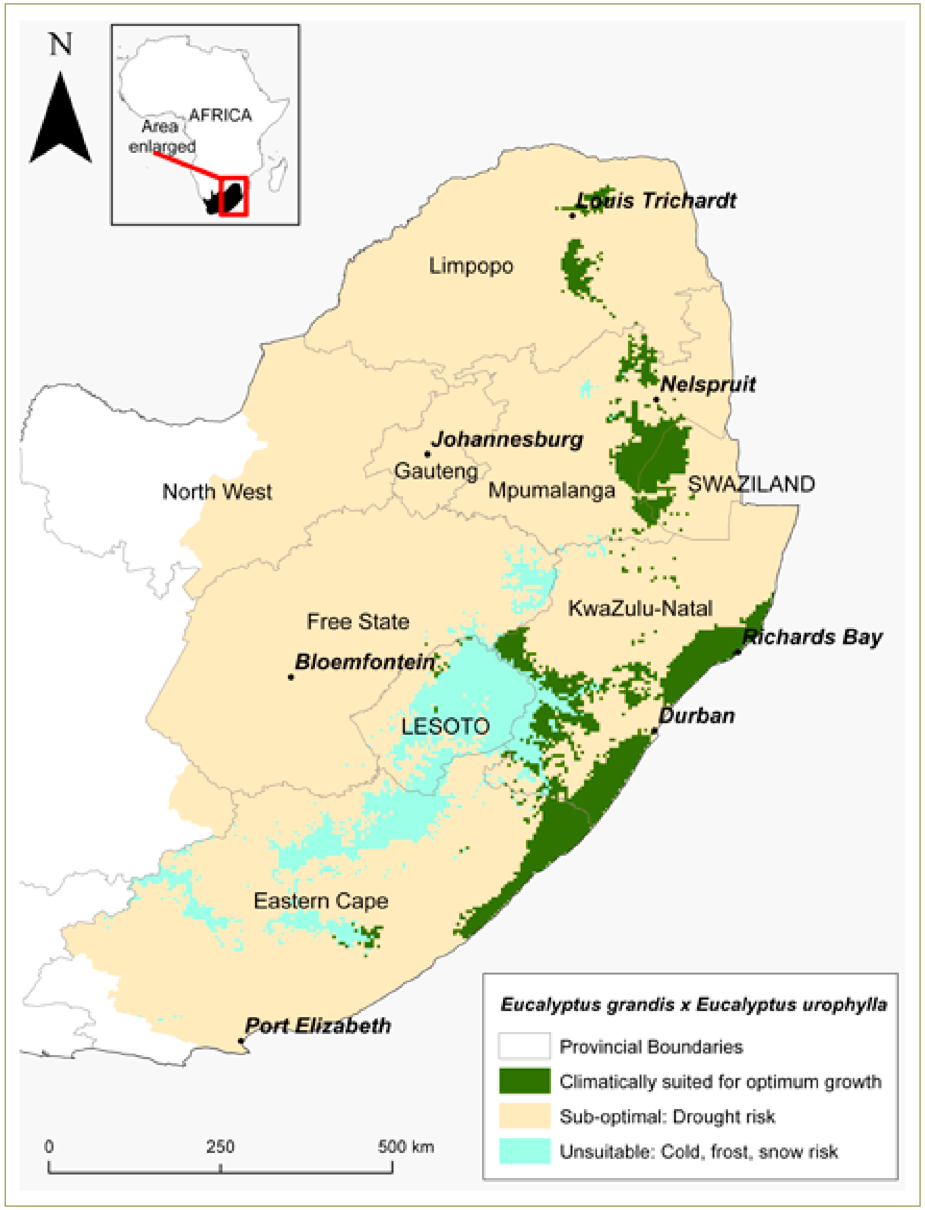

Figure 10.3 *Eucalyptus grandis* x *Eucalyptus urophylla* potential growing areas: Climate change scenario 2081-2100 (Source: Adapted from Smith et al. 2005; CGIAR 2011)

to be a successful management tool in reducing the effects of drought (Pinkard & Bruce 2011) as well as susceptibility to pests and pathogens.

Management practices that are currently applied to reduce forest vulnerability to wildfire are mostly aimed at reducing the fuel load through mechanical removal or controlled burning. However, recent studies have indicated that mulching may be much more effective in reducing stand damage in the event of a wildfire. Battaglia et al. (2010) have observed a reduction in crown damage and soil temperatures in mulched conifer stands subjected to fire. Cooler burns and lower flame heights were also observed in *Pinus patula* and *Eucalyptus macarthurii* stands in South Africa (Pool 2012).

Although human-induced disturbance has the greatest impact on the dynamics of alien vegetation species, climate change is likely to enhance their capacity to invade new areas and increase niche availability (Thuillier et al. 2007). The issue of alien vegetation and forestry is complex. Alien vegetation control is commonly performed to reduce resource competition in commercial forestry stands, and the forestry industry's commitment to sustainable timber production and protection of the environment implies an active effort toward the clearing of alien vegetation inside and outside the forestry estates (Mondlane et al. 2001). Nevertheless, species used in commercial forestry, mostly *Pinus* and *Acacia* genera, are amongst the most widespread alien species in South Africa, and to date no effective biological control has been developed for their management. Alien vegetation control is likely to become a growing concern and cost to the business of sustainable timber production.

Risk modelling

Projected changes in climate pose a serious threat to plantation forestry in southern Africa. Forest disturbances are strongly climate-driven, and current climate change projections foresee an increase in the frequency and intensity of extreme events such as drought, wild fires and severe storms. Current projections also indicate a clear trend toward increasing temperatures. A warmer climate is generally more favourable to pests and pathogens and associated with higher population growth, geographic spread and more frequent outbreaks (Vanhanen et al. 2007). Hence, there is a strong possibility that plantation forests in South Africa will be under a growing threat from a range of existing and new damaging agents. Predicting the level of risk potentially caused by biotic and abiotic threats, now and into the future, is crucial for the development of a successful adaptation strategy. The application

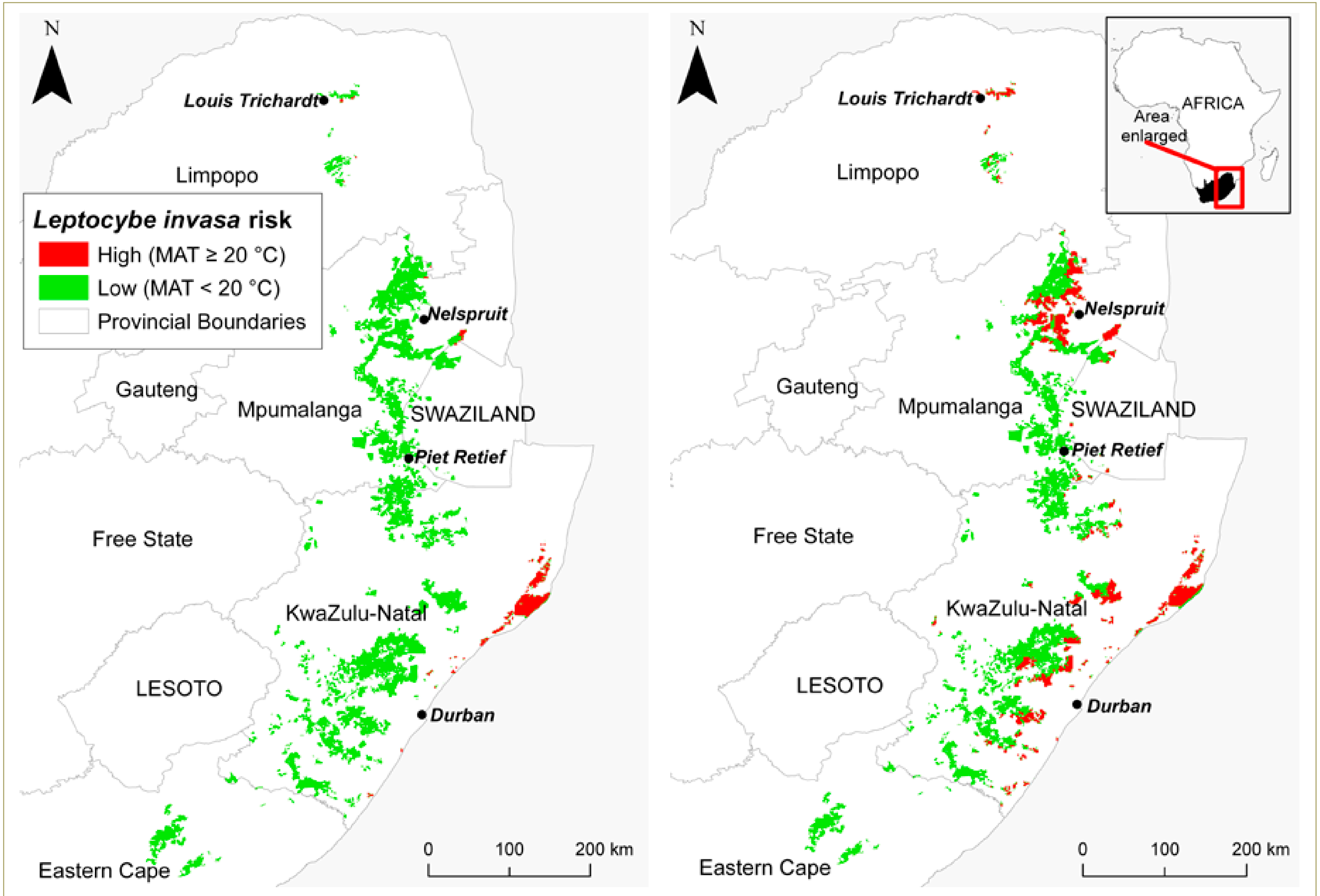

Figure 10.4 Current and potential (climate change scenario 2081–2100; CGIAR 2011) risk of the gall wasp, *Leptocybe invasa,* for *Eucalyptus* plantations in the summer rainfall region of South Africa (Source: Adapted from Nyeko et al. 2010)

of GIS and remote-sensing technologies into a multi-criteria modelling environment, allows for the development of spatially explicit dynamic risk scenarios at a local and national scale. These risk scenarios can be used to produce risk maps that provide essential information – both for a strategic risk appraisal and for decision-making at an operational level (see Figure 10.4).

Conclusion

The potential impact of climate change on South African forestry is complex and has a high level of uncertainty. The process of adaptation of the forestry sector to a changing environment requires a foundation of sound scientific principles based on research in the area of forestry and climate change. These should be aimed at addressing specific areas of vulnerability, particularly within the fields of tree improvement and risk modelling.

South Africa has endorsed a low carbon, long-term plan of economic development that implies moving away from burning fossil fuel in favour of climate-friendly renewable energy. It includes the use of forestry bi-products for the production of biofuels (DEAT 2004). The potential use of forest bi-products for the production of biofuels, paired with the inherent mitigating role that forests play by removing atmospheric CO_2, makes the forestry sector a key contributor to the country's green economy growth path.

Thus, although climate change is definitely a major challenge to the forestry sector, it also provides the opportunity to further forestry's commitment to sustainability.

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Case Study

The principles, criteria, indicators and standards framework: a tool for achieving sustainable forest management in the context of climate change mitigation, specifically the REDD+ mechanism under the UNFCCC

Itchell Guiney[1]

Introduction

With the ever-increasing tropical forest destruction and unsustainable timber harvesting in the mid-1980s, the growing concern over the state of the world's forests, as well as the association with global warming and ozone depletion, much attention was drawn to the concept of sustainable forest management (SFM).

The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, called upon governments to develop methods that would reduce the destruction of natural resources, including forests. The South African government accepted the call through its development of the National Forestry Action Programme (DWAF 1997), and subsequently, the *National Forests Act (No. 84 of 1998)* (NFA) (RSA 1998), which binds state forestry operations to principles of sustainable forest management and promotes the development of a system of Principles, Criteria, Indicators and Standards (PCIS) for sustainable forest management (DAFF 2008).

The Principles, Criteria, Indicators and Standards framework

The 'Principles, Criteria, Indicators and Standards' can be defined as a management framework that must ensure that forests are managed sustainably and in a systematic way. This framework allows the systematic monitoring, auditing and reporting on the achievement of sustainable forest management.

The PCIS framework contains 23 criteria, which are all based on the provisions set out by the NFA. Criteria 1 to 6 deal with ecological issues, Criteria 7 and 8 are related to the economy, and Criteria 9 to 23 focus on social aspects.

The current set of PCIS, published in 2012, is the result of an intensive stakeholder consultative review process of the first edition, which was conducted in 2001. The reviewed framework may be used by stakeholders and implemented as part of their management practices.

The REDD+ mechanism under the United Nations Framework for the Convention on Climate Change (UNFCCC)

The reduced emissions caused by deforestation and forest degradation in developing countries, the role of conservation, sustainable management of forests and the enhancement of forest carbon stocks in developing countries' (REDD+) mechanism, were all results of the alarming global deforestation rate of approximately 13 million ha per year (or 17 to 20%). Deforestation is a major cause of biodiversity loss and climate change. The IPCC estimated emissions from deforestation in the 1990s to be more or less 5.8 gigatons of carbon dioxide per year, or approximately 20% of annual global greenhouse gas emissions (IPCC 2007). Therefore, reducing and/or preventing deforestation is an important climate change mitigation option – an objective to which SFM could most certainly contribute.

Paragraph 70 of the Cancun Decision 1/CP.16 suggests the following five activities under REDD+ that can be undertaken to potentially contribute toward mitigation actions in different countries, based on the various countries' national circumstances and respective capabilities:

1. Reduce emissions caused by deforestation.
2. Reduce emissions caused by forest degradation.
3. Conservation of forest carbon stocks.
4. Sustainable management of forests.
5. Enhancement of forest carbon stocks. (UNFCCC 2010)

The REDD+ mechanism requires the further development of its four elements outlined in Paragraph 71 of Decision 1/CP.16, in order for developing countries to

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obtain results-based payments for the full implementation of REDD+ activities. These four elements are:

1. A national strategy or action plan.
2. A national forest reference emission level and/or forest reference level.
3. A national forest monitoring system.
4. A system of information on safeguards (biodiversity and social safeguards contained in Addendum I of Decision 1/CP.16. (UNFCCC 2010)

REDD+ should ideally be implemented in three phases: (1) The development of national strategies or action plans, policies and measures, and capacity-building; (2) the implementation of national policies and measures and national strategies or action plans; and (3) results-based demonstration activities, as well as results-based actions that should be fully measured, reported and verified.

The South African PCIS framework and the UNFCCC REDD+ mechanism

Table 1 outlines the linkages and synergies between the PCIS framework and the UNFCCC REDD+ mechanism.

Table 1 Linkages/synergies between the PCIS framework and the UNFCCC REDD+ mechanism

Aspect	PCIS (SFM)	REDD+
Ecological/environmental	Criteria 1 to 6	• All five activities • Biodiversity safeguards • Non-carbon benefits • Forest monitoring – National Forest Monitoring System (NFMS) and measuring, reporting and verification (MRV)
Economic	Criteria 7 and 8	• Phases 1, 2 and 3 – readiness of support and results-based payments for the implementation of REDD+ activities
Social	Criteria 9 to 23	• Social safeguards

Discussion and conclusion

The effective implementation of the PCIS framework can subsequently lead to carbon and non-carbon benefits. It also has the potential to assist South Africa in implementing the REDD+ mechanism on a national level under the UNFCCC.

Future third party audits will have to be linked to the REDD+ in order to fully understand the connections and synergies between the PCIS framework and the mentioned mechanism.

It is suggested that the PCIS framework as well as the REDD+ mechanism should be given the potential to promote and support the conservation of both carbon (biomass) and non-carbon benefits. However, a carbon component should be tailor-fitted into the future review of the PCIS framework, which would then explicitly draw linkages between the PCIS framework and climate change mitigation. This component should, therefore, also include the assessment of carbon stocks and flows within forests.

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CHAPTER 11

Biodiversity
Natural capital to be wisely used

Bob Scholes,[1] Amanda Driver,[2]
Reinette Biggs[3] and Greg Forsyth[4]

Introduction

The biodiversity section in the first edition of SARVA (Midgely 2011) introduced the exceptionally rich biota of South Africa. It included maps of the main areas of endemism (i.e. places where there are concentrations of species that do not occur naturally anywhere else in the world) and of the protected area network that has been established to conserve biodiversity. Furthermore, it outlined the threat to biodiversity posed by land use and climate change, and presented a case study of the Kruger-to-Canyons area in the north-east of the country. This chapter builds on that foundation without repeating the information.

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2 South Africa National Biodiversity Institute (SANBI)
3 University of Stellenbosch – Centre for Studies in Complexity
4 Council for Scientific and Industrial Research (CSIR) – Natural Resources and the Environment

Measuring changes in biodiversity

The modern understanding of the term 'biodiversity' involves much more than just a list of plants and animals. It includes the *genetic* variability within species (including the species we have domesticated, such as maize or cattle), the *abundance* and *distribution* of populations of species, and the pattern and condition of various *ecosystems*. Therefore, various measures of biodiversity are possible – some biodiversity indicators may suggest that the status of biodiversity is improving, while others show it to be declining. This can be quite confusing if one merely wants to know the general state in which biodiversity currently is.

One way of combining the several aspects of biodiversity is through the Biodiversity Intactness Index (BII) (Scholes & Biggs 2005). This index estimates the average abundance of organisms within a particular area – across a wide range of plant and vertebrate species – for all the ecosystems in the area, regardless of whether they are protected, semi-natural, or transformed. It acts as a robust measure of the 'average biodiversity' that underpins our wellbeing as humans. Tracking 'rare and threatened biodiversity' in a sensitive way requires a different approach, such as the Red List of Threatened Species or ecosystems.

The BII indicates a relatively steady loss of biodiversity for South Africa during the 20th century, with some steeper loss associated with periods of rapid land use change, for example in the 1950s (see Figure 11.1). Ecosystems heavily affected by cultivation (such as the grasslands) or urban expansion (such as the coast) show the greatest loss of biodiversity, especially if such ecosystems coincide with areas of high species richness and endemism. Overall, it has been calculated that cultivation is the cause of 52% of the total decline in BII, while extensive livestock farming accounts for 25%, land degradation for 12%, urbanisation for 6% and plantation forestry for 5% (Biggs et al. 2006).

Notwithstanding these losses, South Africa, unlike many other countries, still has a lot of its original biodiversity. This is a national asset to be used sustainably. Biodiversity assets and ecological infrastructure can contribute to national goals such as job creation, poverty alleviation and rural development. These assets can also play a key role in helping us cope with the impacts of climate and other changes – often more effectively and at a lesser cost than technology-based solutions.

Climate change-related risks to biodiversity

All species have a tolerance range with respect to climate variables such as temperature and moisture, known as their 'climate niche'. Interactions with other species in ecosystems and non-climate factors cause the 'realised niche' which they occupy to become smaller than this potential niche. When the climate changes, species must either adapt physiologically or genetically, or migrate to places where the climate meets their needs. The climate changes projected for southern Africa in the 21st century are sufficient to put a large fraction of South African species outside their preferred climate niches (Midgley et al. 2002; Thomas et al. 2004; Midgley et al. 2011). Species with slow adaptation and migration rates, those whose migration pathway is blocked by hostile land uses or topography, those which are dependent on other species that are not able to adapt or migrate rapidly enough, or species for which suitable future climate combinations simply do not exist, face an increased risk of extinction. Clearly the climate risks interact with the risks involved in a change in land use.

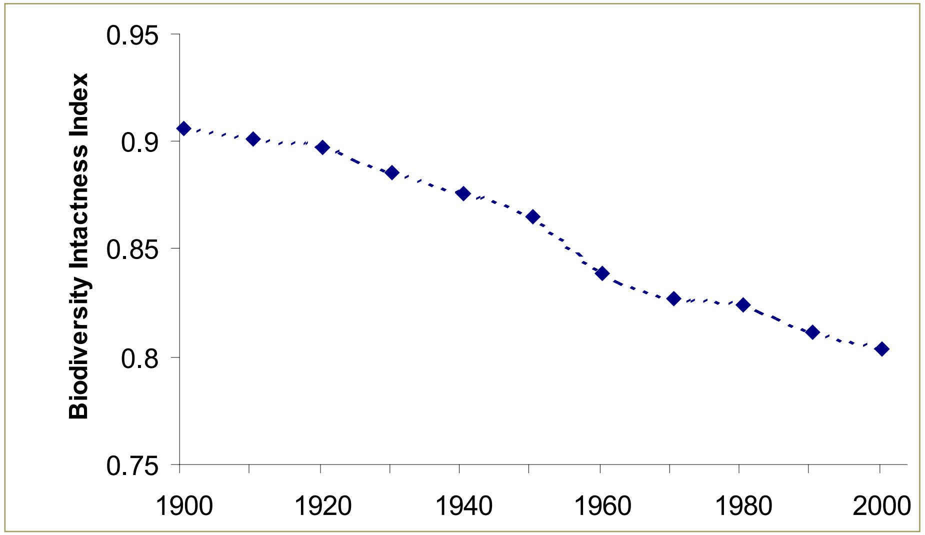

Figure 11.1 The terrestrial Biodiversity intactness index for South Africa over the period 1900-2000 (Biggs & Scholes 2007)

Biodiversity priority areas and climate change resilience

In order to make the most of the national biodiversity asset, South Africa's approach to managing and conserving it is two-fold: (1) Expanding and linking the network of protected areas; and (2) ensuring biodiversity-compatible management and resource use in priority areas outside the protected area network.

'Protected areas' are those that are formally recognised in terms of the Protected Areas Act of 2003. They include not only state-owned parks and reserves, but also private or communally-owned protected areas in which landowners have entered into a contractual agreement with a conservation authority. The land-based protected area network currently makes up about 7% of the country's land area, and the marine protected area network less than 1% of our marine territory, which is, in fact, much larger than the land area.

Biodiversity-compatible land use can take many forms, e.g. appropriately managed extensive livestock grazing or wildlife ranching, sustainable harvesting of wild resources from the land or sea, or a range of recreational and ecotourism activities. Even cultivation, plantation forestry, mining and urban development can take less damaging forms, if carefully executed.

South Africa has a strong tradition of identifying spatial priority areas to guide biodiversity management and conservation action, and we always aim toward getting the best possible outcome from the resources available for biodiversity protection. Priority areas – including those intended for conserving a representative sample of ecosystems and species, for maintaining ecological processes, and for delivering ecosystem services – are identified using systematic biodiversity planning. The National Biodiversity Assessment of 2011 (Driver et al. 2012) consolidated all spatial biodiversity priority areas into a single national map for the first time (shown in Figure 11.2, with the categories described in Box 1). In some priority areas the objective is to keep the landscape in a natural or near-natural condition; in others the focus is mainly to maintain key ecological functions while permitting compatible land uses. Information on all biodiversity priority areas is available on the South African National Biodiversity Institute's website (http://bgis.sanbi.org).

Box 1: Biodiversity priority areas in South Africa

Biodiversity priority areas include the following categories (as shown in Figure 11.2):

- Protected areas are areas of land or sea that are formally protected by law and managed mainly for biodiversity conservation.
- Critically endangered ecosystems are ecosystem types that have very little of their original extent left in natural or near-natural condition.
- Endangered ecosystems are ecosystem types that are close to becoming critically endangered.
- Critical Biodiversity Areas (CBAs) are areas required to meet biodiversity targets for ecosystems, species or ecological processes, as identified in a systematic biodiversity plan.*
- Ecological Support Areas (ESAs) play an important role in supporting the ecological functioning of CBAs or in delivering ecosystem services.*
- Freshwater Ecosystem Priority Areas (FEPAs) are rivers and wetlands required to meet biodiversity targets for freshwater ecosystems (see Nel et al. 2011).
- High water yield areas are sub-catchments where mean annual runoff is at least three times more than the average for the related primary catchment (see Nel et al. 2011).
- Priority estuaries are those required to meet biodiversity targets for estuarine ecosystems, habitats and estuarine-dependent species.
- Focus areas for land-based protected area expansion are large, intact and unfragmented areas of high biodiversity importance, suitable for the creation or expansion of large protected areas.
- Focus areas for offshore protection are areas identified as priorities for representing offshore marine biodiversity, for protecting vulnerable marine ecosystems for contributing to fisheries' sustainability, for supporting management of by-catch, or for a combination of these (see Sink et al. 2011).

* CBAs and ESAs are yet to be identified in some provinces (Free State and parts of the Northern Cape) as well as in the marine environment.

The need to promote resilience to climate change is one of several considerations in identifying priority areas for biodiversity protection. For example, the National Protected Area Expansion Strategy (PSA 2010) identified 42 focus areas for land-based protected area expansion. These not only contain those ecosystems that are under-represented in the current protected area network, but also those landscape features necessary to allow species to disperse and migrate in response to climate change. Temperature and rainfall gradients, topographic and habitat variability, centres of floral endemism, coastal ecological processes, and river-associated movement corridors, were all favoured in their selection.

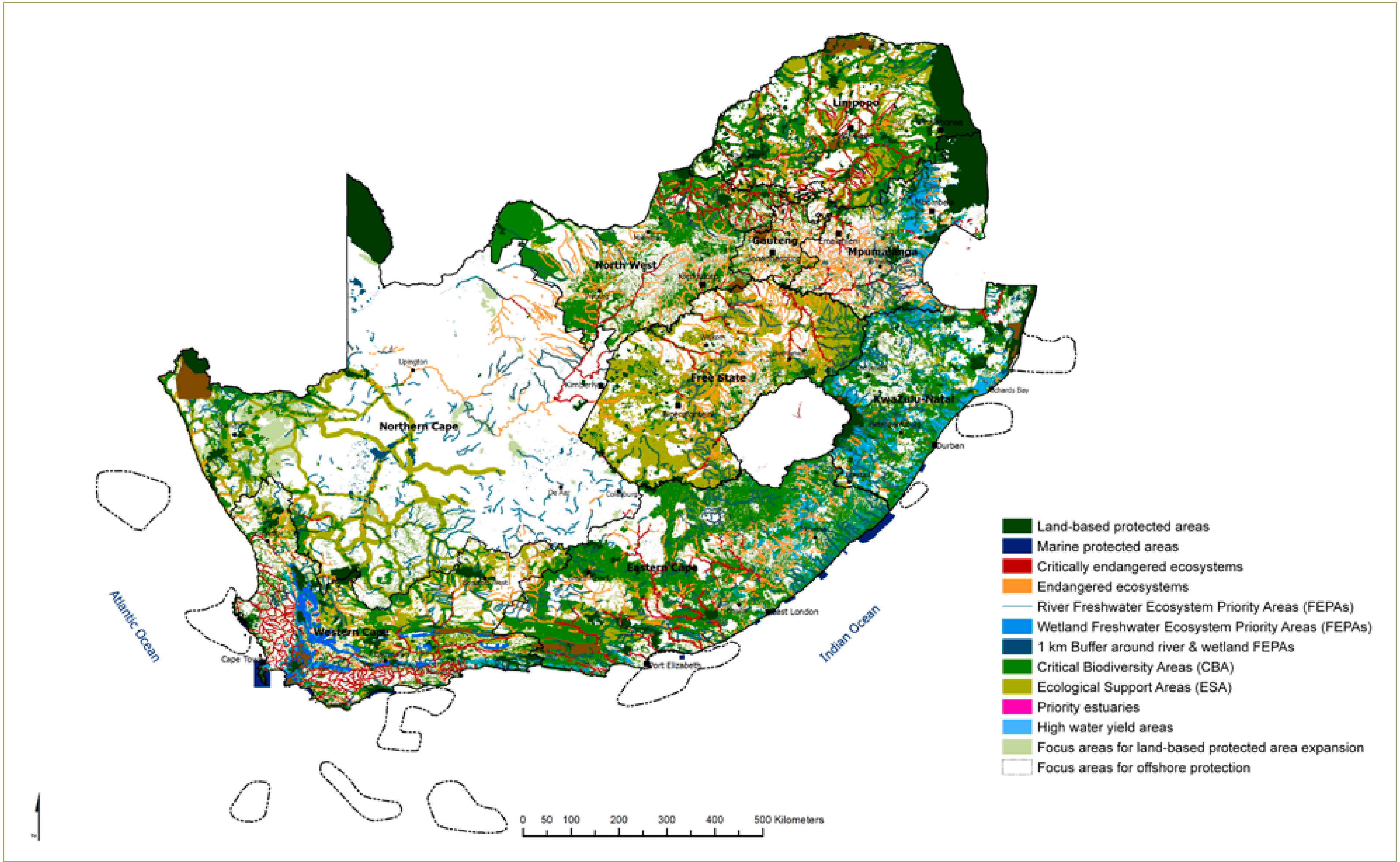

Figure 11.2 Biodiversity priority areas in South Africa (Driver et al. 2012). This map is used for guiding land use planning and natural resource management decisions

It is now standard practice in biodiversity planning in South Africa to build features such as climatic and altitudinal gradients, ecological corridors of various types, and climate refuge sites into the identification of biodiversity priority areas. This helps to maintain the country's natural capital base and the supply of ecosystem services.

Ecosystem services and natural capital

Ecosystem services are the benefits that humans obtain from nature (MA 2003), including tangible things such as fresh water, food, timber and clean air. They also include the foundation for our growing nature-based tourism sector, and many unseen ecological processes that support our existence, such as nutrient cycling, climate regulation, pollination and the control of diseases (Summers et al. 2012). The sustained and reliable supply of ecosystem services depends on sufficient, healthy biodiversity – broadly defined, as above, to include ecosystems and functioning ecological processes (Reyers et al. 2012). Ecosystem services can be measured and mapped (e.g. for southern Africa by Scholes & Biggs 2004), and in some cases even quantified in terms of money. 'Natural capital' can be defined in a similar way as 'financial capital': An asset that generates future income, in this case in the form of ecosystem goods or services.

Wealth creation is the process of using various forms of capital, including natural capital, to generate flows of goods and services that people need. A decline in natural capital is a sign of unsustainability if it is not accompanied by larger increases in other forms of capital (Ekins et al. 2003). Human activities – including those aimed at meeting demands for food, water, timber or fuel – can disrupt the functioning of ecosystems, reducing the delivery of ecosystem services (Summers et al. 2012). While some ecosystem processes can be partly substituted with human technology (e.g. water can be purified in a treatment plant if wetlands no longer perform that function), there are many ecosystem services which simply cannot be substituted at all. If we allow the ecosystems that provide these services to deteriorate due to unsustainable land management (e.g. over-grazing, soil erosion, invasion by alien plants and water pollution), our wellbeing also suffers and our development opportunities will be hampered (MA 2005). Over-exploiting a resource can temporarily alleviate poverty; however, because it is unsustainable, it will limit socio-economic development in the future.

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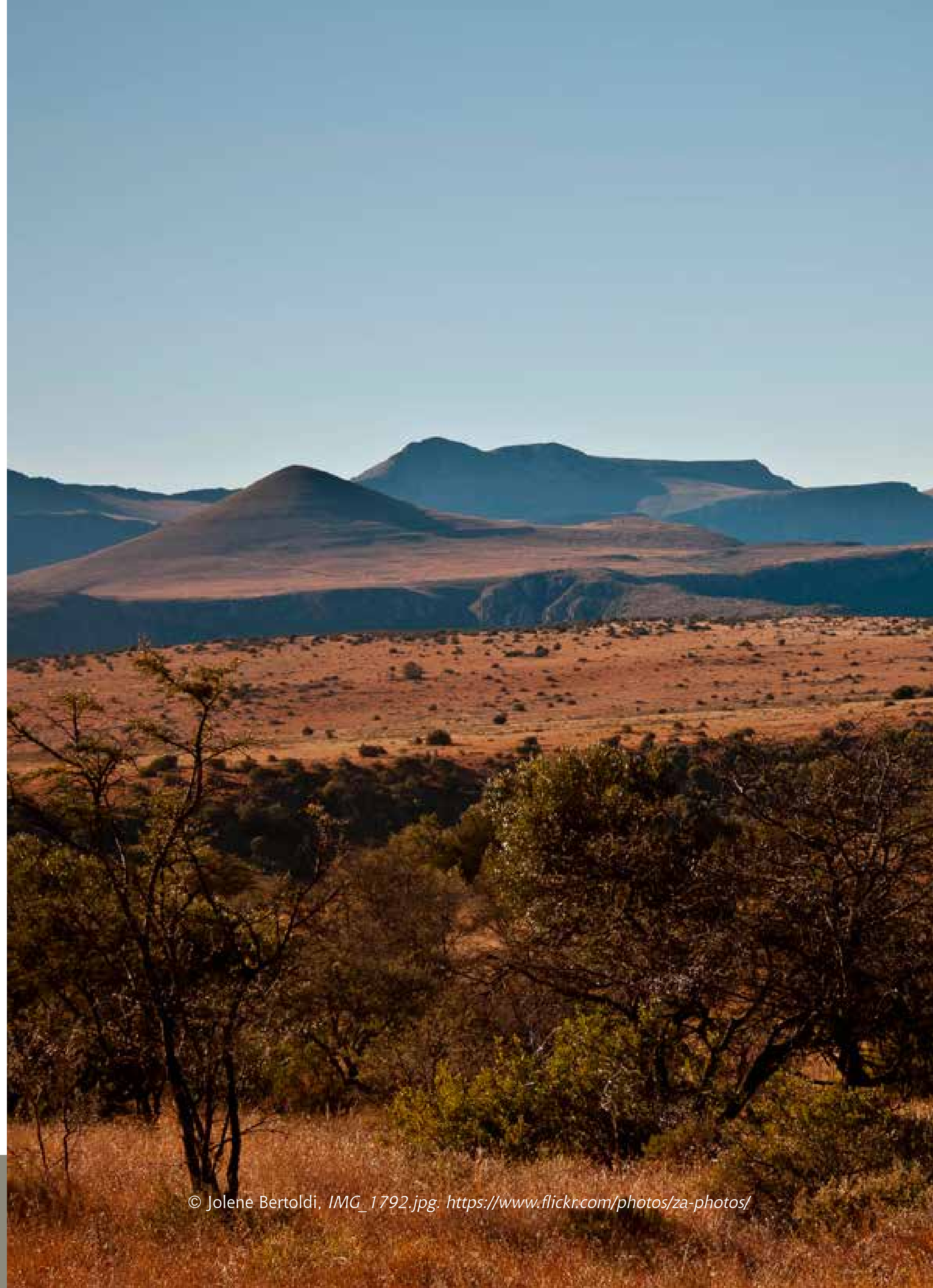

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Case Study

Ecosystem services in the Little Karoo

The Little Karoo (see Figure 1) is a semi-arid biodiversity hot spot in the south-east part of South Africa's Western Cape province (Reyers et al. 2009). Like in many other dry areas, the people living in this region face declining ecosystem services (MA 2005), threatened biodiversity, high unemployment, and deteriorating future social and economic options. The economy of the Little Karoo is mainly based on agriculture and tourism, both of which depend a great deal on ecosystem services. The key services in this region are the production of forage for domestic livestock, the capturing and storage of atmospheric carbon dioxide in vegetation and soils (which helps to mitigate climate change), erosion control, freshwater flow regulation, and offering a landscape that is attractive to tourism. It is self-evident that a disruption of these services negatively affects the livelihoods of all those who reside within the region.

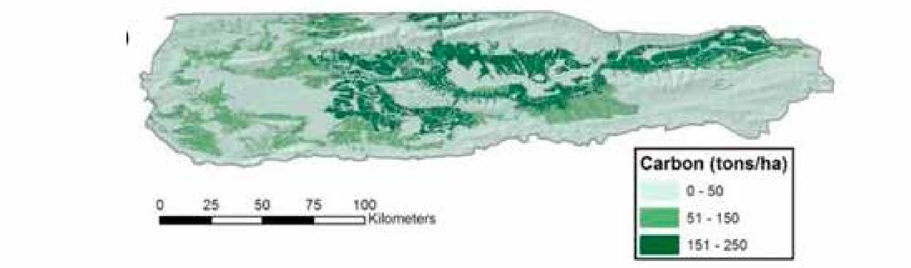

Figure 1 The ecosystem service of carbon storage in the Little Karoo – one of several services mapped and quantified in this area

The greatest relative negative change within the Little Karoo's key ecosystem services, is in erosion control, while water flow regulation is still at over 80% of its potential (see Figure 2). Forage production, carbon storage and tourism view sheds have also declined by 28%, 27% and 25% respectively.

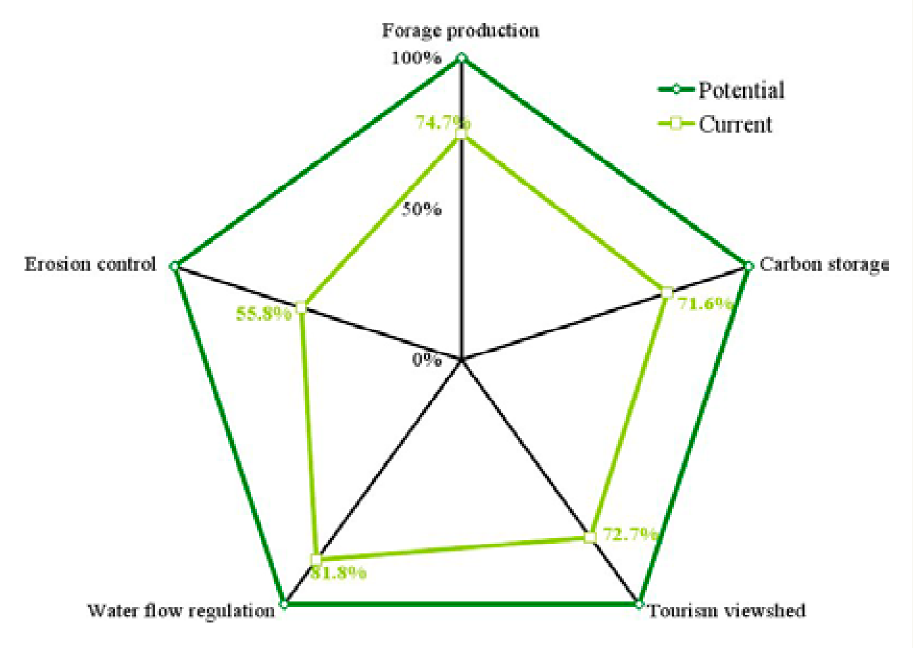

Figure 2 Changes in the supply of the five most important ecosystem services produced in the Little Karoo. Data labels indicate the current levels of ecosystem services as a percentage of the potential, prior to European settlement (Source: Reyers et al. 2009)

Over-grazing, together with the clearing of land to plant crops to supplement forage production, have been the main drivers of these declines in ecosystem services. This has mainly occurred in the lowlands and foothills, where land transformation has been more severe than in the high water-yielding, mountainous areas. Declines in the ecosystem services delivered in the Little Karoo match similar biodiversity losses in the area (Rouget et al. 2006; Gallo et al. 2009) – such declines tend to reduce the region's resilience to economic and climatic shocks, such as droughts and floods.

Maintaining a sustainable Little Karoo requires that the condition of its natural capital be improved. Future land uses must promote maximum sustained water yields and quality, as well as the efficient use of water. In addition, actions taken to secure the water-related and climate-related ecosystem services (by restoring and conserving the natural vegetation) will also benefit biodiversity conservation and the wellbeing of people in the region.

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CHAPTER 12

An overview of the impacts of global change on South Africa's coasts and oceans

Kim Bernard[1] and Anthony Bernard[2]

Global change is widely recognised as having a significant impact on the world's coasts and oceans (Harley et al. 2006; Hoegh-Guldberg & Bruno 2010). A large portion of South Africa's population is heavily dependent on a wide variety of marine resources, with plans for new initiatives that aim to unlock the economic potential of South Africa's oceans even further (see Box 1). It is, therefore, essential that we understand the possible risks and vulnerabilities posed by global change in order to better manage and conserve such valuable resources. In this chapter we define global change as a concept which includes both climate change and other human-induced environmental change.

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2 South Africa Institute for Aquatic Biodiversity

Operation Phakisa

A South African government initiative aiming to unlock the economic potential of South Africa's oceans through fast-tracking marine development. The initiative aims to translate detailed governance, development, and management plans into results through dedicated delivery and collaborations. The collaborations are grouped in laboratories (Labs), focussing on economic growth areas (Offshore Oil and Gas Exploration Lab, Marine Transport Lab, Marine Manufacturing Lab, Aquaculture Lab) as well as Marine Protection and Governance. The Labs bring together key stakeholders from the public and private sectors, academia, and civil society to set development and conservation priorities. The objectives of the selected Labs are summarised below.

Oil and Gas Lab

Vision: *To determine the extent of South African offshore oil and gas reserves through exploration.*

This will see the drilling of 30 offshore exploration wells in the next ten years. To ensure this, the Lab identified six fundamental initiatives with priority on (1) providing legislative clarity and stability, (2) building end-to-end institutional structure, (3) developing and implementing a skills strategy roadmap, as well as (4) a local content roadmap. (http://www.operationphakisa.gov.za/operations/oel/oilgas)

Aquaculture Lab

Vision: *Unlocking the potential of the aquaculture sector in South Africa.*

The Lab aims to (1) increase aquaculture revenue from R0,67 billion to R3 billion, (2) increase the amount of jobs from 2 227 to 15 000, and (3) to increase production by 20 000 tonnes. To achieve this, eight initiatives were developed. These will see the implementation of 24 aquaculture projects that will improve the number and quality of farms. In addition, the initiatives will focus on development of an enabling regulatory environment, increasing skills and awareness and garnering funding support. (http://www.operationphakisa.gov.za/operations/oel/aquaculture)

Marine Protection Services and Governance Lab

This Lab aspires to support the development of the new growth areas in the ocean economy through the 'implementation of a new coordinated ocean governance approach for South Africa's ocean space'. Three key focus areas have been identified and will be addressed over the next five years: (1) **Integrated framework and governance –** implementing an overarching governance plan by mid-2016; (2) **Ocean protection –** protecting the ocean environment and promoting its multiple socio-economic benefits by improving and expanding the marine protected area (MPA) network, reducing illegal and unregulated activities in the ocean space, and reducing human health and environmental risks to pollution, with results by 2017; (3) **Marine spatial planning (MSP) –** establishing a system to guide the development, implementation, monitoring and refinement of national and regional MSP frameworks, and enable a sustainable ocean economy by December 2015. To achieve these targets, ten initiatives have been identified, with six being critical from the three focus areas (indicated below by the number in parenthesis): Establishment of a ministerial committee and secretariat to govern activities (1), accelerated capacity-building intervention in ocean governance (1), enhanced and coordinated enforcement programme (2), national ocean and coastal information system and extended earth observation capacity (2), creation of a MPA representative network (2), and the MSP process (3). (http://www.operationphakisa.gov.za/operations/oel/pmpg/)

Box 1: Operation Phakisa

Climate change: Risks and vulnerability

It is now widely accepted that climate change is affecting South Africa's coastlines and oceans, with serious implications. For example, the Agulhas Current is strengthening and warming, and is predicted to shift even further offshore as a result of climate change (Lutjeharms & de Ruijter 1996). On the west coast, the intensity of the Benguela Current upwelling system is expected to increase as a result of increased wind stress in the region (Lutjeharms et al. 2001). Weather patterns are also changing with droughts, wind- and rainstorms becoming more severe (James & Hermes 2011). Sea level has already begun rising along South Africa's coastline, posing a major threat to the country's coastal cities (Theron 2011). Carbon dioxide levels continue to increase, resulting in ocean acidification which, in turn, impacts coral reefs and shell-forming organisms like mussels and oysters (Orr et al. 2005). Elevated ultra violet (UV) radiation and water temperature are further impacting coral reefs through bleaching (Celliers & Schleyer 2002).

The primary risks associated with climate change in the marine environment include (1) **changes in local physical processes**, such as upwelling or the formation of Agulhas Current rings; (2) **altered freshwater inflow**, as a result of changes in rainfall patterns; (3) **altered water properties**, caused by increased seawater temperature, increased UV radiation, ocean acidification, increased sediment suspension, etc.; (4) **the destruction of habitats**, such as estuaries, mangroves, beaches, and coral reefs due to sea level rise, increased intensity of storms, UV radiation, and ocean acidification; (5) **damage to the man-made environment** due to an increased intensity of coastal storms, sea level rise, and coastal flooding. These risks all carry various implications (see Figure 12.1), many of which have already been observed in South African coastal and marine ecosystems (Sink et al. 2012).

Human-induced environmental change: Risks and vulnerability

In addition to climate-related change, human activities also have a major direct impact on the country's coastlines and oceans, with a vast array of implications impacting on the ecosystem services which they provide (see Figure 12.2). Of the human activities along our coastline, the over-exploitation of marine and coastal resources – from fish and invertebrates, to minerals and oil – has arguably the strongest negative impact. More than 630 marine and coastal species are currently exploited in South Africa through commercial, subsistence and recreational fisheries. Of these species, only 6% (41 species) have up-to-date stock status reports, and more than half of these (25 species) are considered over-exploited (Sink et al. 2012). Over the next ten years, oil and gas exploration on South Africa's continental shelf will significantly increase, with potential risks of habitat destruction and pollution if not regulated and managed appropriately (see Box 1).

While over-exploitation represents the biggest threat to the marine environment, coastal development poses a significant risk to South Africa's coastline. Up to 70% of the country's coastline is currently developed, with additional future developments planned (Sink et al. 2012). Freshwater abstraction (i.e. the removal of freshwater from rivers upstream) in the form of dams or irrigation schemes, directly impacts freshwater delivery to the coast. This results in significantly less freshwater reaching estuarine and coastal environments, with knock-on effects to biota (Whitfield 2005). According to the National Biodiversity Assessment 2011 (Sink et al. 2012), there has been a 40% reduction in freshwater flow from the country's 20 largest catchments to its estuaries and coastal zones.

Furthermore, pollution – an all-encompassing term referring to waste products that are continually pumped into oceans or dumped on beaches – also has a detrimental impact on coastal and marine organisms and ecosystems in South Africa.

The risks associated with human activity include (1) **the decline in marine and coastal species**, as a result of over-fishing and indiscriminate fishing techniques; (2) **altered freshwater inflow**, due to river abstraction in, for example, the catchment areas; (3) **altered water properties and water quality** caused by pollution and coastal development; and (4) **the destruction of habitat**, a major risk associated with all human activities – from unregulated and unsustainable resource exploitation and river abstraction, to pollution and coastal development.

Critical trends: South Africa's coasts and oceans

Climate change and human-induced environmental change do not impact on the South African marine and coastal ecosystems in isolation. Typically, one aggravates the other. Climate change is adding increasingly more pressure to coastal and ocean ecosystems, and the ability of the South African marine environment to (1) withstand the impacts of climate change and other environmental perturbations; and (2) to continue to provide us with its resources, will be determined by the overall health of the marine environment. Over-exploitation of marine resources and increased coastal development will reduce the health of South Africa's marine environment, and, consequently, the ability of our coasts and oceans to endure the impacts of continued climate change. Below are three examples of critical trends caused by the impact of global change on South Africa's coastlines and oceans.

Example 1: Coastal development and our ability to withstand storm surges and sea level rise

The increase in frequency and intensity of coastal storms, as a direct result of climate change, has already caused substantial damage and destruction along the South African coastline. For example, the storms of 19 March 2007 (Durban) and 31 July 2008 (Cape Town to Port Elizabeth) saw severe coastal flooding and erosion, with property damages exceeding R1 billion as well as a number of lives lost (Smith et al. 2013; DEA 2015). Storm surges are becoming more and more frequent – where they used to occur only every 20 years, storm surges in the Cape were reported for 2001, 2002 and 2008 (Brundrit 2009).

Coastal development covers 70% of South Africa's coastline, and communities living in these areas are extremely vulnerable to increased frequency and intensity of storm surges as well as sea level rise (Sink et al. 2012). Ironically, it is the fact that these coastal areas are developed that makes them more vulnerable to storm surges – coastal development results in the degradation of the natural coastal habitats and ecosystems, thereby reducing their ability to buffer the impacts of high seas (O'Connor et al. 2009). In addition to storm surges, sea level rise is already being observed along the South African coastline, with an increase of 1.2 mm per year over the last three decades (Brundrit 1995; Theron 2011).

One of the major causes of local sea level rise is the heating and expansion of the Agulhas Current. Areas along South Africa's coastline that have been identified as vulnerable to sea level rise include northern False Bay, Table Bay, Saldanha Bay, the Southern Cape coast, Mossel Bay to Nature's Valley, Port Elizabeth, and developed areas along the KwaZulu-Natal coast (Palmer et al. 2011; Theron 2011). In order to ensure that we are able to mitigate the impacts of increased storm surges and sea level rise, it is essential for coastal development to be managed properly. The Coastal Vulnerability Index (CVI), developed by Palmer et al. (2011), can be used to identify vulnerable areas along our coastline and help improve our ability to predict and respond to future high sea events. Furthermore, it is recommended that our coast's resilience to climate change be strengthened through the conservation and rehabilitation of key buffering ecosystems, including beaches, dunes, estuaries, mangroves and wetlands (Sink et al. 2012). In turn, these coastal ecosystems will provide other important ecosystem services, such as water filtration, nutrient cycling, as well as nursery grounds for many fish species. Ensuring that coastal ecosystems are well managed and conserved, will benefit the South African society as a whole.

Example 2: Combined effects of drought and freshwater abstraction: Reduced freshwater inflow to the coasts

The latest National Biodiversity Assessment 2011 (Sink et al. 2012) indicates that freshwater delivery to the marine and coastal environment has been reduced by more than 11 300 million m^3/year. This is primarily due to water abstraction in the form of dams and irrigation schemes along South Africa's major rivers, but also as a result of reduced rainfall. It has been predicted that, as climate change continues, severe droughts will occur more frequently throughout large areas of South Africa. The western part of the country will be most strongly affected, altering the necessary flow of freshwater into estuaries and coastal ecosystems (Engelbrecht et al. 2011; Engelbrecht et al. 2009). It has been predicted that the freshwater run-off from rivers on the southern and western coasts of South Africa will be reduced by 11-84% in the future (Clark et al. 2000)[1]. This will greatly intensify the impacts of reduced freshwater delivery to our estuaries, lagoons and wetlands.

Sufficient freshwater delivery is essential as it aids in structuring the physical habitat and also provides the nutrients to the ecosystem that are necessary to support productivity and sustain food webs (Taljaard et al. 2009; Turpie et al. 2002; Whitfield 2005). Freshwater inflow also helps to provide nursery grounds for fish and invertebrates, and triggers environmental cues used in the life cycles of certain species (Whitfield 2005). The impact of freshwater inflow can extend offshore by as far as 40 km or more, rendering freshwater delivery as an important component – not only of estuaries, lagoons and wetlands, but also of coastal and marine ecosystems. Reduced freshwater inflow has even been associated with a decrease in the number

1 Though not pertinent to this example, which looks at the impacts of drought, the eastern part of South Africa is predicted to experience more rainfall, with increased frequency and severity of storms.

of catches of certain line fish species, prawns, sole, cob, mussels and red bait (Demetriades et al. 2000; Lamberth et al. 2009; Porter 2009).

The majority of estuaries along the South African coastline are naturally closed off from the sea – typically by a sand bar across the river mouth – and periodically breach during floods and storm surges (Whitfield 1998). Although small in size, these estuaries play a vital role by number, acting as nurseries for many commercially important fish and invertebrate species harvested in the marine environment. Water abstraction and drought will reduce the frequency of breaching events, counteracting their role as nurseries and, in turn, compromise the sustainability of fisheries in general. It is, therefore, essential that the freshwater inflow requirements of the coastlines and oceans are taken into account in the allocation of freshwater resources (Turpie et al. 2002). This will go a long way toward ensuring the resilience of our marine and coastal ecosystems, as well as their continued ability to support productive fisheries.

Example 3: Pressures on South African fisheries

The risks described above, as well as numerous others also associated with climate change, will impact South Africa's marine habitats – ranging from estuaries and sandy beaches, to the pelagic open ocean (Clark 2006). These habitats support a vast array of fish stocks and fisheries (harvesting of, for example, rock lobster, abalone and line fish) that are represented by commercial, recreational and subsistence fishing sectors[2]. Fish stocks and fisheries associated with South Africa's marine habitats will thus also be affected by climate change (DEA 2013). However, it is the fisheries themselves that currently have the greatest impact on the resilience of our marine and coastal ecosystems (Sink et al. 2012).

Key issues in the fisheries sector include over-exploitation, by-catch, incidental seabird mortalities, habitat degradation, and disruption of population structures and food webs. The stock status is known for about 6% of the 630 harvested marine species. Of that, 61% are considered to be over-exploited (Sink et al. 2012). This is an unstable position for these species and associated fisheries, as the resilience of the populations may have already been compromised, reducing their adaptive capacity to the expected climate change. The lack of data for the remaining 94% of harvested species, is equally alarming (Sink et al. 2012). It is highly likely that many more harvested species are over-exploited and their fisheries unsustainable. Although the commercial fisheries are often blamed for over-exploitation, it should be noted that the recreational and subsistence sectors have also contributed to the unsustainable harvesting of many species, in particular the reef-associated species.

In order to ensure stock recovery and long-term food and job security, adequate management interventions (based on scientific data from robust stock assessments) need to be implemented. The inadequacy of traditional single-species fisheries management practices are recognised globally, and managers are moving toward more holistic ecosystem-based principles such as Marine Protected Areas (MPAs). To date, South Africa has made a considerable effort toward establishing a network of MPAs. However, the existing network is not comprehensive and needs to be strategically expanded in order to protect critical fish habitats such as spawning aggregations and nursery areas – both in coastal and offshore environments. The recovery of over-exploited fish stocks will be slow, but if the critical issues are attended to and the management recommendations implemented effectively, over-exploited fish stocks can recover to provide long-term food and job security (Sink et al. 2012). For the 94% of species that we do not have stock assessments for, considerable efforts need to be made to gather sufficient data in order to assess each stock's status.

Our future: The value of scientific research and long-term monitoring

Although it is essential to understand how global change can alter South Africa's coastlines and oceans, as well as its knock-on effects on ecosystem services, there are still numerous knowledge gaps that limit our ability to accurately predict the impact of global change (James & Hermes 2011; Sink et al. 2012; DEA 2013). However, through coordinated and comprehensive research and monitoring programmes (see the Algoa Bay Case Study), South Africa's scientists can provide valuable information for decision-makers. This information can be used to guide policy development in order to protect and conserve our country's oceans and coastlines, to utilise its resources sustainably, and to aid in the improved health, safety and security of our people. By simply improving our understanding of how our coastlines and oceans respond to global change, we can empower our country with the ability to predict and adapt to future changes.

2 Fisheries are estimated to contribute R2,5 billion to South Africa's Gross Domestic Product (GDP) annually.

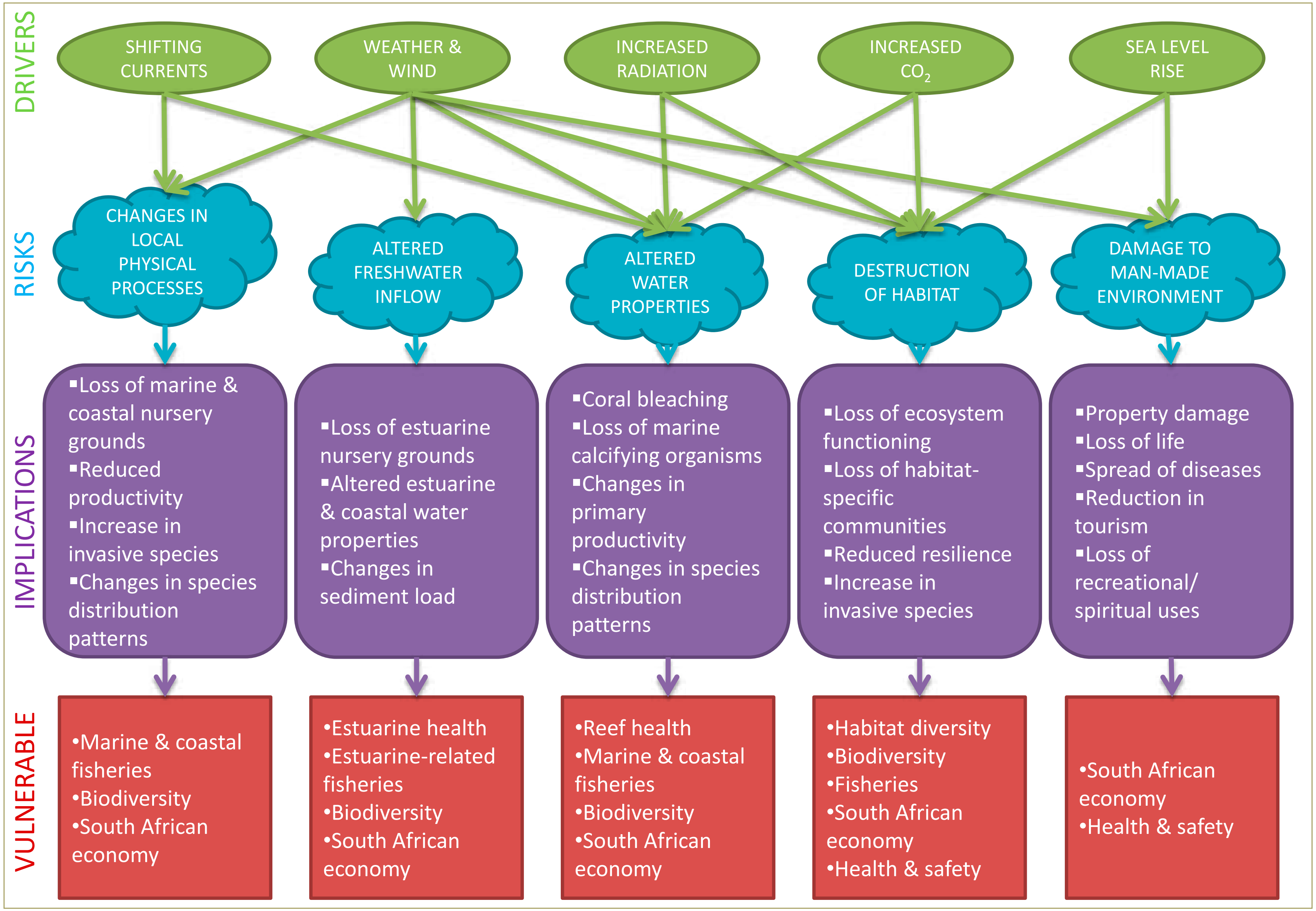

Figure 12.1 Flow diagram showing connections between climate change drivers, risks associated with those drivers, implications of those risks, and aspects of the marine and coastal environment that are vulnerable to those implications

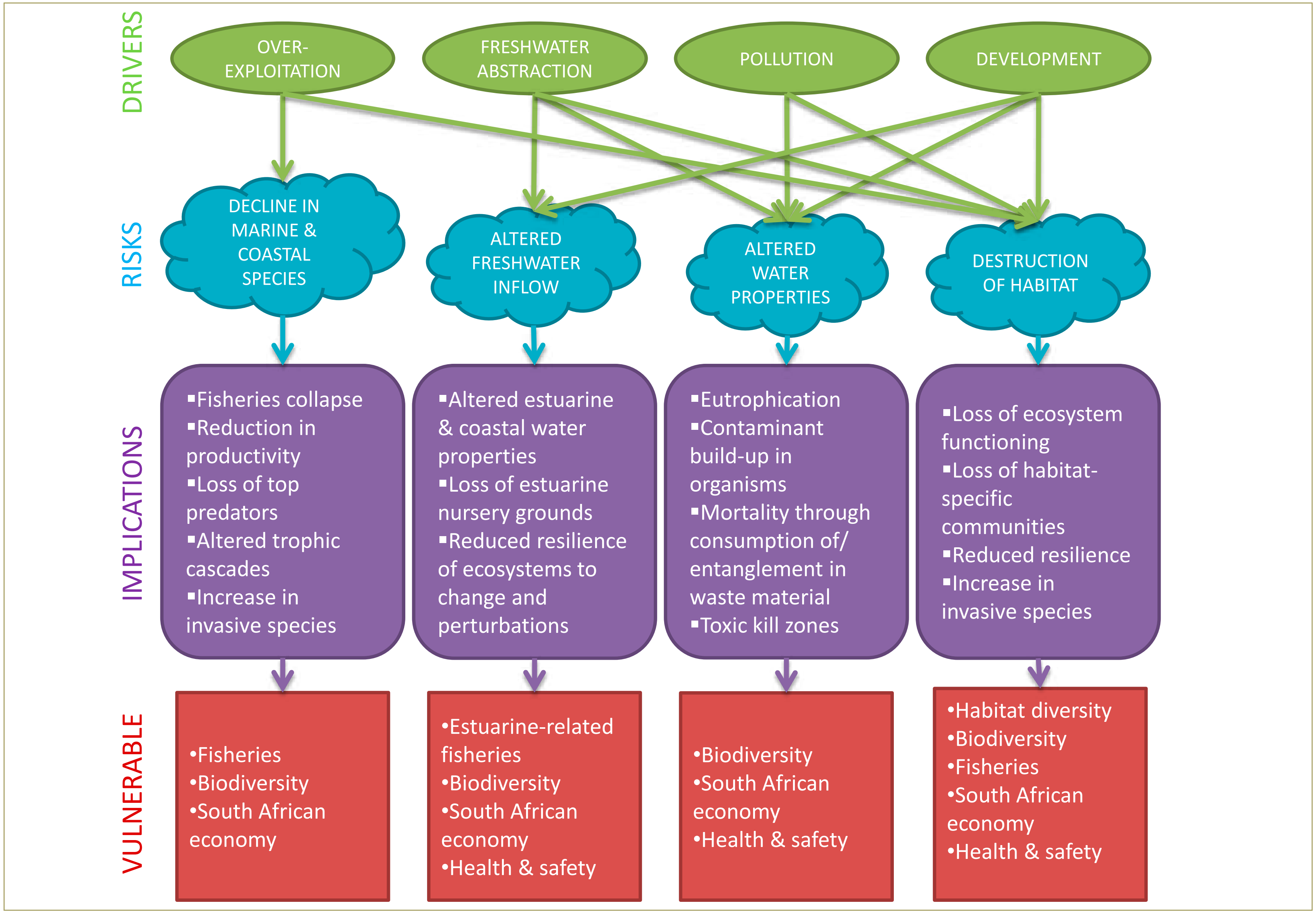

Figure 12.2 Flow diagram showing connections between anthropogenic drivers, risks associated with those drivers, implications of those risks, and aspects of the marine and coastal environment that are vulnerable to those implications.

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Case Study

Algoa Bay – building a sentinel site for long-term environmental observation

Tommy Bornman[1], Wayne Goschen[2], Andre Theron[3], Eileen Campbell[4] and Paul Cowley[5]

Understanding how global change will alter the coasts and oceans of South Africa requires the monitoring of multiple components of the different ecosystems. However, due to the associated costs of long-term ecological research, collecting data for the entire coastline is not feasible. Sentinel sites, situated at key locations, are an alternative option and have the ability to provide insight into real time changes associated with global change. Algoa Bay, on the Eastern Cape coastline of South Africa, is one such sentinel site.

Algoa Bay offers significant opportunities for integrated socio-economic and ecological long-term monitoring and research. The bay supports a metropolitan area, the Nelson Mandela Bay Municipality, with a population of over 1 million people, two harbours, and a large industrial area. It contains nearly all the different temperate coastal habitat types, including sandy beaches, permanently open and temporarily open/closed estuaries, rocky shores, sub-tidal reefs, sub-tidal soft sediments, coastal dune fields, headland bypass dune fields, two island groups, and the eastern Agulhas Bank continental shelf ecosystem.

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Furthermore, Algoa Bay includes conservation areas such as the Bird Island Marine Protected Area, as well as the proposed marine and coastal extension of the Addo Elephant National Park. In addition, Algoa Bay is particularly susceptible to climate change due to the following reasons:

- An increase in wind stress curl in the South Indian Ocean, which is due to a poleward shift of westerly wind in the Southern Hemisphere, has caused the sea surface temperature and volume flow of the Agulhas Current to increase (Rouault et al. 2009). Algoa Bay lies adjacent to the Agulhas Current and is thus directly influenced by these changes.
- With this increase it has been shown that coastal and shelf waters of the eastern Agulhas Bank are cooling (Rouault et al. 2009). However, preliminary data (5 years) from *in situ* instruments in Algoa Bay (see Figure 1) indicate a positive trend of increasing temperatures (0.3 °C to 2.7 °C ± 0.8 °C) throughout the water column.
- It is also predicted that the frequency of large episodic meanders in the Agulhas Current ('Natal Pulses') will increase (Lutjeharms & de Ruijter 1996), causing more current-driven upwelling events and an increased number of warm Agulhas Current surface intrusions into the coastal zone of Algoa Bay (Goschen et al. 2012). The increased ocean variability could reduce biodiversity.

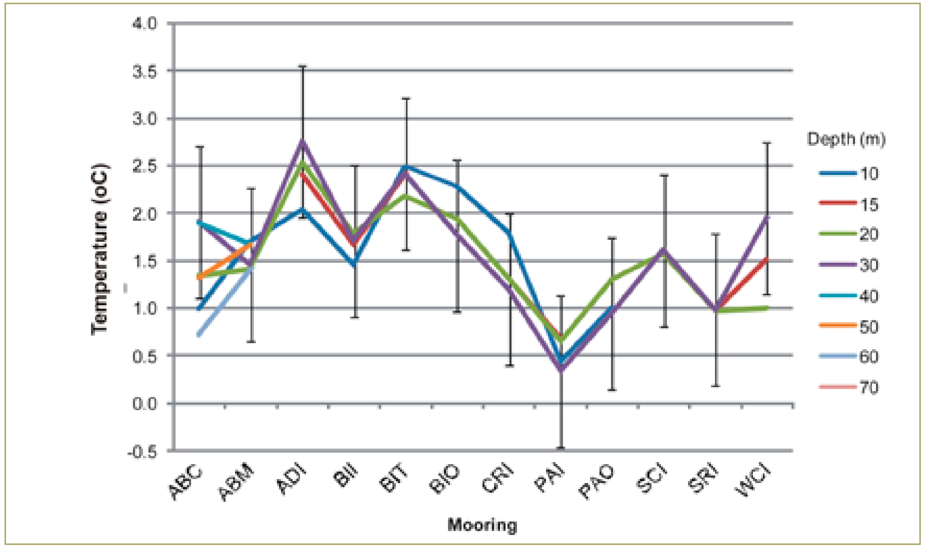

Figure 1 Underwater temperature recorder data averaged over 5 years from SAEONs Algoa Bay thermistor string array

- An increase in the South Atlantic and South Indian Ocean high pressure systems leads to an increase in the easterly wind component in the subtropics (Rouault et al. 2009), and, hence, create more local wind-driven upwelling (Schumann 1999). Increased and prolonged upwelling – although an important source of nutrients to the bay – will increase variability that could, in turn, reduce biodiversity.
- Most of the coastal area is low-lying and threatened by the predicted rise in sea level that will flood and displace estuarine wetlands and lowlands, cause salinity intrusion of estuaries and aquifers, and result in progressive shoreline and habitat erosion.
- For salt marshes to survive rising water levels, they must be able to accrete at such a rate that surface elevation gain is sufficient to offset the rate of water level rise (Cahoon et al. 1995). A possible reduction in mineral sediment input from the catchment and the sea, may cause these estuaries to drown. Figure 2 shows the relative sea level rise rates in the Swartkops Estuary since 2009. The results indicate that three of the RSET[6] stations (2, 3 and 6) show an elevation rate deficit, i.e. sea level is becoming higher in relation to the salt marsh (assuming a 1.48 $mm.y^{-1}$, sea level rise rate in Port Elizabeth (Mather et al. 2009)). These preliminary results indicate that the lower and middle reaches of the estuary will in all likelihood 'drown' as the sea levels continue to rise.
- The combined effects of sea level rise, and possibly increased sea storms, will lead to an increased occurrence and magnitude of extreme inshore seawater levels and, consequently, flooding impacts that could breach existing storm protection measures if these are not reinforced or enhanced.
- Increased wave energy, current, and wind velocity have the potential to increase sediment transport and could lead to the erosion of beaches.
- Reduction in rainfall will result in reduced freshwater supply (Arnell 1999; Clarke et al. 2000) to the marine environment and to estuaries, thereby altering estuarine mouth dynamics and reducing their productivity and nursery function.

6 Rod Set Elevation Table

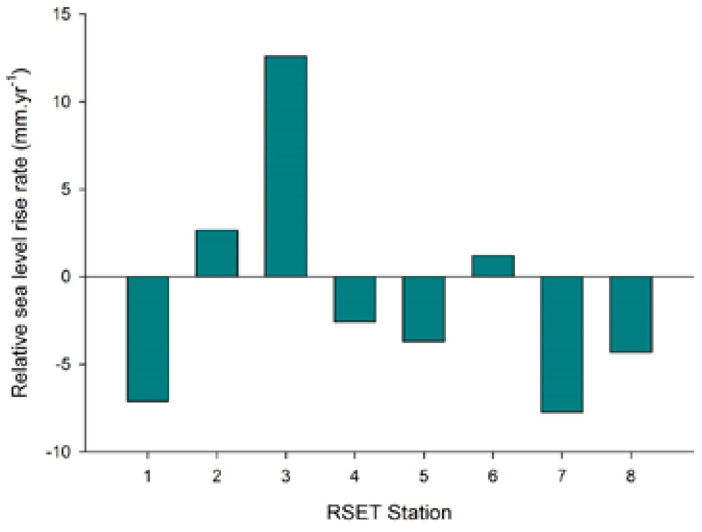

Figure 2 Relative sea level rise rate at 8 RSET stations in the Swartkops Estuary from 2009 until 2014

Between SAEON[7], SAIAB[8], CSIR[9], SANHO[10], SAWS[11], NMMU[12] and DWA[13], over 80 *in situ* instruments have been deployed in Algoa Bay (see Figure 3). These instruments are measuring weather variables, river flow, estuarine salinity and temperature, sediment accretion (using RSETs), sea level, ocean currents, waves, ocean temperature/oxygen/pH/salinity/Photosynthetic Active Radiation/fluorescence/turbidity, and animal (fish/shark/penguin/cetacean/turtle, etc.) movement patterns.

In addition to the *in situ* instruments, SAEON conducts monthly pelagic ecosystem monitoring (physico-chemical, phytoplankton, zooplankton and ichthyoplankton sampling) at eight stations that are spread throughout the bay (PELTRM[14] stations in Figure 3). NMMU also conducts long-term monitoring of surf-zone ecology and groundwater along the Alexandria dune field and rocky shore ecology of the islands.

7 South African Environmental Observation Network

8 South African Institute for Aquatic Biodiversity

9 Council for Scientific and Industrial Research

10 South African Navy Hydrographic Office

11 South African Weather Services

12 Nelson Mandela Metropolitan University

13 Department of Water Affairs

14 Pelagic Ecosystem Long-Term Research and Monitoring

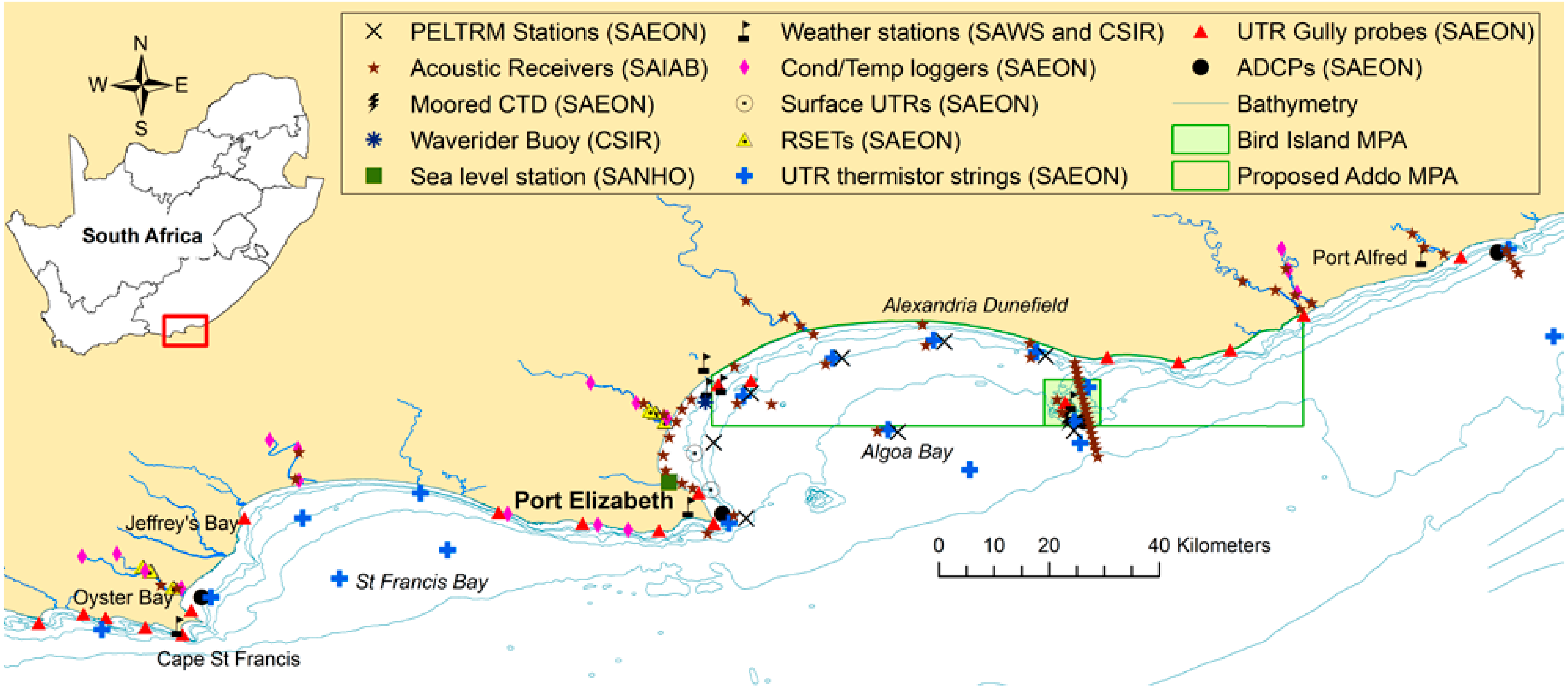

Figure 3 The Algoa Bay sentinel site

Although the current monitoring network is the most comprehensive in Africa, additional systematic long-term ecological research is required to increase our understanding of biophysical or ecosystem functioning, and to capture any trends and/or changes. These include ocean acidification measurements, offshore deep moorings on the eastern Agulhas Bank (with surface weather stations), wave recordings outside of the bay, shoreline topography (either comprehensive beach profile surveys or Lidar), comprehensive coastal sediment sampling, and inshore bathymetry.

The considerable monitoring effort in Algoa Bay will deliver long-term reliable data for scientific research that will assist decision makers to formulate appropriate environmental policies which will, in turn, lessen Algoa Bay's overall risk and vulnerability to climate and global change. The long-term observation network in Algoa Bay will function as a living laboratory and reference site that will enable us to detect, translate and predict environmental change in the coastal environment of South Africa in general.

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CHAPTER 13

Disaster management and risk reduction in South Africa

Ané Bruwer,[1] Mark van Staden,[1]
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Introduction

The 2015 Global Assessment Report on Disaster Risk Reduction concludes that the mortality and economic loss associated with extensive risks (minor but recurrent disaster risks) in low- and middle-income countries are trending up. In the last decade, losses due to extensive risk in 85 countries and territories were equivalent to a total of US$94 billion. Extensive risks are responsible for more deaths and displacement than major disasters, and represent an ongoing erosion of development assets such as houses, schools, health facilities, roads and local infrastructure. However, according to the cost of extensive risk is not visible and tends to be underestimated, as it is usually absorbed by low income households and communities as well as small businesses (UNISDR 2015).

These trends are evident in South Africa, too, where society is not only occasionally exposed to severe disasters, but also frequently exposed to a wide range of minor but recurrent natural hazards, including drought, floods, fires, cyclones and severe

1 National Disaster Management Centre
2 Council for Scientific and Industrial Research (CSIR) – Built Environment

storms that can trigger widespread hardship and devastation for the most vulnerable. The negative impact of these extensive risks leaves the country to deal with issues such as a loss of lives, damage to infrastructure and the environment, and disruptions in livelihoods, schooling and social services. Furthermore, scarce resources are often diverted for disaster relief at the expense of long-term growth and development opportunities, resulting in the worsening of the plight of poverty-stricken communities (Wisner et al. 2004; Parnell et al. 2007; Collins 2009). Climate change, urbanisation and other socio-economic, demographic, physical and environmental global processes magnify existing vulnerabilities to disasters due to changing patterns of some hazards in specific regions (such as heatwaves, droughts and increased precipitation), and due to increased population exposure and land-use changes (Scholes et al., 2008; Collins 2009; FAO 2009; IPCC 2012). As such, disaster risk poses an increasing threat to poverty reduction and sustainable development should the necessary disaster risk reduction measures not be actively applied.

This chapter reflects on disaster management and risk reduction in South Africa and analyses fire hazards as a case study. The number of lives lost and injuries sustained in South Africa due to fires is alarming. Statistics South Africa, in a 2014 analysis of the cause of death in the country based on death certificate records, attributed 2 227 deaths to smoke, fire and flames in 2013 alone (Stats SA 2014: 40). Determining disaster risks, and understanding their potential impact on people and assets, are fundamental elements in guiding development that is more resilient and sustainable.

Terminology and definitions

The terminology on disaster management published by the United Nations Office for Disaster Reduction (UNISDR) defines a 'hazard' as a dangerous phenomenon, substance, human activity or condition 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. In proposed amendment legislation that is currently being considered in the South African Parliament to align its definition better with the UNISDR, a 'disaster' is defined as a serious disruption or a threatening disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceed the ability of the affected community or society to cope using its own resources. 'Risk', on the other hand, is the combination of the probability of an event and its negative consequences, while 'vulnerability' arises from various physical, social, economic, and environmental factors (UNISDR 2009).

Disaster management and risk reduction in South Africa

The primary responsibility for disaster management and risk reduction in South Africa rests with Government as identified in the Constitution (RSA 1996). The *Disaster Management Act (No. 57 of 2002)* (DMA) and the National Disaster Management Framework (NDMF) are the centrepiece legislation regulating the provision of disaster management services (RSA 2002, 2005). The aim of the DMA is to ensure a uniform and integrated approach to disaster management and disaster risk reduction in each and across all spheres of government involving all relevant stakeholders. The NDMC was established to promote this integrated and co-ordinated system of disaster management with the emphasis on risk prevention, reduction and mitigation (RSA 2002).

Essentially, the focus of the DMA is fourfold:

1. It establishes an elaborate institutional framework for disaster management, including the establishment of disaster management centres across the three spheres of government;
2. It entrenches a detailed policy development and strategic planning framework for disaster management;
3. It provides for the classification and declaration of disasters; and
4. It deals provisionally with the funding of post-disaster recovery and rehabilitation.

In the South African context, 'disaster management' is a comprehensive term defined in the DMA as 'a continuous and integrated multi-sectoral, multi-disciplinary process of planning and implementation of measures aimed at:

(a) preventing or reducing the risk of disasters;

(b) mitigating the severity or consequences of disasters;

(c) emergency preparedness;

(d) a rapid and effective response to disasters; and

(e) post-disaster recovery and rehabilitation' (RSA 2002).

One of the key features of the DMA is that it recognises that the function of disaster management cannot be done by national government alone. It requires cooperation and collaboration on the part of all spheres of government, civil society and the private sector. These include public awareness programmes, early warning systems, effective land use planning, conducting disaster risk assessments, and institutional arrangements to facilitate effective coordination. Furthermore, although disaster preparedness measures for more efficient rescue operations will always remain necessary, there is common agreement that much greater attention should be directed to the introduction of preventive strategies aimed at saving lives and protecting assets before they are lost. In line with international trends and national objectives of efficient and effective management of the nation's resources, South Africa's disaster management policy and legislation underscores the importance of preventing human, economic and property losses, and avoiding environmental degradation. The 2002 Act and 2005 Framework provide a well-developed legislative framework to guide and support disaster risk reduction, and to manage those disasters that do occur (RSA 2005; van Niekerk 2007). Other sector legislation and policies also support disaster risk reduction. The *National Climate Change Response White Paper* outlines government's vision for building South Africa's resilience to climate change and promotes the mainstreaming of climate change considerations and responses into all relevant sector planning instruments (RSA 2011). Amendments to the existing legislation also emphasise the importance of incorporating expected climate change impacts and risks as well as identifying and mapping risks, areas, ecosystems, communities and households that are exposed and vulnerable to physical and human-induced threats, into disaster management planning.

Determining current disaster risk

Historical data on hazards is crucial in determining the risks of a given geographic area. The data provides insight into the frequency of the hazard type, and, if coupled with data surrounding the magnitude of the historical incidences (hazard assessment) as well as data on vulnerability (vulnerability assessment), the risk for a disaster in a certain area can be determined (R = H x V, where R stands for risk, H for hazard, and V for vulnerability). (UNISDR 2009).

To determine the disaster risk for South Africa, the NDMC sources cumulative historical data annually from EM-DAT[1], CAELUM[2] and SRS[3] in order to compile a combined hazard index. The CAELUM data are derived from historical weather-related events between 1647 and 2014, as kept by the South African Weather Service (SAWS). The EM-DAT data range from 1920 to 2014. Although this data provide insight into losses and severity, it only accounts for events of a major international magnitude, not capturing minor events. The SRS data (1990 to 2014) are compiled by disaster management stakeholders engaging the NDMC Situation Reporting System[4].

Figure 13.1 is an index of historical events, and indicates that South Africa is primarily exposed to natural hazards of a weather-related origin. The most frequently occurring sudden onset hazards are related to flooding and fires, followed by wind, hail, snow and heavy rain. The index is however not as accurate an indicator of slow onset or creeping events such as drought or an epidemic, which seem to occur less frequently, but cause great losses due their extent, intensity and duration (García-Acosta 2002). Creeping hazards are much more difficult to define, i.e. start and finish, and to measure the extent and impact over time and space.

South Africa, as many other developing countries, suffers significant losses from natural and human-made hazards. Between April 2010 and 31 March 2012, the NDMC classified and recorded disasters that cost the national government more than R3 billion in contributions to post-disaster recovery and rehabilitation projects[5]. This amount excludes expenditure on immediate relief. Disaster losses divert public spending away from development to disaster relief and reconstruction. This is set to

1 Since 1988, the WHO has been maintaining an Emergency Events Database (EM-DAT) through the Centre for Research on the Epidemiology of Disasters (CRED).

2 CAELUM is a database of extreme weather events sourced from the South African Weather Service (SAWS).

3 The Situation Reporting System (SRS) database is hosted by the NDMC and populated by disaster management stakeholders.

4 Attempts to minimise replication across agencies, rectification of reporting errors, and quality control have been made. However, these data constraints still need to be considered in the interpretation of findings as the construction of these datasets lies outside the influence of the NDMC.

5 Also see Research Alliance for Disaster and Risk Reduction (RADAR) data inventories on disaster risk losses (University of Stellenbosch).

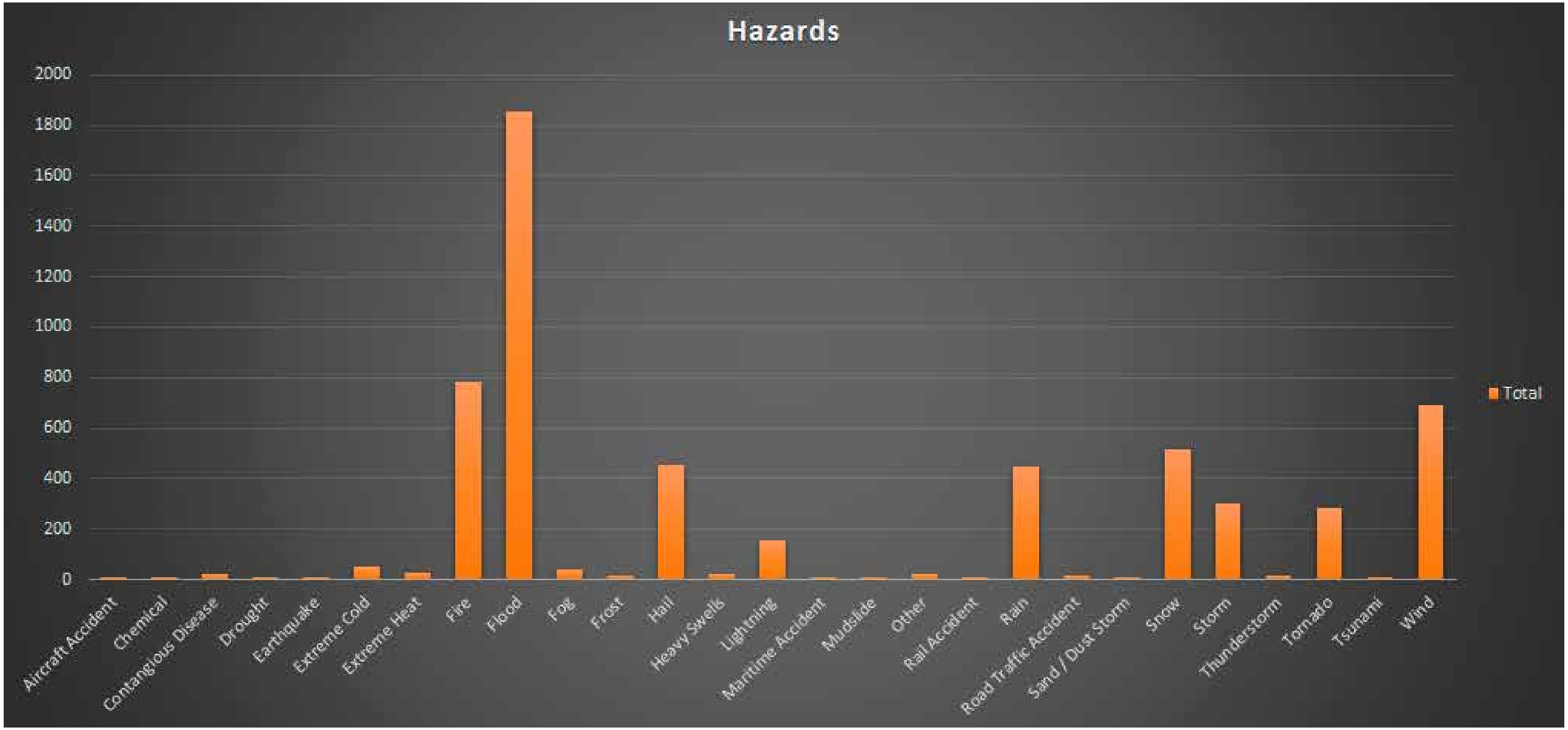

Figure 13.1 Number of events captured by SRS (NDMC) and Caelum (SAWS) databases (1647–2013) by hazard type and by province. (Source: CAELLUM 2014; SRS 2014)

increase exponentially in the future due to climatic changes – especially for weather-related hazards, which pose major threats to various communities in South Africa.

Case Study: Indicative risk profile hazard analysis for fire

Since 2011, the NDMC has undertaken a number of risk-profiling activities at national scale. The outputs of these indicative risk profiles aim at providing insights into the nature of the various hazards being analysed. Additionally, vulnerability and capacities assessments augment the hazard assessment and culminate into a risk profile specific to individual hazards. Indicative risk profiles have been conducted for the most prevalent hazards in South Africa. They include fires, floods, drought, windstorms and snow. Recent partnerships with strategic entities with intrinsic hazard and risk knowledge, has resulted in the NDMC gaining valuable support from local scientific and research institutions, leading to a more scientific and robust national product.

Since fire hazards frequently contribute to significant losses in lives, property and the economy, it was selected to illustrate risk profiling in this chapter. Like many other countries, South Africa is exposed to significant fire risks that are slightly above the international norm in terms of fire deaths per 100 fires (DCoG 2013). Outputs from the updated indicative risk profile hazard analysis for fires (2015) can be observed below. This desktop exercise using geographic information system (GIS) technology characterises fire hazards in terms of frequency, magnitude, predictability and likelihood. The red and orange areas on the maps depict areas with a high and elevated hazard scoring, thus indicating a high risk profile. Yellow represents areas with a medium hazard scoring, and light and dark green illustrate those areas with a below average and low hazard scoring (i.e. areas with a low risk profile). Due to the nature of fires and its dependency on weather, a seasonal aspect has been used.

In the summer months (December to end February), the hazard rating for fires is nationally at its lowest. However, the south-western parts of the country experience an increase in hazard scores.

Autumn (March to end May) hazard scores increase further in the south-western parts of the country, with some interior increase in Gauteng and the Free State.

Winter (June to end August) hazard scores reach their peak in the north-eastern parts of the country (Mpumalanga and KwaZulu-Natal).

High scores remain in spring (September to end October) over the eastern parts of South Africa.

The indicative risk profile, when combined with medium-term weather forecasts, aims to provide disaster management stakeholders with information for operational, tactical and strategic planning related to future hazards and risks. Furthermore, it attempts to highlight areas where disaster risk reduction may be targeted in terms of

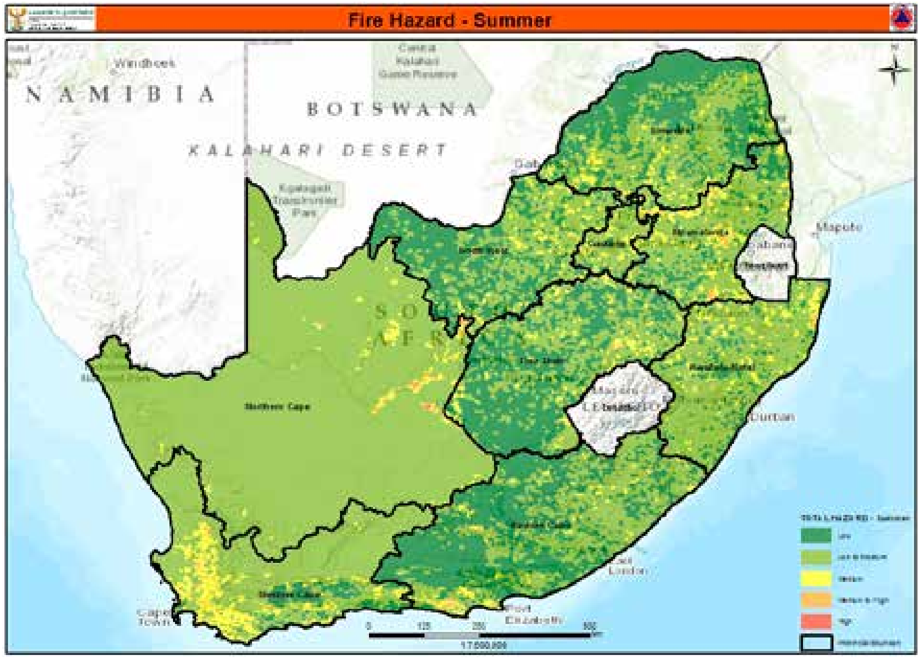

Figure 13.2 Indicative risk profile hazard analysis for fires during summer (NDMC 2015)

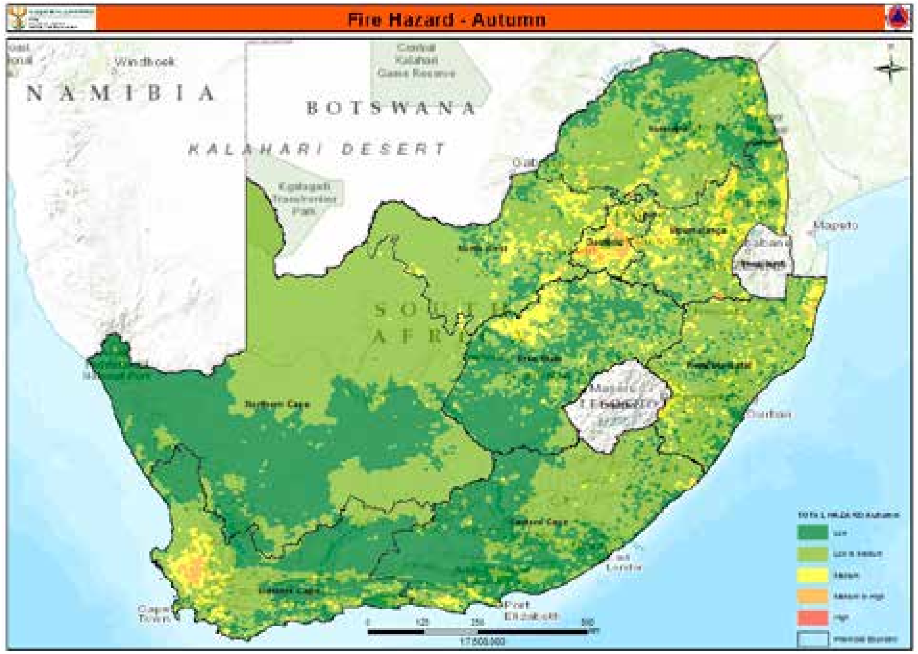

Figure 13.3 Indicative risk profile hazard analysis for fires during autumn (NDMC 2015)

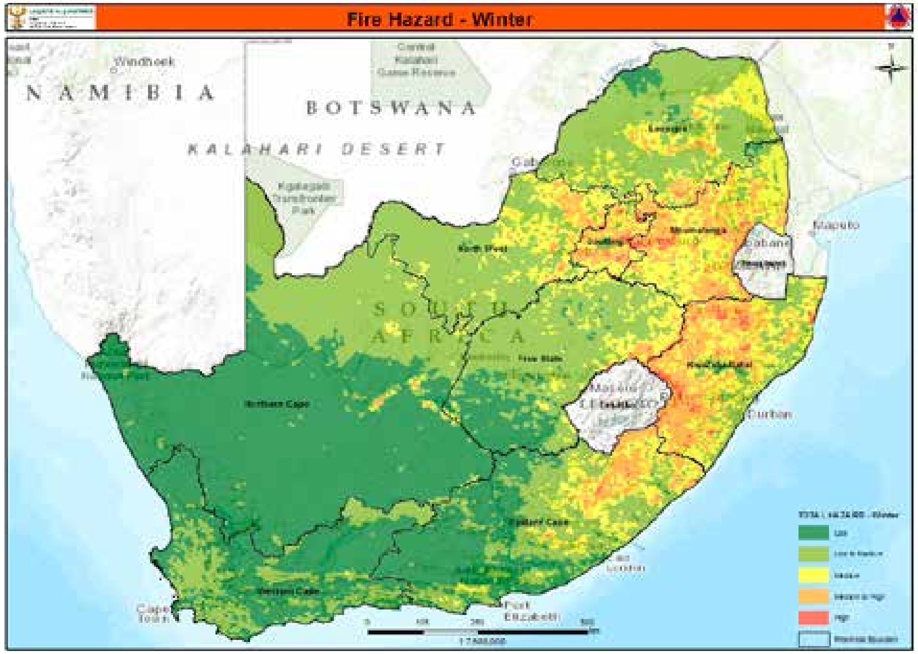

Figure 13.4 Indicative risk profile hazard analysis for fires during winter (NDMC 2015)

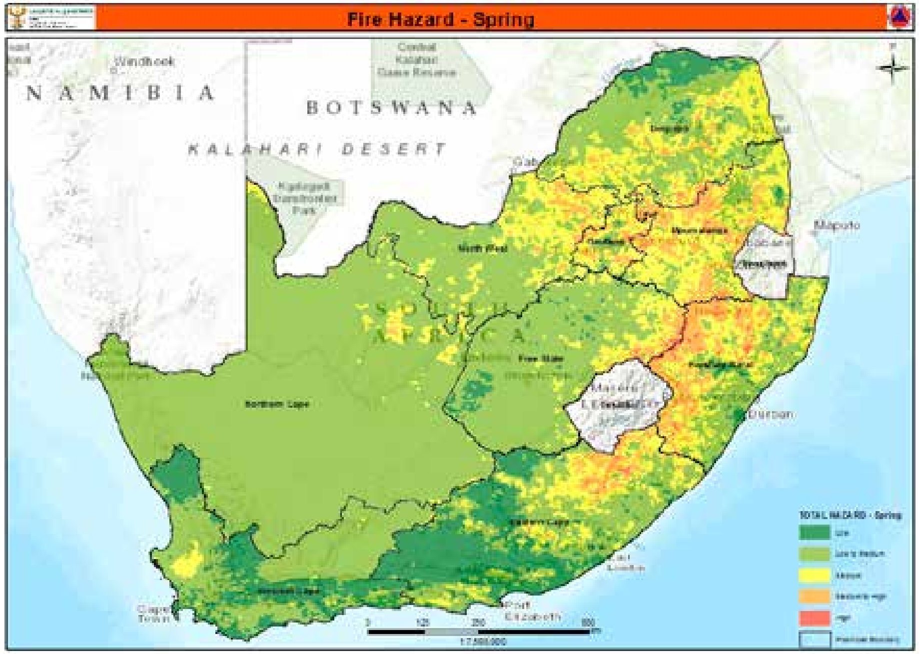

Figure 13.5 Indicative risk profile hazard analysis for fires during spring (NDMC 2015)

addressing social, economic or environmental vulnerabilities and/or limited capacities. Finally, the product aims to become a blueprint for the future standardisation of risk profiling in South Africa.

Conclusion

Various natural hazards pose a significant threat to urban and rural parts of South Africa, particularly when they exceed the capacity of communities to avoid, absorb or recover from these events. These hazards often result in the loss of lives and livelihoods, cause great devastation as well as financial losses, and can even result in the reversal of development gains. Fire hazards in particular are often occurring events that threaten many urban areas as well as agriculture and natural vegetation. A number of processes contribute to increase this hazard risk, including climate change that causes changing rainfall patterns, urbanisation that leads to more people living in informal settlements, and a loss in biodiversity that changes the veld fire ecology. There is a lot more that can be done to help reduce the risk of fire and other hazards in South Africa, and efforts are underway to manage the risk. The DMA has a distinct disaster risk reduction focus, which addresses the need for greater investment in prevention as well as mitigation actions that will avoid the need for expensive, and often repeated, assistance. In order to make a meaningful impact on reducing the physical, social and environmental costs of disasters in the country, rigorous planning needs to be done, ensuring that disaster management principles are incorporated in all planning and implementation efforts. Evidence and information on hazard zones, as was presented in this chapter, can assist in identifying the specific areas that ought to be targeted for disaster risk reduction measures.

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CHAPTER 14

Municipal vulnerability to climate change

Julia Mambo[1] and Miriam Murambadoro[1]

Introduction

South Africa, like the rest of Africa, is considered highly vulnerable to climate change and variability as well as to global change. Climate change is and will continue to be an issue of concern in the development of the country. South Africa faces increased frequencies of extreme weather events, such as floods, hailstorms, heavy rain and winds, veld fires, snow, dry spells and drought (DEA 2013a). This vulnerability is worsened by the interaction between the multiple non-climatic stressors that occur at various spatial scales (affecting geographical areas differently) and which have the potential to worsen vulnerability to climate and global change (DEA et al. 2012). Existing climatic risks in South Africa are a result of stressors resulting from social, economic and political processes that have generated challenges associated with service delivery, access to clean water, sanitation and energy, rapid urbanisation, increased poverty, land use transformation and diseases such as TB and those related to the HIV virus.

1 Council for Scientific and Industrial Research (CSIR) – Natural Resources and the Environment

Rural areas are particularly vulnerable due to their dependency on climate-sensitive resources such as water and agrarian landscapes, low adaptive capacity,[1] as well as their geographic location (Hunter 2007; Dasgupta et al. 2014). Urban areas are also vulnerable to climate change due to the high proportion of the population and economic activities centred there, as well as the large deficits in the provision of infrastructure and services that support climate change adaptation (Revi et al. 2014). A significant amount of greenhouse gas emission is also generated through urban-based activities. There is, however, a dynamic link between rural and urban areas with a back and forward flow of people, natural and economic resources between the two. South Africa faces an increased frequency in extreme weather events such as floods, hailstorms, heavy rain and winds, veld fires, snow, dry spells and drought (DEA 2013a). These have the potential to increase vector-borne diseases and lead to food, energy and water insecurity, which will consequently increase vulnerability and deepen poverty (DEA et al. 2012; DEA 2013b). The Second National Communication on Climate Change indicates that at least 30% of the country's population is vulnerable to climatic shocks and stresses.

Given that the impacts of both climate and global change will be felt at a local level; local governance and institutions, such as municipalities, are becoming key role players in mobilising resilience through different adaptation and response strategies (Mokwena 2009; FFC 2012a, 2012b) There is a need for planners and decision makers to move from reactive crisis management approaches to proactive climate change and disaster risk management approaches. Climate change governance plays a key role in creating an environment conducive for the appropriate climate change mitigation adaptation decisions.

Climate change is a complex global problem driven by competing anthropogenic and natural drivers that requires coordinated efforts by government, the private sector and civic society to increase the resilience of socio-ecological systems and to build the resilience of the affected population. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that in many countries, planning at all levels of society falls short of what is needed to respond to

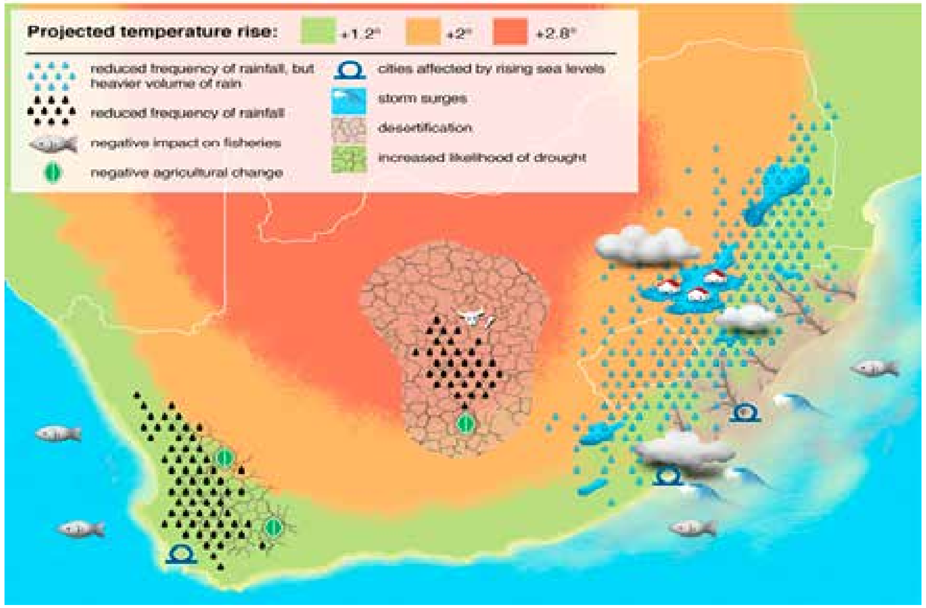

Figure 14.1 A simplified representation of climate change projections in South Africa (Source DEA 2012 LR)

climate change. Without effective implementable measures to reduce vulnerability, the risk of disasters will also increase and this has the potential to amplify the uneven distribution of risk between the poor and those with wealth (CDKN 2012).

In this chapter, we highlight the current climate hazards and the projected changes in climate and extreme weather events that will affect communities in the nine provinces and the role that the different tiers of government can play in supporting communities and businesses to respond to these projected changes in climate. The chapter includes a case study that illustrates some of the challenges faced by local government which hinder effective climate change mitigation and adaptation.

1 'Adaptive capacity' is used here to refer to the ability of a (human) system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Table 14.1 Climatic hazards in provinces and projected changes in climate as a result of climate change and climate variability

Province	Current hazards	Projected changes in climate and extreme weather events
Eastern Cape	Droughts, excessive rainfall and floods, tornadoes, fires, sea level rise and storm surges	• Increase in average temperature of 1–2 °C in the near future • Decrease in the household demand for energy for warming • Increased annual number of very hot days +20 days • More heat wave and high fire danger days • Eastern Cape to become generally wetter except Cape south coast • More extreme rainfall events • Dry years to occur more frequently
Free State	Excessive rainfall, floods and fires	• Increase in average temperature of 1–2 °C • Very hot days to increase by ±20 days per annum • To become generally wetter • Extreme rainfall events to increase (floods, hail) • Wet years to occur more frequently (increased flooding) • Dry years to occur more frequently, although a decrease in the frequency of such events is also possible
Gauteng	Excessive rainfall and floods (which exacerbate the sinkholes in dolomite areas), hailstorms, heat waves, fires, wind storms and droughts	• Increase in average temperature by 2 °C in the near future • Decrease in the number of days with frost • Increase number of hot days (35 °C) +20 days • Heat waves and fire danger • Decrease in annual rainfall • Increase in extreme weather events, thunderstorms, lightning, hail, flash floods and damaging winds • Wet years less frequent • Dry years more frequent
KwaZulu-Natal	Strong winds, thunder storms, droughts, tornadoes, excessive rainfall and flooding, sea level rise and storm surges	• Increase in average temperature of 1–2 °C in the near future • very hot days to increase +30 days per annum • To experience both wetting and drying • More extreme rainfall events • Wet years are plausible to decrease in frequency but could also increase • Dry years to occur more frequently
Limpopo	Thunderstorms, hailstorms, excessive rainfall and flooding, droughts, fires and outbreak of diseases	• Increase in average temperature of 1–2° C in the near future • Increased annual number of very hot days 20 days in the south and 50 days in the Limpopo valley in the north • Decrease in rainfall • increases and decreases in the frequency of extreme weather events • Wet years are likely to occur less frequently • Possible increase in the number of wet years for the Limpopo valley • Dry years to occur more often
Mpumalanga	Excessive rainfall and flooding, hail storms, windstorms, fires and outbreak of diseases	• Increase in average temperature of 1– 2° C in the near future • Decrease in the number of days with frost • Increase in the annual number of very hot days by 20–40 days • Decrease in annual rainfall up to 40 mm • Experience both wetting and drying • Increase in the number of extreme rainfall events- hailstorms, damaging winds, thunderstorms and flooding • More drier years
North West	Excessive rain and flooding, thunderstorms, wind storms	• Increase in average temperature of 1–2° C in the near future • Days with frost are likely to decrease in frequency • Increase in the annual number of very hot days 20–40 days • Increase in the number of heat wave and high fire danger days • To become generally drier in the east and wetter in the west • Both wetting and drying can be expected in all areas • More extreme rainfall events • Western parts projected to have more rainfall and increased incidences of flooding
Northern Cape	Strong winds, rain storms, drought and decreased rainfall (drying)	• Increase in average temperature of 1–2° C • Number of very hot days to increase by 20 to 40 days per year in the northern parts and 50 days per year in the far northern parts of the province • Increase in the number of heat wave and high fire danger days • To become generally wetter in the east and drier in the west • More extreme rainfall events (lightning, damaging winds) • Possible for both wet and dry years to occur more frequently
Western Cape	Sea level rise and storm surges, droughts, heat waves, reduced rainfall, fires, intense storms and diseases	• Increase in average temperature of 1–2° C • Number of very hot days to increase ±20 days/year • To become generally drier, especially in the winter rainfall region • Decrease in the number of extreme rainfall events, although an increase in the frequency of such events is also plausible. • Increased rainfall in the eastern sides of the province • Dry years to occur more frequently

Projected changes in climate and extreme weather events for the nine provinces

Table 14.1 shows some of the climatic hazards currently experienced by provinces as well as the projected changes in climate as a result of climate change and climate variability. These projections are on a provincial scale; however, specific local level risks can be analysed further through community risk and vulnerability assessments.

According to the Financial and Fiscal Commission report, the 20 most vulnerable municipalities in South Africa are rural, small towns and secondary cities. These are found in Limpopo (7), Eastern Cape (5), North West (4), KwaZulu-Natal (3) and Mpumalanga (1) (FFC 2012a). However, it is important to note that vulnerability and the vulnerability context are both dynamic and are influenced by other non-climatic factors such as government policy; access to basic, social and transport services; environmental degradation and poverty.

Role of different tiers of government in climate change response

There are three tiers of government in South Africa, national, provincial and local, each with different roles and functions. All these tiers of government play a crucial role in building the resilience of the country and its people to climate change through different policies and legislation as well as adaptation and mitigation response strategies. South Africa has approximately 278 municipalities spread across the nine provinces, categorised as either metropolitan (8), district (44) and local municipalities (226). Climate change affects all aspects of society are managed by the different tiers of government and can potentially derail social and economic development. An increased frequency and intensity of excessive rainfall events, for example, can result in increased public safety risk on the streets due to damage to infrastructure and increased national or municipal costs associated with disaster recovery, maintenance and replacement of infrastructure. The different tiers of government can, however, play a key role in responding to climate change and building resilient communities by using socio-economic development priorities to mainstream climate change response while also ensuring the realisation of development goals (IPCC 2007; AMCEN 2011).

The paragraphs that follow consider some roles that the different tiers could play in climate change response over and above their other mandates.

National government

National government develops and provides the national framework for development, including policies and sector programmes. The National Climate Change Policy (DEA 2011) has highlighted the role of national government in responding to climate change. This role includes taking a lead in informing all relevant stakeholders about the South African Government's National Climate Change Response Policy (NCCRP) and their role in implementing the policy; revising and disseminating legislation to address climate change; developing and implementing a regulatory framework for mitigation; allocating resources and incentives through the Medium-Term Expenditure Framework; and participating in international negotiations on climate change. Sector departments are also tasked with incorporating climate change into their policies and programmes as well as managing Near-term Priority Flagship programmes.

National government, through the Department of Environmental Affairs (DEA), has been instrumental in driving the climate change agenda at international and regional level with the signing of the UNFCCC and IPCC agreements and involvement in COP activities. Although these commitments are made at national level, they are mainly implemented at lower levels of government and civil society. The national government also coordinates and supports planning for climate change response at sub-national level where adaptive capacity levels are not uniform.

Provincial government

The provincial government facilitates, monitors and guides the implementation of the sector programmes. Provincial government also provides support to local government when needed, including in cases where the local municipalities fail to meet their obligations (Madumo 2015). While national government has been influential in the development of policies and strategies as well as the establishment of institutional arrangements to address issues of climate change, the lower tiers of government play a more direct role in addressing climate change adaptation. Section 8.8 of the NCCRP highlights the role of subnational government in responding to climate change in section 8.8 through the Adaptation Research Flagship Programme (DEA 2011). Under this programme, provincial and local government need to assess the climate change risk and vulnerability in the sub-region so that they can identify possible adaptation response strategies at that level. This work is currently being done by the DEA through initiatives such as the Provincial Adaptation Support Programme and the Local Government Climate Change Support Programme.

Local government

Local government is the organ of state closest to citizens and is instrumental in addressing the challenges posed by climate change over and above fulfilling their mandate of providing basic services as mandated by the constitution (Madumo 2015). The role and functions of municipalities at this level, as mandated by the constitution and other legislation is to produce an atmosphere for efficient and effective delivery of services to communities within their jurisdiction. The municipalities also perform an important role in delivering basic services which include clean and potable water, sanitation, sustainable electricity provision and waste removal. Local governments operationalise national and provincial initiatives in collaboration with other interested parties such as non-governmental organisations and the private sector.

Section 10.2.6 of the National Climate Change Response Strategy (NCCRS) acknowledges the crucial role of local and provincial government in addressing and responding to the threats posed by climate change (DEA 2011). This is supported by the IPCC, which recognises the crucial role local government plays in scaling up climate change adaptation to local communities. The IPCC Fifth Assessment Report (AR5) on impacts, adaption and vulnerability (IPCC 2014) highlights the importance of strengthening local government to enhance the capacity of communities to respond and adapt to climate change. The report specifically deals with the actual or expected impacts of climate to minimise exposure and reduce vulnerability. Further, local government provides the regulatory framework that can be used to facilitate an integrated response to climate change. The Municipal Act, states that it is essential that municipal integrated planning is aligned across municipalities, provincial and national government, through a process of cooperative governance (SALGA 2015). However, local government in South Africa faces a myriad of challenges, which hinder the fulfilment of both the local government mandate of service delivery and the response to climate change.

Climate change support for local government

Section 8.8 of the South African NCCRP highlights the role of sub-national government in responding and supporting climate change response through the Adaptation Research Flagship Programme. The following are some of the ongoing initiatives aimed at supporting local government to improve understanding of climate change risks and vulnerability and assisting them in effectively responding to climate change.

Provincial Adaptation Support Programme and the Local Government Climate Change Support Programme

The Provincial Adaptation Support Programme and the Local Government Climate Change Support Programme (LGCCSP) are run by the DEA to assist provincial and local government in assessing the climate change risk and vulnerability in the sub-region so that they can identify possible adaptation response strategies at that level. The LGCCSP further provides local government officials with the much-needed capacity building and knowledge transfer to increase the capacity for the implementation of climate change adaptation options.

South African Risk and Vulnerability Atlas *and Risk and Vulnerability Science Centres*

The *South African Risk and Vulnerability Atlas* and Risk and Vulnerability Science Centres initiatives are part of the Department of Science and Technology's (DST) ten-year Global Change Grand Challenge that seeks, among other things, to facilitate the science policy link by providing decision makers at various levels of government with climate change information to improve their adaptive capacity and make timely and informed decisions. The atlas is a technology transfer and communication platform for climate change information and research carried out in South Africa. Risk and Vulnerability Science Centres provide local government support by conducting research at the local level as well assisting in the interpretation of data in the Risk Atlas. The science centres also engage in local and international collaborations with other universities and research institutions to build the capacity building of local government and communities to understand and respond to climate change.

Let's Respond Toolkit

The Let's Respond Toolkit is an initiative by the DEA, Department of Cooperative Governance and Traditional Affairs and the South African Local Government Authority. The toolkit was developed to support the local government by facilitating the integration of climate change in the municipal Integrated Development Plan and the LGCCS.

Conclusion

Climate change adaptation is complex, diverse and context-dependent, hence there is no single approach to adaptation planning. To the extent that local governments are central to climate change response at local level, it cannot be the sole prerogative of one level of government. Because of the complexity of climate change, there is a need for partnerships with other stakeholders, such as the private sector and civil society. Communities also need to be empowered to increase their adaptive capacity and resilience while also reducing their dependency on local governments, especially during extreme events. Sectors and individuals with a high adaptive capacity are better able to cope with, recover and even benefit from changes in climate compared to those with a low adaptive capacity who are more vulnerable to the same change (Brooks & Adger 2005). In many countries including South Africa, climate change information still needs to be communicated effectively at the sub-national level so that government officials understand and acknowledge the factors driving vulnerability and the possible adaptation and mitigation measures (Harvey et al. 2012).

The following case study illustrates some of the challenges faced by local government which increase their vulnerability to climate change whilst reducing their adaptive capacity.

Case study

Miriam Murambadoro and Julia Mambo

Climate change in the Amathole District Municipality, Eastern Cape Province

Amathole District Municipality[2] (ADM) is situated in the central coastal portion of the Eastern Cape. It comprises six local municipalities, namely Amahlathi, Raymond Mhlaba, Ngqushwa, Great Kei, Mnquma and Mbhashe. Mnquma local municipality was identified as one of the twenty most vulnerable municipalities in South Africa (FFC 2012b). Figure 1 shows the location of Amathole in the Eastern Cape Province.

Figure 1 Amathole District

2 Amathole District Municipality (ADM) is a Category C2 municipality, indicating a largely rural character and low urbanisation rate, as well as limited municipal staff and budget capacity (Amathole SoER 2012).

The *South African Risk and Vulnerability Atlas* project team conducted a workshop with local government officials from the six local municipalities in the Amathole district to understand their experiences of climate change and climate information needs. The following table highlights the key experiences of climate change affecting each local municipality.

Non-climatic stressors

Non-climatic stressors in the area include:

- high poverty levels, which are more pronounced on the eastern parts where the former homelands are and have had little investment and development;
- low average income (about 50% of the population earn between R500–R3 500);
- high dependency ratio of 64%;
- soil erosion (Amahlathi, Mbhashe);
- alien vegetation (Raymond Mhlaba);
- illegal fishing and poaching (Ngqushwa, Mbhashe, Great Kei);
- water shortages affecting households, farmers and livestock;
- unstable sand dunes (Mbhashe);
- deforestation (Mbhashe);
- limited access to the basic services and other resources;
- illiteracy;
- widespread inequality; and
- human settlements located on wetlands;

Mechanisms/instruments used by the municipality to deal with climate change?

The following were identified as some of the mechanisms or instruments used by the municipalities to mainstream climate change:

- Climate Change Strategy
- Integrated Development Plan
- Disaster Response and Recovery Policy
- Disaster Relief Policy
- Coastal Management Plan

Local municipality	Experiences of climate change
Amahlathi Includes towns such as Stutterheim, Cathcart, Keiskammahoek and Kei Road Numerous peri-urban& rural settlements	Snow Fog Hot and cold weather extremes Abnormal winter rainfall Fires Tornadoes
Raymond Mhlaba Numerous peri-urban and rural settlements	Drought Dry spells Changes in rainfall patterns resulting in flooding High temperatures in summer; extremely low temperatures in winter Fires Tornadoes
Ngqushwa Includes towns such as Peddie, Hamburg as well as numerous peri-urban and rural settlements	Drought Extreme heat Lower than normal rainfall Strong winds
Great Kei Includes towns such as Komga, the small coastal towns of Kei Mouth, Haga Haga, Morgan Bay and Cintsa and a number of rural settlements	Drought Storms Sea level rise
Mnquma The main town is Butterworth. Other small towns include Ngqamakwe and Centani.	Drought Fires Tornadoes Changes in rainfall patterns
Mbhashe Towns include Idutywa, Elliotdale and Willowvale Numerous peri-urban and rural settlements.	Snow (Ugi) Drought Tornadoes Fires

- Environmental Management Plan
- Wetland Report – ICLEI
- Integrated Waste Management Plan
- Solid Waste by-law
- Air Quality Management Plan

Factors constraining adaptive capacity

The following factors constraining adaptive capacity were identified:

- Lack of funding to implement climate change projects with the assumption that they will be integrated into existing budget.
- Lack of skilled capacity to interpret policies and climate information.

- Lack of political buy-in – council resolution vs expert recommendations.
- Lack of partnerships with private sector, civil society and universities to help with generation of local level information and implementation of climate change response projects.
- Corruption.
- Governance structures and procedures.
- High staff turnover in sector departments.
- There are no consequences for non-compliance with the climate change policy, hence it's not prioritised.

Conclusion

Although efforts are being put into climate change adaptation and mitigation in the Amathole district, challenges still arise with regards to the limited funding for disaster response and recovery and reluctance by key players and sector departments to commit to their roles and responsibilities in climate change mitigation and adaptation (ADM 2014). The IPCC Fifth Assessment Report (Mimura et al. 2014) revealed that in most developed and developing countries the sub-national and local governments struggle with climate change adaptation. This is due to inadequate guiding information or data on local vulnerabilities and potential impacts. Responding to climate change in Amathole, as in all municipalities, is an ongoing process that is anticipated to grow in strength, and as such, challenges should not derail the efforts aimed at building a resilient society.

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CHAPTER 15

Global environmental change risks and the private sector

Kristy Faccer[1]

Introduction

The risk landscape of present day businesses is shifting rapidly, exposing new and emerging risk dynamics with the potential to fundamentally change the way in which companies operate. Be they economic, environmental, social or otherwise, these risks are characterised by an order of complexity and interconnectedness which was unknown to businesses only a few decades ago.

This section discusses risk and vulnerability with an emphasis on the import, implications and considerations of businesses and provides a brief snapshot of why and how global environmental change may manifest as a business risk or opportunity.

Today, analysts rank the projected impacts of global environmental change amongst the most urgent issues facing decision-makers worldwide. In a recent report by the World Economic Forum (WEF), for example, the failure of climate adaptation, rising greenhouse gas emissions, mismanaged urbanisation, and food and water insecurity are listed as some of the most likely and consequential risks facing decision-makers today (WEF 2012). Although public attention has focused on corporate climate change mitigation strategies and performance in recent years, there has also been a strong and renewed call for corporate action to ensure businesses and society are

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operating within safe ecological and earth system limits (Whiteman et al. 2013). Recent surveys of leading global businesses as well as businesses in South Africa, such as the one done by the Carbon Disposal Project (CDP), have started pointing to an expanded view of global environmental change – in particular, the risks and opportunities presented by these changes and the need to build strategies which respond to them (CDP 2011).

Overall, global awareness of the potential hazards that are to result from global change is further advanced by the increasing incidence of extreme weather events around the world – many of which have resulted in significant human suffering and economic damage (Coumou & Rahmstorf 2012). The 2011 tsunami in Japan is one example of one of the most extreme of such events, resulting in almost 20 000 deaths, up to $220 billion of direct damages to buildings and infrastructure, and more than double this amount for indirect damages. In South Africa, estimates vary regarding the total economic impact of weather and climate-related disasters over the past few decades. However, accounts of single-event damages to the economy ranging between tens of millions to billions of rand appear to be increasing (e.g. Aon Benfield 2015).

However, recent research has revealed weaknesses in the country's institutional, financial and policy mechanisms to address extreme weather events. It has also emphasised the potential for a greater role to be played by the private sector in supporting disaster management at local and national levels (Madubula & van Niekerk 2013). These events have driven decision-makers to prioritise new approaches which specifically target the issues of loss and damage that are driven by climate extremes such as intense droughts, floods, storms, rising sea levels, and changes in seasons and weather patterns – particularly within vulnerable societies and areas (IPCC 2012).

Business risks and impacts

In a globalised world, and particularly amongst large business entities, goods and services flows can be complex and intricately linked to the broader systems of which they are part. These systems include not only the infrastructure, technological and other networks necessary for supply, distribution and market access, but also the biophysical resources (e.g. the land, water and fuel used as inputs to production) and social actors (including local and global citizens or employees) that make business possible. As such, the risks posed by climate extremes can be direct or indirect, and are often shared between businesses and the communities and networks around them. Although many of these changes may lead to increase costs or liabilities for companies, they may also present opportunities for new products or services, or even offer a contribution to shared system resilience (Porter & Kramer 2011).

Also, while these changes are likely to have broad and far-reaching impacts for businesses and society alike, the likelihood and impact of direct climate risks may be higher for certain sectors and companies (Barton et al. 2011). This could include, for instance, companies, industries and supply chains located in vulnerable geographic areas (e.g. floodplains and coasts), as well as those directly exposed to variability through a dependence on particular resources (e.g. water) or investments and assets within these areas and industries (Linnenluecke et al. 2011). In a recent survey of businesses, over half identified the increasing costs associated with natural resources and raw materials, water scarcity, and energy security as areas of concern with high or very high potential impact on their operations and strategy (UNGC 2011). Many were also concerned with the threats to human health, exposure to extreme events, transportation risks and deterioration of water quality as potential climate risks.

Focus on water

According to the World Resources Institute (WRI), with less than 500 m^3 of water available annually per capita, South Africa is one of the world's most water poor countries (WRI 2000). Future water projections for the country suggest that a period of insecurity could be sooner than 20 years from now, when demand will outstrip supply (by 2025 according to the WRI/WBCSD). According to an estimate by the Water Resources Group (WRG), there is a 17% projected gap between supply and demand for South African water by 2030, independent of the potentially exacerbating effects of climatic variability, changes in irrigation requirements, and losses due to acid mine drainage (WRG 2009). Already today, the country ranks high on international indices of water stress and features areas of extreme water stress sub-nationally. Water supply is limited by low rainfall, limited underground aquifers, and a reliance on inter-basin water transfers from other water sources in the region. The country also suffers from high inefficiencies due to challenges with ageing bulk water infrastructure, insufficient maintenance and inadequate freshwater management, presenting serious economic and potential social costs to South African government and society (SAICE 2009).

While these water challenges will affect all industries, they are most likely to confront those most dependent on this resource for operations, including, for example, the mining, energy and food, and beverage sectors. However, industrials, consumer goods and health sectors will also be affected. In addition to these, financial institutions will play an important role in responding to global change challenges given their influence and exposure through financial and information flows in the economy (Furrer et al. 2012). In South Africa, a recent initiative has encouraged a number of companies listed on the Johannesburg Stock Exchange to reflect more meaningfully on their water risks through global reporting mechanisms such as the Carbon Disclosure Project (CDP)[1].

The objective of the CDP is to promote better awareness, analysis and management of environmental risks by businesses. The development and international expansion of CDP reporting frameworks relating to climate, water and supply chain information, over the past decade, has been facilitated by investor interest in environmental risk data to inform long-term investment decision-making. In South Africa, leading companies have started to voluntarily disclose their water risks through the annual CDP reporting framework, offering useful insight into their perspectives and concerns in this domain. In 2014, 32 companies across the consumer discretionary and consumer staples, energy and materials, healthcare, and industrial sectors, completed the CDP assessment (Figures 15.1 and 15.2).

The *CDP South Africa Water Report 2014*, prepared by the National Business Initiative (NBI) offers insight into a number of regulatory, reputational and physical water-related risks (NBI 2014). The physical risks posed by changing water management and environmental conditions were identified as the most numerous and pressing risks facing businesses. In particular, businesses identified water risks associated with climate change, declining water quality, drought, flooding, inadequate infrastructure, increased water scarcity, increased water stress, and projected water scarcity as the most important water risk types. Be it infrastructure or environmentally-driven (or both), exposure to these risks is largely seen by companies to be already or imminently occurring, with impacts to business expected within the next three years. Of the different sectors, the energy and materials sector reported the highest exposure across physical water risk types, with climate change and water stress ranking as this sector's most significant concerns. Figure 15.1 offers a summary of the chief physical risks faced by these sectors in 2014 (NBI 2014).

1 See the CDP website at https://www.cdp.net

Although company responses indicated that all responding businesses have taken steps to assess risks at a business unit level, few have interrogated risks in their supply chain to any great degree, pointing toward potentially important limitations in business responses to physical water risks (NBI 2014). Despite this, many companies and sectors have already begun mobilising to respond (Figure 14.2). Popular company response strategies include investment in infrastructure, engagement with

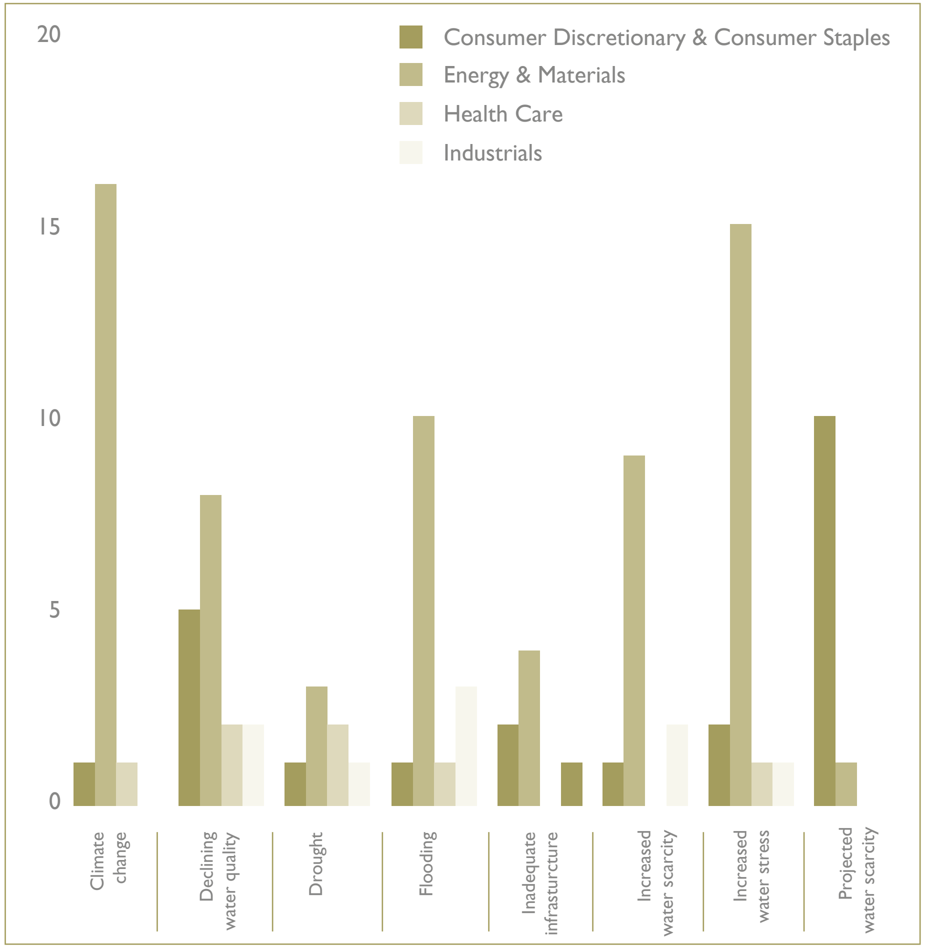

Figure 15.1 Number and category of physical water risks identified by sector (Source: NBI 2014)

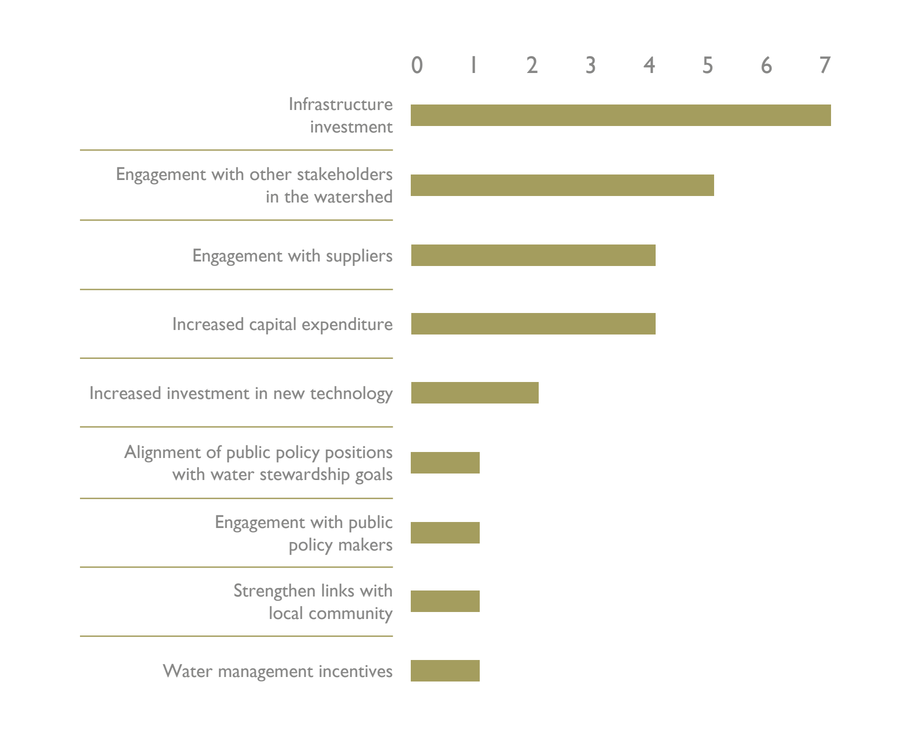

Figure 15.2 Number of companies and their response strategies for addressing recently experienced water-related impacts (Source: NBI 2014)

stakeholders, and increased capital expenditure. Supply chain and local stakeholder partnerships have been identified as particularly promising. One relevant example of such a partnership lies in the recently initiated Strategic Water Partnerships Network (SWPN), led by the DWA. The main objective of this network is to identify appropriate response measures by industry and government to better conserve and manage water and, ultimately, avert a shortfall by 2030 (SWPN n.d.). Thus far, projects in effluent and wastewater management, water use efficiency, leakage reduction, and agricultural supply chain have already been initiated.

Understanding and assessing risk: A new business agenda

A key challenge facing businesses in preparing for these changes lies in the process of understanding and assessing global change risks. One major stumbling block lies in the mismatch between traditional analytical and forecasting tools used by businesses, and the modern-day pressures of strongly interconnected and complex systems (Sargut & McGrath 2011). Although there is overwhelming agreement that global environmental change is occurring (Oreskes 2004; IPCC 2007), we do not yet have the ability to predict the exact nature, timing, location and magnitude of the impacts of these changes, despite the fact that such impacts are already being felt (IPCC 2012). For this reason, and the multiple natural and anthropogenic factors which also influence these processes, risks associated with global environmental change resist responses that demand accurate prediction and control – a common criticism of many risk approaches (Sargut & McGrath 2011; Winn et al. 2011). To support this gap, a number of key tools have recently been developed to inform risk assessment based on available water data, as well as to offer guidance on potential management strategies for global change risks (NBI 2014).

As noted, collective and creative risk assessment strategies are a critical consideration for those engaged in activities aimed at closing the gap between knowledge and decision-making. Here research has demonstrated that there is an increasing role for collaboration between different groups, and that the interaction between, for example, businesses and scientists or civil society groups, may lead to improved collective resilience (Berkes 2007; Vogel et al. 2007). As the case studies show, businesses of all kinds are already starting to draw on unconventional and new sources of information in order to identify and innovate in response to challenges and opportunities associated with global change. In addition to responding to the calls made by the World Economic Forum for systemic and collective assessment of shared risks, these types of actions by businesses speak directly to the South African national government's Climate Change Response Strategy's view of businesses as key partners in improving risk and vulnerability reduction as well as management of changing environmental conditions into the future (DEA 2011).

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Case Study

Business water risk and vulnerability: Santam and SABMiller case studies

In 2010, after recognising the need for business-targeted risk and vulnerability research, the *South African Risk and Vulnerability Atlas* supported collaborative case studies between researchers and two businesses concerned about the impacts of climate extremes – Santam and SABMiller.[1] The two case studies are set in the Eden district along the southern coast of the country – an area of diverse land use, rapid urban growth, and of significant property and agricultural value.

Over the past decade, the district of Eden has seen a number of significant extreme weather events – including those classified as national disasters – which have cost local, provincial and national government billions of rand. In one such case, a single cut-off low event[2] during 2007 resulted in damages of over R707 million to public assets, infrastructure and major parastatals, which provide critical services to the area (Holloway et al. 2010). During another, the district was gripped by a prolonged drought lasting nearly two years (2008–2010) due to record lows in rainfall[3], demanding significant cuts in water use and emergency funding from national treasury. Between 2003 and 2008, Eden incurred over R350 million in damages (or over 70% of the provincial total in direct damage costs) due to cut-off low events, amounting to up to 3.5 times the annual household income in damages in some areas (see Figure 1). For Santam, claims on their holdings of approximately R38 billion in assets for the period since 1995 have amounted to approximately R60 million – 78% of which were paid out since 2005 (Nel et al. 2011a). In the case of SABMiller, drought conditions posed a significant limiting factor to the only area in the country where hops (a critical input to the brewing process) can be produced (Nel et al. 2010).

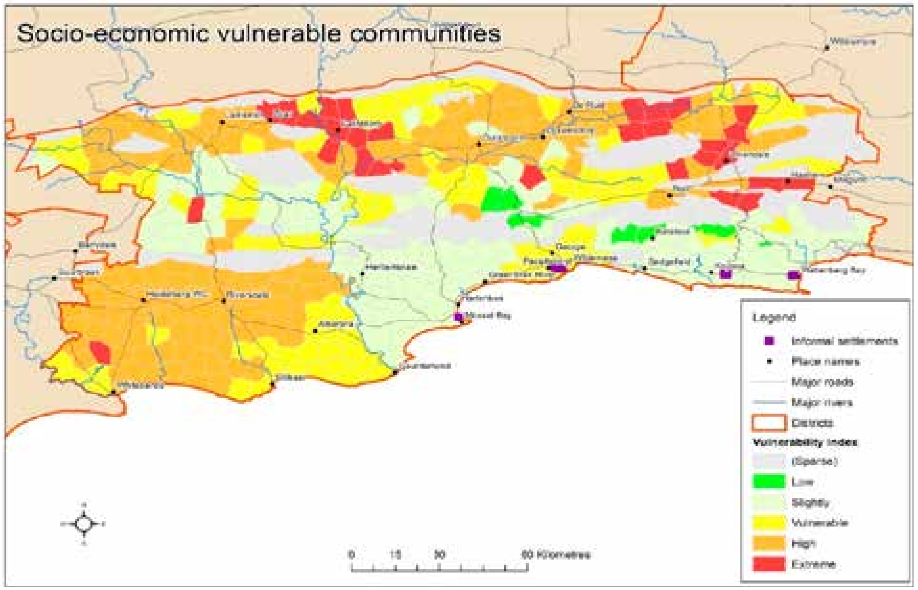

Figure 1 Socio-economically vulnerable communities in Eden per 7 x 7 km grid point, as illustrated by the vulnerability index. The vulnerability index is a composite of two main measures: a) numbers of employed persons relative to economically active individuals in a particular proximity region, and b) proportion of population who are living below the minimum living level (Source: Council for Scientific and Industrial Research)

1 The Santam Research Project was carried out in partnership between the CSIR, the World Wildlife Fund (WWF), Santam and the University of Cape Town. The SABMiller Research Project involved the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), WWF, CSIR, and SABMiller. Detailed descriptions of methods and findings from this research are outlined in Nel et al. (2010, 2011a, 2011b.)

2 A 'cut-off' low is a mid-latitude cyclone that is severed from the main planetary circulation and spins off independently, often moving and dissipating slowly. These events are associated with very strong atmospheric instability and powerful updrafts. They are one of the main drivers of severe weather (such as extreme winds and torrential rainfall) and floods in South Africa.

3 This was recorded in the local municipality of George, where the urban area has increased by 600% from 15 km2 in 1985 to 90 km2 in 2004 (Holloway et al. 2010).

Rationale and approach

Although the abovementioned cases were defined according to the context of each of the companies and risks of interest (see Table 1), both studies were grounded in the broader social and ecological context in Eden. Furthermore, both studies involved explicit engagement with dynamics that are internal and external to the area and are potentially driving, or mitigating, the risks of interest. As such, the risk assessments focused on business assets within a broader system, characterised by a diversity of ecosystem types, urban and rural land uses, population and development pressures, and institutions involved in managing the district. The aim of both case studies was to develop a better understanding of the drivers of risk within the broader landscape, and to identify appropriate responses on the part of businesses toward increased resilience in the area and of the companies themselves.

Table 1 Business drivers, exposed assets and research subcomponents in each case study

	SANTAM	SABMiller
Risk type	Extreme weather events: flood, fire, sea storms	Water scarcity; droughts
Business drivers	Increasing claims and loss of profit margins; slowed industry growth and potential reduced affordability and availability of insurance	Supply costs; South Africa-focused production and brand value; intensity of water use in agricultural supply chain
Exposed assets	Commercial and personal properties	Hops farms
Research subcomponents	Changes in temperature and rainfall trends; coastal and wave systems; vegetation and fire systems; landscape ecology and flood systems	Agro-economics; temperature and rainfall; hydrology; ecology

In approaching this question, the case studies followed four basic steps:

1. Development of a conceptual model and description of key processes, actors and sub-systems associated with the risks of interest. In the Santam case, this included landscape conditions and dynamics associated with veld fires, floods and sea storms affecting properties in Eden. In the SABMiller case, the focus was on water availability for hops production.
2. Identification of main drivers of risk and sub-systems for further analysis, including key areas of exposure and vulnerability in Eden.
3. Analysis of future change scenarios and determination of potential impacts and implications.
4. Discussion and development of appropriate response strategies for the businesses as well as other key actors in Eden.

Findings and responses

Table 2 shows the main findings and main responses of the case studies.

Table 2 Major drivers of change and responses in each case study

	SANTAM	SABMiller
Drivers of change	Climate-induced increases in wave run-up, extreme rainfall and fire; land cover change; exposed surfaces (through large fires and clear felling) and hardening of surfaces	Climate-induced temperature increase; spread of alien invasive species; competition for water through urban development
Responses	Ecological rehabilitation and fire management; support to land use and disaster management agencies; improved risk assessment methodologies	Improved groundwater monitoring and source protection; improved water use efficiencies; ecological conservation and rehabilitation

In both the Santam and SABMiller case studies, research findings confirmed the increased potential threat posed by future climatic variability, especially in terms of higher temperatures and more intense and sporadic rainfall (as well as wave run-up in the Santam case) to various parts of the Eden district. The expected impact of increased climate variability includes threats to property, crops and insurance assets through extreme weather events as well as problems with water availability for agriculture. Both case studies also highlighted the role of environmental degradation through, for example, the transformation of natural areas for human or commercial use (e.g. development or clear-cut commercial forestry) as well as the spread of invasive alien species as further key determinants of risk. In addition, the SABMiller case study found that competition for water with municipal users also posed a threat to future water availability for the hops farms. Finally, in terms of risk modelling, the Santam case study offered insight into the implications of modelling complex systems such as that of the Eden landscape, indicating that 'the predictive power of models is limited in cases where multiple drivers and risks interact.' (Nel et al. 2011b). Overall the case studies indicated that proactive management of local drivers of risk (such as fire, degraded natural areas and alien invasives) will go a long way toward offsetting most of the increased risks associated with global change.

The findings of these case studies are consistent with previous research done in the area as well as with a recently completed DEAT environmental management framework (EMF) study (DEAT 2007). The EMF emphasises the impacts of unplanned and uncontrolled urban sprawl in the area, and focuses on the role of the natural environment in providing a buffer against climate extremes and related hazards. As such, the research also suggests an increased role for businesses and other actors, including particularly local authorities and conservation initiatives, in partnering to improve local resources, land use planning, and ecological restoration in Eden. This information will not only be critical to the landowners, farmers, property owners in Eden, and businesses like SABMiller and Santam, but also to other community members exposed to the same or similar risks.

Business leadership

Since the implementation of this research, Santam and SABMiller have both taken a number of steps to increase resilience in their own companies and with the communities in the area, including water re-use, reduction and awareness initiatives. For SABMiller this has taken the form of improved farming methods, removal of invasive alien species, water use monitoring and efficiencies, and the development of a wastewater treatment plant for irrigation purposes in Port Elizabeth (DWA n.d). In Santam's case, the company is now working to build a proactive risk management process through better advice (for instance around flood prevention) to clients, the mainstreaming of climate information into investment and other strategies, and by working directly with communities to restore ecosystem service delivery (Ray-Anne Sedres, Santam, personal communication, 16 April 2015). These examples are just a few amongst many actions being taken by these two leaders in paving the way for greater collective resilience to global change. Innovative thinking and addressing risk assessment from a shared, social-ecological perspective will enable businesses to mitigate and withstand the expected and unexpected future realities of global change.

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Afterword

South Africa
Risk and vulnerability

Julia Mambo

Climate change and its impacts have become a harsh reality, both in the southern Africa region and in South Africa as a country. Climate change will continue to rise despite efforts at all levels (international, regional and local) to reduce emissions and mitigate its effects on the social, economic and natural systems. The impacts of both global and climate change will increasingly be felt for decades to come. These impacts will affect population groups dependent on natural resources for their livelihood, as well as economic sectors that depend greatly on natural resources to generate income and create employment. The country is becoming hotter and drier, and as extreme weather events such as floods, sea level rise and drought, increase in frequency and intensity (Chapters 3 and 4), impacts are expected to worsen the already vulnerability economic sectors, biodiversity and social systems. As highlighted by the chapters in this atlas, these sectors will especially be at risk.

Risk and vulnerability assessments have and will continue to play a key role in the identification of the social and economic sectors, as well as population groups and settlements (Chapter 4) that are currently and projected to be vulnerable to global and climate change. Understanding the extent and nature of the current- as well as the future vulnerability from global and climate change will provide key inputs into strategies for responding appropriately to these impacts as well as in devising climate change adaptation and disaster risk reductions strategies. This will aid in the planning of responses at all levels of government (national, provincial and local) including the roles and responsibilities of each level of government, the private sectors and non-governmental organisations.

The vulnerability of our water resources, both surface (Chapter 7) and ground (Chapter 6), will have far-reaching detrimental impacts on all sectors, including human health and wellbeing. The worst-affected sectors will include agriculture (Chapter 9), which has suffered immensely during the recent drought that is continuing in parts of the country. The ongoing drought will affect the sustainability of agriculture, which will, in turn, have a detrimental effect on food security. Water availability will also affect other key business sectors directly or indirectly associated with agriculture (Chapter 15). Furthermore, increases in temperature will have a myriad of impacts on human health (Chapter 8) and commercial forestry (Chapter 10) (for example, by increasing the risk of fires)(Chapter 13). Human health will also be affected by poor air quality, which will thus need constant monitoring (Chapter 5). The impacts of climate change on both the terrestrial and coastal and marine ecosystems will affect the ability of these resources to provide the much-needed ecosystems with services for human survival.

Local government (Chapter 14), which is the level where most of the impacts of climate change will be felt, will play an increasingly important role in responding to the impacts of climate and global change and need to be capacitated to do so. Collaborations between government departments, research councils and non-governmental organisation have resulted in numerous tools and resources that specifically target local government officials. SARVA has contributed to some of these initiatives and tools, such as the 'Let's Respond'. This tool aims to integrate climate change vulnerabilities into municipal planning documents, such as the Integrated Development Plan (IDP), which allows climate change response to be initiated at the local level. Considering that the impacts of climate change will affect service delivery, or result in the diversion of the resources needed for service delivery to respond to impacts, this integration will enhance the preparedness of local government to meet the basic needs and build the resilience of the population.

The *South African Risk and Vulnerability Atlas* (under the new management of SAEON) will continue its efforts to gather and disseminate spatial and non-spatial data that describe, assess and evaluate the risk and vulnerabilities facing the country's economic and social sectors as a result of climate and global change. As the main climate-change focus transcends vulnerability and incorporates solutions towards climate change adaptation, a few crucial research priorities emerge. These include the continued need for observation of climate variables effecting the changes, continued innovative research on climate modelling and projections, refining the resolution at which the changes can be mapped, continued identification of new vulnerabilities created by the ever-changing social and physical conditions, as well as the monitoring of adaptation initiatives across the country. It is thus critical that this research initiative continues to embrace and promote inter-disciplinary, as well as cross-disciplinary (natural vs social science) approaches for understanding various dimensions of climate change. This will contribute to the development of appropriate adaptation measures. Questions that may be of importance in this process include: Is adaptation taking place? Are we adapting more over time? What drives progress in adaptation?

Regarding the research initiatives, it important to remember that the consideration of cross- and inter-disciplinarity alone does not guarantee impact but should incorporate aspects that will ensure collective impact, – one of which revolves around meaningful engagement of knowledge users from different disciplines.

List of Contributors

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Ané has 25 years' experience in a government environment (21 years in a disaster management capacity), and holds a Master's Degree in Management and Development as well as a B.Proc degree. She currently serves on the National Council of the Disaster Management Institute of Southern Africa, is a member of the United Nations Disaster Assessment and Coordination (UNDAC) team, and also represents South Africa in the technical committee for Security (TC292) of the International Standards Organisation.

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