LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

HUMAN SETTLEMENTS

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz

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

SANBI
Biodiversity for Life

Citation:

DEA (Department of Environmental Affairs). 2016. Climate Change Adaptation Perspective on Urban, Rural and Coastal Human Settlements in South Africa (ed. Munzhedzi, SM, Khavhagali, VP., Midgley, GM., de Abreu, P., Scorgie, S., Braun, M., Abdul, Z., Gaylard, M., Jesse Harber, J. Crispian Oliver, O., Schulze, R., Pegram, G. and Cullis, J). Long-Term Adaptation Scenarios Flagship Research Programme. Pretoria.

LONG-TERM ADAPTATION SCENARIOS
FLAGSHIP RESEARCH PROGRAMME (LTAS)

CLIMATE CHANGE ADAPTATION PERSPECTIVES ON URBAN, RURAL AND COASTAL HUMAN SETTLEMENTS IN SOUTH AFRICA

LTAS Phase II, Technical Report (no. 4 of 7)

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

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz

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

SANBI
Biodiversity for Life

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACRU	Agricultural Catchments Research Unit
CGCM3.1(T47)	Canadian Center for Climate Modelling and Analysis (CCCma), Canada
CNRM-CM3	Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France
CSA	Conservation South Africa
CSAG	Climate Systems Analysis Group (University of Cape Town)
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEDEA	Department of Economic Development and Environmental Affairs (Eastern Cape)
DHS	Department of Human Settlements
DRDLR	Department of Rural Development and Land Reform
DST	Department of Science and Technology
DWA	Department of Water Affairs
ECHAM5/MPI-OM	Max Planck Institute for Meteorology (MPI-M), Germany
FAO	Food and Agriculture Organisation of the United Nations
GCM	global circulation model
GISS-ER	NASA / Goddard Institute for Space Studies (GISS), USA
GIZ	Gesellschaft für Internationale Zusammenarbeit
GVA	gross value added
IF	intermediate future
IFC	International Finance Corporation
IGCCC	Intergovernmental Committee on Climate Change
IGCCC	Intergovernmental Committee on Climate Change
IPCC	Intergovernmental Panel on Climate Change
IPSL-CM4	Institut Pierre Simon Laplace (IPSL), France
LTAS	Long-Term Adaptation Flagship Research Programme
MAP	mean annual precipitation
MDF	more distant future

NCCR	National Climate Change Response policy
NDMC	National Disaster Management Centre
NDP	National Development Plan
RC	rainfall concentration
RDP	Reconstruction and Development Programme
RH	relative humidity
SANBI	South African National Biodiversity Institute
SAWS	South African Weather Service
SDR	short duration rainfall
T	temperature
TDI	Thom's Human Discomfort Index
UKZN	University of KwaZulu-Natal
UNFCCC	United Nations Framework Convention on Climate Change

ACKNOWLEDGEMENTS

The Long-Term Adaptation Flagship Research Programme (LTAS) responds to the South African National Climate Change Response White Paper by undertaking climate change adaptation research and scenario planning for South Africa and the Southern African sub-region. The Department of Environmental Affairs (DEA) is leading the process in collaboration with technical research partners and with technical and financial assistance from the Gesellschaft für Internationale Zusammenarbeit (GIZ).

DEA would like to acknowledge the LTAS Phase I and 2 Project Management Team who contributed to the development of the LTAS technical reports, namely Mr Shonisani Munzhedzi and Mr Vhalinavho Khavhagali (DEA), Prof Guy Midgley (SANBI), Ms Petra de Abreu and Ms Sarshen Scorgie (Conservation South Africa), and Dr Michaela Braun and Mr Zane Abdul (GIZ). DEA would also like to thank the sector departments and other partners for their insights into this work, in particular the Department of Water Affairs (DWA), Department of Agriculture, Forestry and Fisheries (DAFF), National Disaster Management Centre (NDMC), Department of Rural Development and Land Reform (DRDLR) and the South African Weather Service (SAWS).

Specifically, we would like to extend gratitude to the groups, organisations and individuals who participated and provided technical expertise and key inputs to the "Climate Change Adaptation: Perspectives on Urban, Rural and Coastal Human Settlements in South Africa" report, namely Matthew Gaylard, Jesse Harber and Dr Crispian Olver (Linkd), Professor Roland Schulze (UKZN), Guy Pegram (Pegasys) and James Cullinan.

Furthermore, we thank the stakeholders who attended the LTAS workshops held in January and March 2014 for their feedback and inputs on proposed methodologies, content and results. Their contributions were instrumental to writing this final report.

REPORT OVERVIEW

This report builds on Phase I of the LTAS process to provide a desktop review of the implications of climate change for human settlements in South Africa. The report is informed by the initial workshop for Phase 2 of the LTAS process, which provided direction and identified resources to guide this work.

The content of the report is structured as follows:

- **Introduction:** This provides an overview of the existing policy mandates relating to both climate change and human settlements, including the National Climate Change Response Policy, the National Development Plan and sector climate change plans.
- **Methodology:** This describes the research strategy, defines key concepts and establishes the typology of human settlements used in the report, as well as highlighting key sources used.
- **Climate change impacts on human settlements:** This provides an overview of the environmental risks posed by climate change to human settlements and their interaction with social vulnerabilities before providing a more in-depth description of impacts on the following settlement types:
    - *Urban settlements:* These are discussed in terms of urban settlements, peri-urban settlements and mixed (urban/rural) settlements.
    - *Rural settlements:* These include relatively sparsely populated rural areas containing small settlement nodes and denser, spatially distributed rural settlements.
    - *Coastal settlements:* Here climate change vulnerabilities that are specific to the coastal context of affected cities and towns are discussed, such as those driven by sea level rise and storm surges.

This section concludes with a summary of key drivers of vulnerability to climate change in human settlements.

- **Climate change impacts on migration and human conflict:** This section provides a description of issues arising from both domestic and sub-regional migration and displacement of peoples as a consequence of climate change, and the potential for conflict.
- **Climate change adaptation responses:** This section provides a broad description of adaptation responses, focusing firstly on "no regrets" measures that are relevant across the four LTAS scenarios, and then explores some of the longer term options and decisions that need to be considered in relation to human settlements and that depend on particular scenarios and development trajectories.
- **Policy recommendations:** This section identifies the key policy challenges and policy levers in relation to human settlements with respect to the LTAS scenarios.
- **Future research needs:** This briefly identifies areas in which current uncertainty and lack of data can be reduced, and the priorities in terms of monitoring requirements.
- **Conclusion:** A brief statement of the key imperatives for stakeholders arising from this work.

The report was further refined as a result of detailed engagement with stakeholders in the scenario planning workshop planned for Phase 2, as well as engagement with the Intergovernmental Committee on Climate Change (IGCCC).

EXECUTIVE SUMMARY

This study of climate change vulnerability and adaptation options for human settlements is informed by the priorities for human settlements outlined in the National Climate Change Response and the National Development Plan. It also draws on existing research, sector plans and vulnerability assessments, as well as the climate modelling undertaken during Phase I of the LTAS process.

Climate change impacts on human settlements

The vulnerability of human settlements to climate change is understood as an outcome of their exposure to environmental risks and changes resulting from climate change, and the extent to which the adaptive capacity of affected communities and households is reduced by social vulnerability. Many of these factors are location specific, related to particular local climate, topography and human settlement patterns, while others are related to socio-economic factors.

Environmental factors driving vulnerability and their potential consequence for human settlements due to climate change include:

- **Increased temperatures:** heat stress impacts on human health exacerbated by urban heat islands, loss of productivity, declining air quality in cities and increased demand for cooling.
- **Extreme weather – heat waves and droughts:** increased water demand, water quality problems, heat-related deaths and reduced quality of life, food insecurity.
- **Extreme weather – heavy rainfall and violent storms:** water quality problems, deaths and injuries, infections and waterborne disease, damage to infrastructure and economy, loss of property.
- **Sea level rise and coastal storm surges:** salt water intrusion on fresh water reservoirs, deaths and injuries, forced relocations, property losses, erosion and submersion of land, damage to infrastructure and services

Social drivers of vulnerability include:

- **Access to basic services:** Households without access to electricity, water, sanitation and waste management services are more impacted by climate extremes.
- **Type of dwelling:** Houses that are poorly built, are poorly located, or lack flood and lightning protection, efficient water systems, cool spaces, heat-reflective surfaces or damp-proofing are a source of climate vulnerability. Informal housing (shacks) is particularly vulnerable.
- **Health:** Climate resilience is dependent on baseline health and age. Children and the elderly are more susceptible to illness, heat stress, food insecurity and malnutrition, all of which are projected climate hazards.
- **Economic factors:** Poverty and unemployment link to many of the abovementioned factors and reduce the ability of households to recover from climate shocks. Land tenure status is another important factor; households with insecure tenure such as squatters are less likely or able to invest in adaptation.
- **Demographic factors including age and gender:** In addition to age-related vulnerabilities to health impacts, asymmetrical power relations may increase the vulnerability of women. Communities with a smaller than average proportion of working-age adults are particularly vulnerable.

Urban, rural and coastal human settlements face particular environmental and social challenges in relation to climate change. South Africa is experiencing a long term urbanisation trend which places infrastructural stresses on urban resources and results in a "hollowing out" of the productive potential of rural areas due to an exodus of working-age adults.

Vulnerability in urban settlements

Apartheid spatial planning has shaped urban settlements in maladaptive ways, particularly with respect to spatial planning, as poor, historically disadvantaged households are relegated to the urban periphery far from economic opportunities. This increases the percentage of their income that poor households must spend on transport, which is exacerbated by the fact that their transport options are often neither safe nor affordable.

The projected impacts of climate change on urban economies are complex and diverse, and both direct and indirect. They include:

- Direct impacts of weather on construction and other industries in terms of loss of production.
- Increases in the costs of water, liquid fuels and electricity as industrial inputs.
- Increased costs of labour linked to food, energy, water and transport costs.
- Potential impacts arising from regulation of carbon emissions.
- Disruptions to water and electricity supply reducing productivity.

In the context of a water scarce country, water is a major vulnerability for human settlements. Apart from the need to deliver piped water to the approximately 4.5 million people who currently lack it, South Africa faces challenges of rapidly deteriorating infrastructure for those who already have water. Higher temperatures will increase demand and place increased pressure on water quality.

Extreme weather will also damage roads, railways, bridges, airports, tunnels, and other transportation infrastructure incurring delays and maintenance costs. In addition groundwater changes may threaten to damage structures and foundations of the transportation system and higher temperatures will cause stress to construction materials, in particular steel. Extreme weather will also result in increased traffic congestion and collisions.

Climate change and extreme weather events also pose a threat to human health through increased temperature-related morbidity and mortality, reduced water supply and quality, increased exposure to water-borne diseases and disease vectors, such as the malaria mosquito, and water supply problems. Higher temperatures also result in an increased incidence of temperature inversions that trap pollution above cities leading to a range of health risks.

Peri-urban settlements

South African metros and towns are characterised by extensive peri-urban development as urban centres expand into formerly rural areas in a phenomenon referred to as urban sprawl. The resulting settlement patterns may include the following features:

- **Affluent residential areas:** Such residential areas are often lucrative targets for high-end property developers and there are strong market pressures to exclude low cost housing or social housing developments on this land. These areas typically have reliable access to basic services and high consumption patterns of water and electricity, particularly when attached to golfing estates. They typically have a relatively high adaptive capacity but may support patterns of water and energy consumption that are not environmentally sustainable.
- **Gap, low cost and social housing estates:** These include many new Reconstruction and Development Programme (RDP) housing estates dating from the post-1994 era, often on degraded land with a low market value. Leasing of informal or semi-formal structures (shacks) in backyards of low cost or gap housing is widespread, and these households are

likely to be highly insecure in terms of tenure and other indicators of social vulnerability. Price has played a defining role in the design and construction of low cost housing and these structures are generally not "climate-proof". They may be structurally vulnerable to extreme weather, poorly insulated against temperature extremes, and prone to leaks and flooding during heavy rainfall. Equally important, in the design and implementation of low cost or gap housing estates inadequate attention is often paid to accessibility of public services, community facilities, recreational spaces, urban aesthetics and social cohesion.

- **Informal settlements:** The majority of vacant land occupied in this way is on the urban periphery and is often located in areas that are unsuitable for human settlement due to local topographical features such as unstable soils, wetlands and flood risks. A significant percentage of the backlog in service delivery is associated with informal settlements. Informal settlements often have high population densities and their residents have high social vulnerability to climate change.
- **Mixed settlements:** These combine features of urban settlements and rural settlements. They are typically not as densely settled as urban areas, but are too densely settled to support intensive commercial agriculture. They may include traditional, formal and informal housing types and access to basic services is often both patchy and unreliable. This settlement type not only exists on the perimeter of some urban settlements, but is also a characteristic settlement pattern in the former homelands. It is further characterised by settlement layouts that are not formally planned, which can complicate service delivery, and by uncertainty in relation to land tenure associated with the administration of communal lands.

In general, poor households located in peri-urban settlements are likely to experience heightened vulnerability to climate change not only as an intrinsic consequence of socio-economic demographics, but also as a consequence of the distances wage earners need to travel, inadequate access to basic services, insecurity of tenure, and physical vulnerabilities of informal, unplanned or poorly planned housing.

Rural human settlements

Rural economies are primarily dependent on agriculture, herding, and tourism, all of which are directly or indirectly vulnerable to climate change. Many of the drivers of social vulnerability already identified in the context of urban and peri-urban settlements are particularly prevalent in rural communities.

Additional vulnerabilities that are more specific to human settlements in rural areas include:

- Diminished biodiversity and already degraded ecosystems are a source of vulnerability for poor rural communities that rely on informal resource use for survival and on jobs provided by biotourism.
- Physical isolation of rural communities as a result poor rural roads vulnerable to flooding and erosion
- Insecurity of tenure associated with the Communal Land Act or poor enforcement of farm workers' tenancy rights.
- Governance arrangements in rural areas, in which the responsibilities of traditional authorities and local authorities may not be clearly demarcated, or may not be exercised in a democratic and equitable manner with respect to allocation of land and land use rights.

It must be recognised that the situation with respect to rural land rights and traditional authorities is complex and uniform solutions are unlikely to be appropriate in all situations. While the status of communal lands has certainly in many cases acted as an impediment to investment, it has also provided for allocation of land in rural areas to be driven by social rather than market imperatives and provides access to land for households that may not be in a position to purchase land commercially.

Coastal settlements

Coastal settlements are vulnerable to climate change primarily through the effects of climate change on sea level rise, storm surges and coastal flooding, and the impact of climate change on the marine environment and estuaries, including ocean acidification, higher sea temperatures, and changes to ocean currents. Dry spells and droughts will concentrate effluent discharges, damaging coastal ecosystems and their dependent economies.

In addition to the impacts affecting urban, peri-urban and rural settlements, the following climate change impacts are specific to coastal settlements:

- Impacts on marine diversity are likely to affect livelihoods. It is estimated that climate change may reduce the value of South Africa's fisheries by up to 18%. This impact will be disproportionately felt by artisanal fishing communities.
- Rising sea levels and extreme weather events will result in partial or total inundation of some coastal areas resulting in loss of property, damage to infrastructure and disruption of basic services.
- Rising seas could also backwash through the sewerage and wastewater systems, causing both damage and hazardous pollution.
- Increased groundwater salinity will threaten smallholders who depend on vulnerable aquifers.
- Marine recreational activities, tourism-supporting infrastructure such as beach-access roads and the aesthetic appeal of the coastline are vulnerable, reducing income from tourism.
- Coastal roads and railways are vulnerable to erosion and damage as a consequence of sea level rise and storm surges.
- Small fishing ports and harbours may need to upgrade their infrastructure – alternatively, rising sea levels may deepen some harbours, reducing the need for dredging activities.
- Critical infrastructure, such as the Koeberg nuclear power station, may be affected.

Climate change impacts on human migration and conflict

Climate change is likely to disproportionately affect socially vulnerable populations already inclined to migration, thereby increasing rates of migration. Specifically, climate-related food insecurity, service incapacity, extreme weather events and water security could lead to increased migration. Migration is likely to be experienced both internationally (from neighbouring countries) and domestically. In both cases, it is likely that climate change will accentuate the existing trend towards urbanisation due to the negative impacts of climate change on rural livelihoods. Changes to settlement patterns may not be restricted to the socially vulnerable. For instance, the value of beachfront properties in some areas may drop as a consequence of their vulnerability.

Large population movements caused by deteriorating environmental conditions may lead to conflict through competition for resources in the receiving area, or by exacerbating existing ethnic, nationalistic or class divisions. South Africa has already experienced localised xenophobic violence linked to migration. Climate change could also contribute to failures of service provision, exacerbating the existing phenomenon of service delivery protests.

Adaptation responses

In relation to the planning of human settlements infrastructure, downscaling of climate change projections needs to inform the identification of water constraints, revised flood and coastal setback lines, and engineering parameters for future temperature tolerances of infrastructure at local level. National and provincial government need to support local authorities with research and guidelines to assist them in incorporating these implications of climate change into service delivery, planning processes and land use decisions.

Adaptation to climate change needs to be viewed as an integral part of the broader developmental challenges facing South Africa's human settlements. Addressing existing deficits in the provision of water, sanitation, drainage, electricity, tenure, healthcare, emergency services, schools, and public transport backlogs is fundamental to building climate resilience in vulnerable human settlements.

The housing backlog is a particular source of vulnerability in relation to human settlements and we need to learn from past mistakes in the provision of low cost housing:

- Informal settlement upgrades and relocations need to be fully accepted as an integral part of the housing strategy at all levels of government, and environmental risks relating to climate change need to be considered in these processes. Local authorities need to support community driven re-blocking projects and integrate them into strategies for the delivery of basic services to these communities. The planning skills needed for these projects do not revolve around technology so much as the facilitation of community processes.

- Policies and programmes that improve tenure security and safely provide basic services to backyard tenants need to be developed.

- Formal planning of low cost and social housing needs to prioritise urban densification and where possible the state should intervene to ensure market values do not dictate property development to the detriment of social equity. In relation to existing low cost housing developments, deficits in the structural design of individual units need to be addressed, as well as deficits in urban design in the form of inadequate community facilities, public services and infrastructure.

- Ecological infrastructure and ecosystem based adaptation needs to be mainstreamed into human settlement planning. For instance, measures to improve and maintain the health of catchments support downstream service delivery. National and local government should identify and implement supporting incentives – such as water pricing and water use charges – that encourage landowners to restore degraded catchments and maintain healthy ones.

- Urban development strategies that leverage adaptation opportunities in mixed settlements, (such as urban agriculture) and mitigate vulnerabilities, such as inadequate access to basic services, need to be pursued.

1. INTRODUCTION

The implications of climate change for human settlements will be profound, and human settlements therefore represent a crucial vector for adaptation strategies. The overarching strategic framework for the development of human settlements is described in the National Development Plan (NDP) and, more specifically in relation to the implications for climate change, in the National Climate Change Response policy (NCCR) (DEA 2011).

Noting that 60% of South Africa's population resides in urban areas, the NCCR outlines challenges in relation to inertia and risks created by existing investment in infrastructure and mechanisms of service delivery that may not be well adapted to a changing climate. The NCCR also points out the legacy of apartheid planning in urban design, which has generally resulted in poor communities and informal settlements being located in the urban perimeter and therefore disadvantaged in terms of access to economic opportunities and social infrastructure.

The NCCR suggests adaptation strategies for urban settlements that include:

- promoting urban densification to build climate resilient infrastructure
- improving climate resilience of low-cost housing
- encouraging water-sensitive urban design
- incorporating down-scaling of climate projections, and effective information and assessment tools to inform land-use planning and urban design that is climate resilient.

This review attempts to build on the insights of the NCCR to develop a more nuanced understanding of the challenges and options for adaptation in urban human settlements that takes into account the unusually diverse urban forms of human settlement in the South African context, and the importance of ecological infrastructure in supporting service delivery and building resilient communities. In particular, this study looks at issues in relation to the extended urban perimeter that is such a feature of South African cities, and the challenges of the significant areas of land that are neither clearly urban, nor purely rural. This last is a feature of some areas within our metros, but also of relatively densely populated areas within the former homelands.

As identified in the NCCR, rural areas are particularly vulnerable due to the close dependencies that exist between climate and agriculture in all its forms – both commercial and subsistence. There are also dependencies between rural areas and urban areas, particularly in relation to food security and ecosystem services, that are critical to developing climate resilience on a national scale.

The NCCR suggests adaptation strategies for rural settlements that include:

- Support to small-scale farmers in the adoption of agricultural practices that conserve underlying ecosystems, thereby strengthening resilience to climate change.
- Researching and developing appropriate agricultural technologies that promote soil and water conservation and developing and introducing drought resistant crops and livestock species.
- Empowering local communities (and particularly women) and diversifying rural livelihoods.

The NCCR also points out the particular vulnerabilities that low-lying coastal communities face as a result of the threat of sea level rise and storm surges, which may lead to flooding and coastal erosion damaging to property and infrastructure. It suggests the following adaptation strategies in coastal human settlements:

- The impact of sea level rise must be incorporated into coastal setback lines when undertaking development in coastal areas and into disaster risk management planning.

- Protection and rehabilitation of natural systems that help resist erosion and mitigate flooding.
- Investigation of the impacts of climate change on artisanal fishing and livelihoods in coastal areas.

The NDP outlines a number of challenges that relate to human settlements, particularly targeted at eliminating the phenomenon of "poverty traps" in rural and urban settlements. The challenges for urban settlement that the NDP notes include:

- A continued trend of urbanisation, particularly involving the rural poor.
- The rapid growth of a demographic of young, unemployed urban residents driving discontent.
- The apartheid legacy of fragmented urban communities, coupled with the urgent need to leverage transport networks to achieve spatial transformation.
- Ecological and resource limits facing cities, including water stress, food security and power shortages
- Weaknesses in institutional capacity to respond to these challenges

The NDP also notes the differentiated nature of rural settlements, with commercial farming areas and former homelands facing very different challenges and constraints. In general though, there has been a decline in the rural economy, with sharp drops in agricultural employment, although there has been some growth in areas near to metropolitan markets or along transport corridors and the system of state grants has contributed to economic activity in the former homelands. Of particular importance in relation to rural areas is the need for:

- Infrastructure that is location appropriate in terms of type and level of services that are provided.
- More attention to be given to the specifics of spatial location in the land reform process to ensure the successful development of agriculture and agro-processing industries that are linked to markets.
- Local food production to be supported to create jobs and provide food security in rural areas, with commonages having an important role to play in this respect.
- Policy and processes to mediate conflicts over land use in rural areas between, for instance, agriculture, mining, tourism and biodiversity.

In relation to housing, the NDP notes that the housing backlog has worsened since 1994. Further, financing has focused on individual housing units to the detriment of public and communal spaces, and has tended to involve uniform solutions that do not address a diversity of needs. The imperatives outlined in the NDP are to better locate housing developments and provide a more diverse set of solutions tailored to individual needs and capabilities. A primary role of the state should be in financing public infrastructure and services on well-located land to support a diversity of housing types, including rental stock.

In addressing these challenges, the NDP proposes the following principles be applied to spatial development:

- **Spatial justice:** Addressing historical injustices and inequalities in the allocation of space and public resources.
- **Spatial sustainability:** Creating environmentally sustainable neighbourhoods that promote low-impact lifestyles.
- **Spatial resilience:** Reducing vulnerability to environmental shocks and protecting ecosystems.
- **Spatial quality:** Improving the aesthetic and functional quality of the built environment.
- **Spatial efficiency:** Efficient commuting and

circulation of goods and services without unnecessary regulatory burdens on businesses.

The principle of spatial resilience is clearly relevant to climate change response and needs to be viewed within the context of the spatial development framework proposed in the NDP, which includes:

- **A national competiveness corridor** linking Gauteng and eThekwini.
- **Nodes of competitiveness** including coastal ports and settlements with high growth potential.
- **Rural restructuring zones** for rural areas with large populations such as the former homelands.
- **Resource critical regions** which include regions with important mineral, water, and biodiversity resources.
- **Transitional development corridors** that link South Africa with neighbouring states.
- **Special intervention areas** that are selected as a result of their economic vulnerability, rapid growth potential requiring special planning, or the potential for development as green economy zones.

In implementing the NDP, the Spatial Planning and Land Use Management Act, No. 16 of 2013 (SPLUMA) is a critical piece of framework legislation that provides an administrative framework and high-level policy guidance for land-use decisions. The Act anticipates the promulgation of guidelines by the Minister of Rural Development and Land Reform to provide more detailed guidance to decision-makers in land-use planning – these should include, for instance, guidelines on how to include the risk of environmental shocks arising from climate change in decisions. For the Act to be effectively implemented, it is essential that it be supported by detailed environmental guidelines that take into account the risks and vulnerabilities caused by climate change.

A key obstacle in applying the principles of the NDP and the NCCR in relation to rural areas, and particularly the former homelands, is the gap in the regulatory framework for the administration of communal lands created by the fact that large parts of the Communal Land Rights Act, No. 11 of 2004 have been found to be unconstitutional. Addressing this gap is a necessary step to resolving issues around security of tenure that currently increase the vulnerability of poor rural communities.

2. METHODOLOGY

The conceptual framework for understanding vulnerability of human settlements used in this study is informed by the perception that vulnerability is an outcome of the interaction between social vulnerabilities and the environmental risk and stresses arising from climate change. A widely used representation of these relationships is presented in the diagram below.

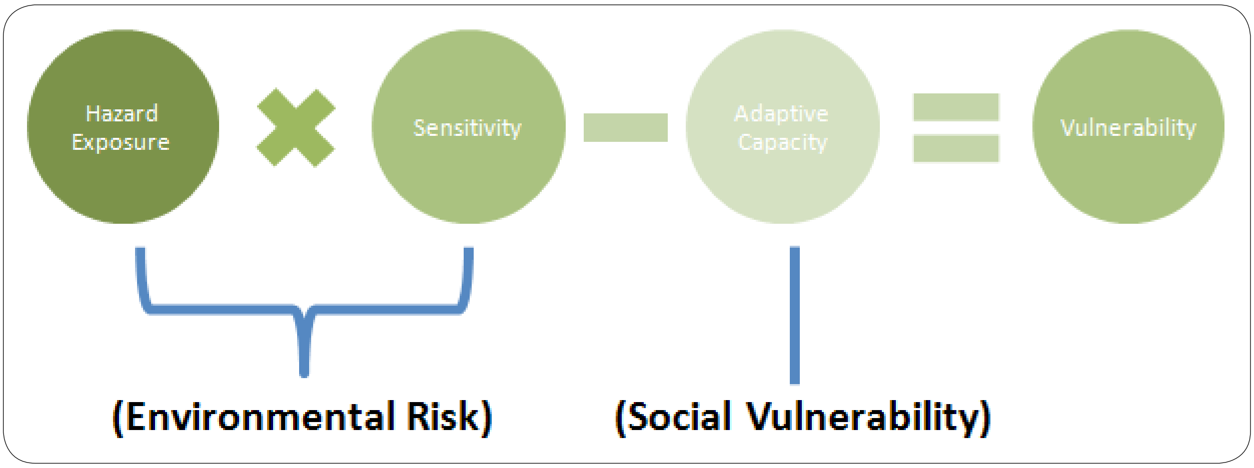


Figure 1: Vulnerability to climate change
Source: Linkd

In this approach, the interaction between climate change impacts and hazard exposure, based on climate change projections, and sensitivity, based on an analysis of the responses of living systems, can be understood as encompassing the environmental risks posed by climate change. Vulnerability is therefore a product of the extent to which these risks are mitigated or exacerbated by the presence or absence of adaptive capacity, as well as the particular sensitivities of communities to the impacts of climate change – agricultural communities, for instance, have different sensitivities to urban communities.

Adaptive capacity represents the ability of communities to respond to the environmental risks presented by climate change. Therefore, where adaptive capacity is high, social vulnerability is low and vice versa. As a concept, adaptive capacity combines subjective qualities, such as levels of organisation and institutional capacity, which are difficult to measure directly, with characteristics of communities that influence social vulnerability which can be and are measured, such as income levels and access to basic services.

This study seeks to identify climate change adaptation responses for human settlements that:

1. *Respond to particular environmental risks* posed by climate change.
2. *Build particular adaptive capacities or reduce particular social vulnerabilities* to the environmental risks posed by climate change.
3. *Have ancillary developmental benefits* associated with national priorities such as job creation and the reduction of poverty and inequality.

While vulnerability to climate change is location specific, and adaptation responses need ultimately to be defined at local level, there are inevitably certain features that human settlements either have in common, or that differentiate them. An important challenge for this study was therefore to arrive at a meaningful typology of human settlements to assist in identifying climate change vulnerabilities specific to the South African social context.

It is worth noting that the significance of distinctions between rural and urban communities has been discussed within Working Group II of the IPCC and that the Council for Scientific and Industrial Research (CSIR) has already developed an updated typology for South African settlements that includes the categories shown in **Table 1**.

Table 1: Typology of human settlements in South Africa

City region	Population >1 million
Cities	Population >400 000
Regional service centres 1	Population 300 000 – 500 000
Regional service centres 2	Population 100 000 – 300 000
Regional service centres 3	Population 60 000 – 100 000
Service town	Significant role in hinterland (service index 0.065 – 0.25) and population mostly >20 000
Local and niche towns	Service role in immediate surroundings (service index 0.001 – 0.065), population size varies widely
Rural nodes in high density settlement areas	Mesozones with >100 people/square km OR more than 10 people/square km PLUS economic activity in service sector – identified as areas within high density settlement areas, with highest levels of access to household income
High density settlement areas	Mesozones with >100 people/square km OR more than 10 people/square km PLUS economic activity in service sector
Rest of South Africa	Less densely populated areas, sparsely populated areas, mountainous, national parks

Source: Adapted from SACN/CSIR Settlement Typology 2013 v6

For the purposes of this study, of particular interest were issues of urban form that reflect the urban/rural divide, but that also capture:

- Planning issues relevant to specific environmental challenges and social vulnerabilities associated with settlement patterns that cut across the CSIR typology, such as informal settlements.
- Planning issues arising from sea level rise that are specific to coastal settlements.

For these reasons, we have used an analytical typology for human settlements that builds on the categories in the NCCR as follows:

- Urban settlements: This includes densely settled, spatially compact central business districts and surrounding suburbs that typically enjoy good access to basic services, but also encompasses:
    - o peri-urban settlements on the perimeter of the urban complex, which include a diverse range of settlements, including informal settlements
    - o mixed settlements that combine features of both the urban and rural environments.
- Rural areas: This includes sparsely populated farming communities and small towns with close linkages to these agricultural communities, as well as more densely populated areas often located in the former homelands, that share many characteristics with mixed settlements.
- Coastal settlements: This includes cities and towns in low-lying coastal areas that contain infrastructure vulnerable to sea level rise and storm surges.

The research methodology has been that of a literature review, focusing in the first instance on climate change risk and vulnerability assessments and adaptation plans already undertaken and developed by local authorities and national sectors. This has been substantially augmented by a review of contextual issues, policies and delivery outcomes encompassing:

- Academic research papers specifically addressing climate change impacts and adaptation.
- Policy and research outputs from the CSIR, Water Research Commission and various government departments including the Department of Human Settlements and the Department of Rural Development and Land Reform that are relevant to understanding the adaptation challenges facing human settlements.

3. CLIMATE CHANGE IMPACTS ON HUMAN SETTLEMENTS

South Africa is a diverse country, not just in terms of populations and biodiversity, but also in terms of its human settlements. At one end of the spectrum is Gauteng, a regional hub and the economic centre of Southern Africa containing the most densely settled municipality in the country (the City of Johannesburg). On the other is the Namakwa District Municipality, which is both the largest municipality in the country at 126 747 km^2, and the most sparsely populated with approximately 1 person per km^2 (Bourne et al. 2012). Johannesburg and the Namakwa District Municipality have very different climate vulnerabilities, but so do Johannesburg, Cape Town and Durban; and Namakwa, OR Tambo, and Gert Sibande District Municipalities.

Even before climate change is taken into account, South African cities face severe challenges. Four of the five most populous metropolitan areas (with the exception of eThekwini) experienced immigration of greater than 4% of their populations between 2001 and 2006 (Presidency 2006). This urbanisation strains urban infrastructure and services (Golder Associates 2008) and despite the fact that migration is often to areas with high economic activity these same areas have the highest concentrations of people living in poverty: 67% of people living below subsistence level[1] live in areas generating 82% of South Africa's gross value added (Presidency 2006).

At the same time, these population movements result in rural areas shedding working-age population. This "hollowing-out" (Presidency 2006, 83) of areas such as the eastern parts of the Western Cape, the western parts of the Eastern Cape, the entire Northern Cape, the south-west of North West, and much of the Free State (all of which are dry areas) reflects the failure of rural economies to provide livelihoods, and established population patterns in these areas of young children and old people who survive off state grants. Furthermore 7.5% of people earning below subsistence level, about 1.5 million people, live in high-density areas that are remote from major economic activity (Presidency, 2006). This is largely due to the residual effects of apartheid-era homeland policy, which resulted in artificially large settlements far from economic centres.

The National Spatial Development Perspective (Presidency 2006) identifies 26 areas of "national economic significance" which occupy 10.4% of South Africa's area but hold 66.6% of its population, and produce 77% of its gross value added (GVA), a measure of economic activity. These areas can be divided into three broad categories:

1. **Highly diversified and diversified economic concentrations:** These areas produce the greater portion (65%) of national GVA, with activity in all sectors except agriculture, and are marked by urban sprawl, environmental degradation, high concentrations of severe poverty, in-migration and housing shortages, and growing informal settlements. Examples of highly diversified economic concentrations include Gauteng, Cape Town–Worcester, and Durban–Pietermaritzburg. Examples of diversified service economy concentrations include Port Elizabeth, Bloemfontein, East London, Polokwane and Kimberley.

2. **Public and other service economy areas:** These areas are not economically diverse, relying primarily on public service and administration, other services, and retail. Examples include Kroonstad, Umtata, and Mafikeng–Lichtenburg.

1 Defined according to a basket of goods. For more see Presidency (2006).

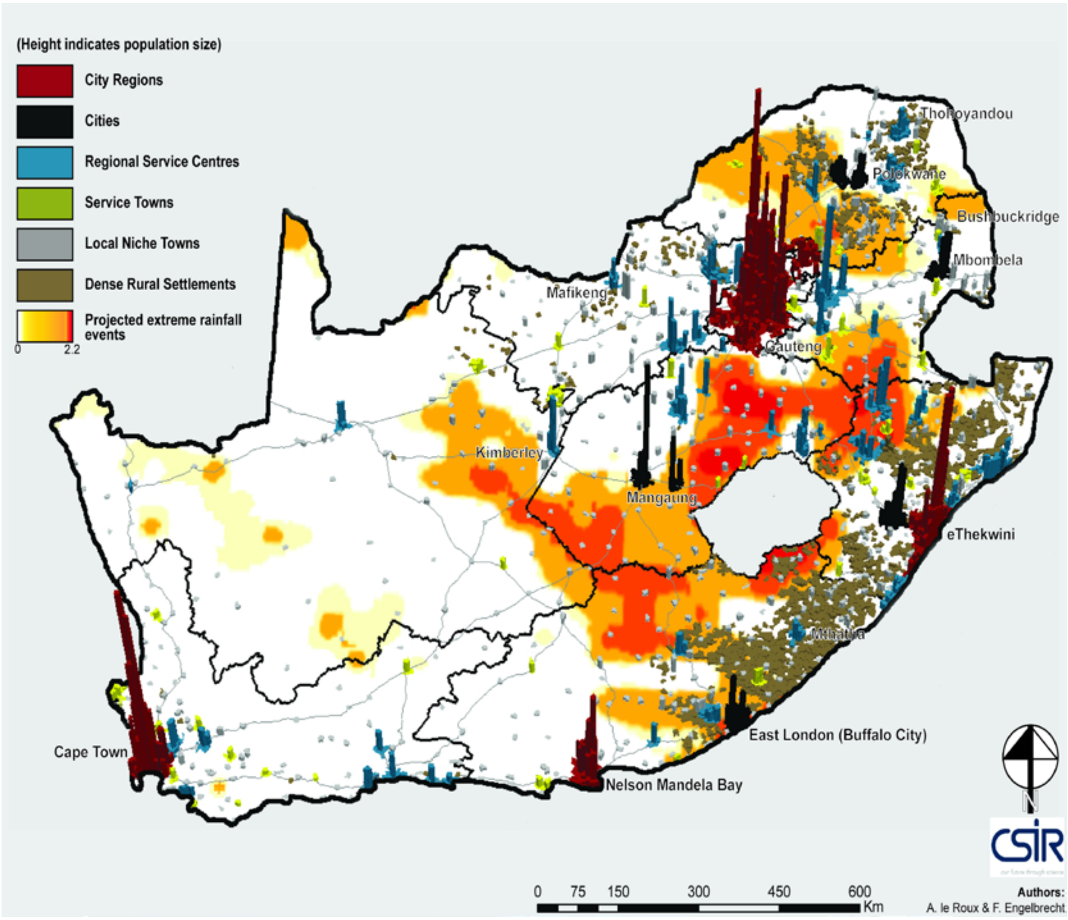


Figure 2: Population density and risk of extreme rainfall events
Source: DST (2010)

3. **Mass-produced and specialised economy concentrations:** These areas are highly labour-intensive but are largely dominated by a single economic activity. Examples are Rustenburg, Welkom, and Phalaborwa, specialising in mining; Witbank–Secunda, Richards Bay, and Newcastle, specialising in industrial and high-value differentiated goods; and Potchefstroom-Klerksdorp, Tzaneen, Thabazimbi and Upington, specialising in services and retail, in combination with construction and industry or agriculture.

The sectoral and spatial concentration of economic activity reflects South Africa's reliance on mineral extraction. The low labour absorption rate is a result of historical labour market policies as well as the increasing capital intensity of South African industry since at least the 1970s, and contributes to South Africa's extremely high poverty rate. Low rates of economic participation in South Africa are a major contributor to social vulnerability, and contribute to climate vulnerability in both urban and rural areas.

Climate change hazard exposure

The Long-Term Adaptation Scenarios Phase I (2013) projections for the future climate of South Africa are detailed and important, but they can be (over)simplified as temperatures will rise by either a little (<3°C) or a lot (>3°C), while average rainfall will either increase or decrease. This is represented in the matrix diagram below.

However as the LTAS Phase I report is at pains to point out, these only represent national average scenarios. Different parts of South Africa will experience different patterns of climate change. For example, the following table indicates projected rainfall patterns disaggregated by the four climate scenarios as well as by hydrological zone (indicated in **Figure 4**). Note that although national trends are evident within each climate scenario, the intensity and seasonality of precipitation changes vary by region.

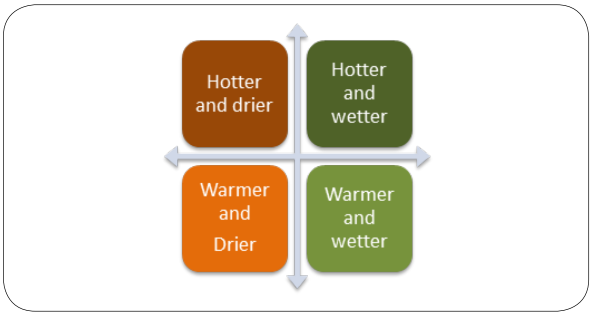


Figure 3: Climate scenarios
Source: DEA (2013a)

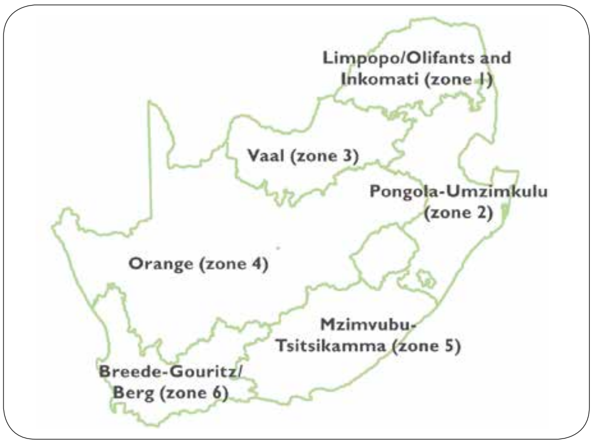


Figure 4: South Africa's hydrological zones
Source: DEA (2013a)

Table 2: Regional climate scenarios

Scenario	Limpopo/ Olifants/Inkomati	Pongola-Umzimkulu	Vaal	Orange	Mzimvubu-Tsitsikamma	Breede-Gouritz/ Berg
1: warmer/ wetter	↑ spring and summer	↑ spring	↑ spring and summer	↑ in all seasons	↑ in all seasons	↓ autumn, ↑ winter and spring
2: warmer/ drier	↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ in all seasons, strongly ↓ summer and autumn	↓ in all seasons, strongly ↓ in the west
3: hotter/ wetter	Strongly ↑ spring and summer	Strongly ↑ spring	↑ spring and summer	↑ in all seasons	Strongly ↑ in all seasons	↓ autumn, ↑ winter and spring
4: hotter/ drier	Strongly ↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ all seasons, strongly ↓ in summer and autumn	↓ all seasons, strongly ↓ in the west

Source: DEA (2013a)

In general, we can expect temperatures to rise most dramatically, by as much as 5–8°C, in the interior of the country, with smaller rises around the coast. The west and south of South Africa are most at risk of drying, whereas increased precipitation is most likely in the east (DEA 2013b).

Uncertainty as to which climate scenario is in our future, as well as the differentiated impact of climate change on different parts of the country, make it difficult to identify vulnerabilities that apply generally to human settlements. However there are broad patterns that emerge, which will be examined in detail in the following sections.

A further complication is the relationship between human settlements and climate change. Rather than being passively exposed to climate change, there are complex two-way interactions between the two (above and beyond human settlements' contribution to carbon emissions).

For example, settlements will be exposed to higher ambient temperatures as the South African climate warms. However, urban settlements, and particularly dense, built-up areas, cause a further heat island effect where heat is absorbed by the built environment raising the ambient temperature by up to 7°C in extreme cases.

Similarly, evaporation and precipitation are affected by human settlements. The proliferation of non-permeable surfaces that characterise human settlement, along with the destruction of wetlands, greatly increase runoff increasing flood risk and altering catchment behaviour. Agriculture (both irrigated and non-irrigated) also changes water runoff and catchment behaviour, and this includes the irrigated "lawn crops" that are so prevalent in suburban areas.

Furthermore, the very existence of many human settlements in such a water-scarce country depends on one of the most extensive water transfer networks in the world. South Africa has 28 inter-basin transfer schemes with a total transfer capacity of over 7 billion m^3/year (DWA 2013). This represents an existing adaptation to climate-linked water scarcity, but is also a reflection of the ways in which human settlement has changed the availability of water in South Africa.

Extreme weather and sea level rise are similarly hazardous in ways affected by the nature of human settlement: the development of construction techniques, together with insurance underwriting, has made construction possible in areas that were previously too flood-prone or exposed to the sea. Although agriculture has always depended on water, the water-intensity of industrial agriculture has changed the nature of drought risk, and national and international food markets can transmit risk into regions that would otherwise be shielded (just as they can transmit risk out of areas that would otherwise be risky).

The relationship between human settlements and climate hazards should therefore be understood as a complex interaction, which this report necessarily simplifies.

The table below summarises potential direct impacts on human settlements of particular climate change phenomena in terms of general warming, heat waves and drought, heavy and/or extreme precipitation events and storms, and sea level rise. Due to the likelihood of increased overall variability in climate, an increased likelihood of both drought and heavy precipitation in the same location is possible, despite the broad trend towards drying in the west of the country and wetting in the east identified in the phase 1 LTAS climate models.

Table 3: Possible impacts of climate change phenomena on human settlements

Climate change phenomenon	Consequences for human settlements
General warming – less intense with fewer cold days and nights, more frequent and intensely hot days and nights	• Intensified heat island effect • Increased energy demand for cooling • Declining air quality in cities • Reduced energy demand for heating • Reduced disruption to transport due to snow, ice
Extreme weather – heat waves and drought	• Increased water demand • Water quality problems • Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and poor. • Reduction in quality of life for people without appropriate housing
Extreme weather – heavy precipitation events and violent storms	• Adverse effects on quality of surface and groundwater, contamination of water supply • Increased risk of deaths; injuries; infectious, respiratory and skin diseases; water and food-borne diseases; and post-traumatic stress disorders • Disruption to commerce • Large displacement of people and distress migration to urban areas • Pressures on urban and rural infrastructure, including power outages, disruption of public water supplies and transport • Loss of property and withdrawal of risk coverage in vulnerable areas by private insurers
Sea level rise and storm surges	• Decreased freshwater availability due to saltwater intrusion • Increased risk of deaths and injuries by drowning in floods and migration-related health effects • Loss of property and livelihoods, loss of property and withdrawal of risk coverage in vulnerable areas by private insurers • Permanent erosion and submersion of land • Costs of coastal protection versus costs of land-use relocation and damage to natural infrastructure – potential requirement for movement of populations and infrastructure

Climate change and economies

Climate change will affect economic activity in complex ways, some direct, many not. Different types of human settlements hold different positions in the economy and so will be affected in different ways. But climate change will also have a number of systemic effects on the economy.

Certain raw materials are likely to become scarcer, and therefore increase in cost, most notably water (Golder Associates 2008) and ecologically-derived inputs (Naidu et al. 2006). More expensive inputs will damage all businesses, but will disproportionately affect small firms and the poor (Golder Associates 2008). The cost of living will increase, and living standards will decrease correspondingly – especially among the poor, who are both more vulnerable to rising costs and more likely to live in areas that are directly vulnerable to climate change-related events (Mukheibir & Ziervogel 2006). Increased costs of food and water and the increasing cost of adaptation will not only diminish living standards but also drive up labour costs (Golder Associates 2008).

The South African economy is exceptionally energy-intensive, and the energy sector is a major source of climate vulnerability. As this report was being drafted an unseasonable week of intense rain caused rolling blackouts on the national grid. Temperature rises will increase demand for energy-intensive cooling (air conditioning) although they may also decrease demand for electrical heating (which is a large component of winter energy demand). More problematic is damage by extreme weather to generation and transmission infrastructure threatening supply (City of Johannesburg 2009; Golder Associates 2008). Even with fully-functional infrastructure, supply could nonetheless be a problem. The nature of electricity is such that generation has to be matched to demand with some precision. Too much power generated means wasted coal, and too little means blackouts. Decisions about how much electricity to generate at any given moment are based on demand predictions using historical baselines, but unpredictably shifting climate-linked demand means that historical baselines will be of diminishing usefulness, constraining the ability to match generation to demand.

The precise economic effects of climate change are difficult to predict because economies are complex systems that shift and restructure in response to changing factor prices and other conditions. One major shift that might occur is to a low-carbon economy driven by South Africa's own mitigation policy or by as-yet-hypothetical EU emissions standards for imports. A move to sharply reduce carbon emissions would entail dramatic changes to the structure of the South African economy, the consequences of which are regrettably opaque.

Water and waste

Water supplies represent a major vulnerability of human settlements. South Africa is a high risk hydro-climatic environment to begin with (Schulze 2005). In 2011 91.2% of South African households had access to piped water, including from communal taps (StatsSA 2011a). Apart from delivering piped water to the approximately 4.5 million people who currently lack it, South Africa faces challenges of rapidly deteriorating infrastructure for those who already have water. In the 2011 General Household Survey only 62.1% of respondents reported that the quality of their water was good (StatsSA, 2011b). According to the CSIR the need to extend water services to the unserviced is great, yet is "far surpassed" by the need for rehabilitation or replacement of existing infrastructure and the "provision of infrastructure for population growth and new household formation due to the gradual reduction in average household size, immigrants from beyond our borders, and migration within South Africa" (CSIR 2010, 41).

Climate change will exacerbate these challenges in water delivery. Higher temperatures will increase demand both by people who have access to piped water and people who do not (City of Johannesburg 2009; Golder Associates 2008). Climate change will exacerbate water supply limitations both due to general water scarcity and increased evaporative loss (Naidu et al. 2006) and decreased water quality: "higher water temperatures will alter water-gas equilibria and increase the rates of microbial processes; these will in turn accelerate nitrification, de-nitrification, respiration and methanogenesis" (CSIR 2010, 13). An example of this is an increased risk of toxic blue-green algae blooms in warm, slow-moving bodies of water, which can be fatal for aquatic life. This will increase the requirements and costs of treating water and, if unmitigated, affect the biodiversity of aquatic systems.

Drivers of individual vulnerability

Vulnerability not only varies (in degree and nature) between settlements, but within settlements at the individual or household level. These individual factors also cumulatively affect the vulnerability of settlements. Factors determining the vulnerability of a given household include:

- **Access to basic services:** many households in South Africa have limited or no access to electricity, water and sanitation services. Access to electricity and water significantly affects the labour demands on household members as these services obviate the need to collect firewood or water from distant sources. This makes time available for paid labour or food production. Access to electricity, water and sanitation services also improves household health, by reducing reliance on fuel sources which pollute homes, unsafe water sources, and exposure to health-threatening waste.

- **Type of dwelling:** although this is dealt with below as settlements often contain many dwellings of one type, this is a household-level factor. Houses that are poorly built, are poorly located, or lack flood and lightning protection, efficient water systems, cool spaces, heat-reflective surfaces or damp-proofing are a source of climate vulnerability.

- **Health:** climate resilience is dependent on baseline health, including age. Children and the elderly are more susceptible to illness, heat stress, food insecurity and malnutrition, all of which are projected climate hazards. Baseline malnutrition and food insecurity are also sources of vulnerability, as is being HIV-positive.

- **Economic factors:** such as poverty and unemployment are major sources of climate vulnerability, not least because they link to many of the abovementioned factors. Poverty and unemployment also limit adaptive capacity directly: poor households might not be able to afford even modest investments to adapt to climate change. Land tenure status is another important factor: households with insecure tenure such as squatters are less likely or able to invest in adaptations.

- **Demographic factors:** including age (discussed above) and gender. The precise relationship between gender and climate vulnerability is under-researched and poorly understood, particularly in South Africa. However initial studies indicate that climate change affects men and women differently due to asymmetrical power relations and "social inequalities and ascribed social and economic roles that are manifested in differences in property rights, access to information, lack of employment and unequal access to resources" (Babugura 2010, 18; Banda & Mehlwana 2005). Differentiated social roles around the provision of income, food and water are particularly significant. In communities where women are expected to provide water, water scarcity dramatically and disproportionately affects the labour demands on women.

Many of the most vulnerable people in South Africa depend on social grants for income: as climate change advances, we can expect the grants system to come under increasing strain as vulnerability drives more people to depend on relatives' grants.

Case study: Gender and climate change

In one of the only studies to involve primary research into gender-differentiated impacts of climate change in South Africa, Babugura (2010) found that social expectations around the respective roles and responsibilities of men and women were a major differentiating factor.

In two poor, peri-urban communities in KwaZulu-Natal, women's responsibility to ensure household food security resulted in their having to increase their labour contribution in times of climate-driven food insecurity. In other words the greater burden of livelihood diversification fell on women. In addition water scarcity dramatically affected women's labour burden, as they were expected to fetch water if it was not available at the house (as was generally the case in one of the communities). Men reported awareness of these additional burdens for women, and for their part experienced primarily psychological impacts, specifically feelings of helplessness in executing their responsibilities to provide for the family.

However, to adapt to climate change, communities were weakening the gender differentiation of social roles: greater burdens on women, male unemployment, and changing gender norms interacted to result in men increasingly adopting activities previously reserved for women, such as domestic food production and collection of water.

3.1. Urbanisation, migration and conflict

South Africa is a highly migrant society, with large flows of people both from rural areas to urban, and between urban (or peri-urban) areas. South Africa is frequently presumed to be urbanising along with much of the rest of the world; however, South African migration does not take the form of urbanisation in a straightforward manner.

At different points in history South African policy has either encouraged or discouraged urbanisation. Many colonial and early apartheid laws were explicitly and directly designed around influx control, or preventing urbanisation. The reasons for this policy were complex and changed over time, but they served to guarantee a large and stable supply of cheap black labour for the white-owned industrial farms. The mines, for their part, relied on a large migrant labour force predominantly from neighbouring countries. This helped establish the patterns of cross-border migration which persist to this day. It also resulted in rural overcrowding and intensive subsistence agriculture, which in turn caused widespread ecological degradation and falling rural living standards. As the homelands became less able to support their residents, who had been confined to them by law, people increasingly defied influx controls to seek better lives in the cities.

By the 1970s influx control had mostly broken down, and "unemployment and poverty could no longer be externalized to the homelands" (Beinart 2001, 257). Starting with the Riekert Commission's findings, government policy shifted from influx control to inward industrialisation which relied on urbanising skilled black workers to provide new markets for manufactured goods (RSA 1979). This partial reform didn't last, and the scale of resulting migration defeated the state's efforts to control urbanisation. After the President's Council Report South Africa abandoned all racial controls on urbanisation, only to replace them with "orderly urbanisation" and the introduction of squatting laws and urban planning legislation (RSA 1985). This period of South African policy, which remains largely unreformed, helped create informal settlements on urban peripheries.

Migration today is the result of a combination of these historical dynamics and contemporary deprivation. Cross (2001) holds that in contemporary job-scarce South Africa, "there may be little advantage for the rural unemployed in moving to the city to look for work" and migration is thus largely driven by access to basic services. Access to water, electricity, telecommunications and transport is therefore a "second-best substitute goal", after employment. This means that social vulnerability caused by lack of access to services is closely linked, albeit in uncertain ways, to migration. It also means that migration is an existing adaptation strategy, both to vulnerability arising from joblessness and from lack of access to basic services.

Climate change and migration

Migration of one form or another is a common response to climate-related disasters such as floods and famines, and if these events increase in frequency then so too could the number of migrants (IPCC 2007, Box 7.2). Migration can be broadly divided into internal migration and regional migration, although they share many features.

In this context, it is possible that climate change, which will disproportionately affect the populations already inclined to migration (namely the socially vulnerable), will increase rates of migration. Specifically, climate-related food insecurity, service incapacity, extreme weather events and water security could lead to increased migration. On the latter, "There is no current research data to support the trend of migration due to climatic change as such, but anecdotal evidence shows that unfavourable rainfall seasons lead to increased urbanization" (City of Johannesburg 2009, 69).

Much of the above applies to regional migration, but there are additional, complicating factors. Since the end of apartheid South Africa has experienced large and growing flows of migrants from its neighbours: numbers of legal migrants alone grew from less than half a million to 4 million between 1990 and 1994 (Crush & McDonald 2002). Numbers of illegal migrants are (for obvious reasons) uncertain, and such estimates as exist are highly contested but around 150 000 people were deported from South Africa each year between 2000 and 2004 (Waller 2006, citing Department of Home Affairs).

Many of South Africa's existing and potential migrants come from countries that are likely to be dramatically affected by climate change – some more so than South Africa. For example half of South Africa's deportations were to Mozambique in 2004 (down from 87% in 1996) (Waller 2006); Mozambique has experienced a "significant increase in heavy rainfall events" (IPCC 2007, 436) which contributed to the devastating floods of the early 2000s. Mozambique is also among the African countries most vulnerable to rising sea levels (Dasgupta et al. 2007; see map opposite).

Migration, including climate-induced migration, has several effects relevant to human settlements in South Africa, the most prominent of which is urbanisation, although some particularities of South Africa's job market result in less clear urbanisation than in many other countries (Cross 2001). The migration described by Cross nonetheless strains infrastructure and services in receiving areas, and damages biodiversity (Phalatse & Mbara 2009). Furthermore "unplanned, unmeasured and unpredictable migration of unskilled people into an area with already stressed infrastructure and high unemployment will further reduce the livelihood index of the region" (City of Johannesburg 2009, 69). Migration risks (but does not necessarily result in) disruption of the destination's social fabric due to an influx of people not connected to the receiving community (Cartwright 2008). However migration can also result in the formation of new communities, as long as in-migrants do not move once again – as they are likely to do (Cross 2013).

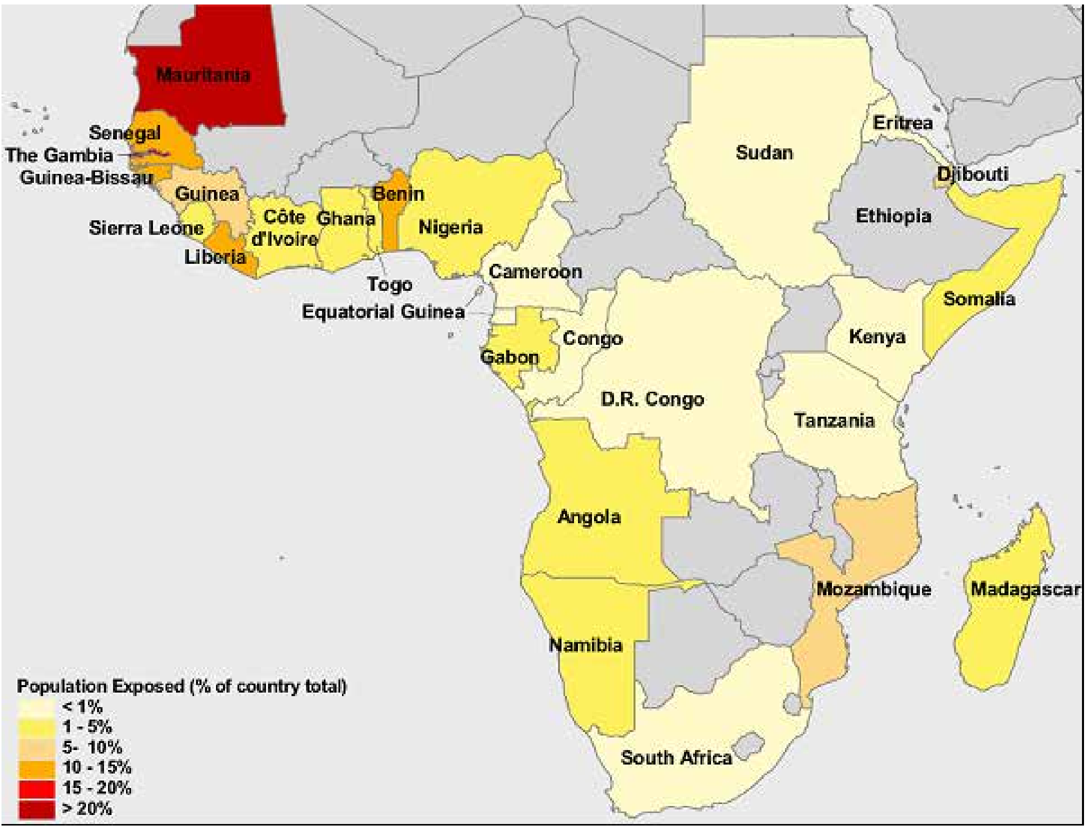


Figure 5: Vulnerability to sea level rise
Source: Dasgupta (2007)

Migration is not the exclusive preserve of the poor: many of the areas most vulnerable to sea level rise encroachment have been settled by the very wealthiest in South Africa; we can thus expect significant out-migration from wealthy coastal areas such as Muizenberg and Woodbridge Island (Cartwright 2008).

Standard policy approaches to migration and urbanisation are often misguided. Migrants seeking jobs usually settle informally in city centres, and are not well-served by "government attempts to channel settlement and provide formal housing in specific categories of locations" (Cross 2013, 253). Furthermore "permanent housing at the city edge can become a highly attractive, scarce and valuable good … trapping migrants in job-poor areas" (Cross 2013, 250).

Conflict

The relationship between climate change and human conflict is unclear: "few scholars claim a direct link between resource scarcity and armed conflict" (Buhaug et al. 2010, 81). However research indicates that resource scarcity, including climate change-driven scarcity, "adds yet another stone to the burden" (Buhaug et al. 2010, 81).

Case study: Migration and conflict in Bangladesh

Bangladesh is historically flood-prone: up to 18% of the country is routinely inundated. However in 1987 and 1988 floods inundated 40% and 84% of the country's surface area, respectively. Each flood killed around 1 600 people directly, and more due to subsequent disease outbreaks, and the 1988 flood displaced 40% of the Bangladeshi population (Hafiz & Islam 1992).

These floods, as well as major cyclones in 1970 and 1991, contributed to dramatic migration both within and out of Bangladesh: "millions of people have migrated from Bangladesh to neighbouring West Bengal and Assam in India" (Homer-Dixon 1991, 97).

Although it is difficult to ascribe specific causes to conflict, these large-scale population movements have probably contributed to group-identity conflict in Assam (Homer-Dixon 1991) as well as anti-state insurgency in the Chittagong Hill Tracts region of Bangladesh (Hafiz & Islam 1992).

Climate change should thus be understood as *contextual* to conflict. That is to say, conflict is the result of complex interactions of phenomena combined with the actions and attitudes of individuals, but climate change can exacerbate many of the underlying causes of conflict. For example, reduced state income due to resource scarcity (and the costs of adaptation) could result in failures of service provision (Homer-Dixon 1999). This is particularly relevant in South Africa where state services or lack thereof are linked to ongoing protests, some violent. Opportunistic elites might also take advantage of increasing scarcity to radicalise communities or sections of communities, possibly along ethnic or nationalistic lines (Kahl 2006). Loss of livelihoods in climate-dependent economies is another exacerbating factor (Homer-Dixon 1999), while large population movements caused by deteriorating environmental conditions, including rising sea levels, can lead to conflict through competition for resources in the receiving area, or by exacerbating existing social cleavages such as ethnicity or class (Reuveny 2007).

Reuveny (2007) documents 19 international examples of conflict linked to environmental migration, and another 19 examples where environmental migration did not lead to conflict. This is further evidence that there is no straightforward relationship between climate change, migration and conflict. South Africa has already experienced localised conflict linked to migration in the form of protests about service delivery and state incapacity that have taken the form of xenophobic violence. Climate change could exacerbate these existing causes of conflict in South Africa.

3.2. Urban settlements

All cities are unique, but South African cities are more unique than most. Apartheid, apart from anything else, was a form of racial urban planning that relied on "a variety of devices, from compounds for mine-workers to racial exclusion clauses in property deeds and even removals following plague" to secure segregation (Goodlad 1996, 1630). These and other policies, and the apartheid political economy, left lasting effects on the demographics, spatial characteristics and economies of each city.

South African cities are characterised both by areas of high density and by urban sprawl. City planners and developers combined modernist city centres with remote satellite communities designed to provide domestic labour. Spatial segregation by race was inconsistently successful but broke down entirely starting in the 1970s, to be increasingly replaced by spatial segregation by class as the white middle classes formed suburban enclaves and the black working classes moved into the inner city. Today even as neighbourhoods integrate racially, class barriers remain. Apartheid spatial and economic policy was also designed to silo black people by housing them in residential areas with few economic opportunities, thus forcing them to sell their labour cheaply. To this day South Africa has a relatively small informal economy. These areas were similarly designed to resist the development of strong communities, so as to reduce the likelihood of insurrection. South African cities remain characterised by weak local economies and weak communities, both of which are a significant source of climate vulnerability.

Capital intensification trends in agriculture and industry dating from roughly the 1970s resulted in mass urbanisation and steadily rising unemployment in both urban and rural areas. Urbanisation and the weakening of apartheid control in the 1980s and early 1990s led to even more urban sprawl and the proliferation of informal settlements in peri-urban areas. These informal settlements have proved extremely resistant to housing policy, despite the state trying a variety of approaches including social housing, forced removals, and informal settlement upgrading. Thus South African cities today are marked both by economic vibrancy and extreme deprivation, sometimes in close proximity.

The unusual spatial nature of South African cities is a source of climate vulnerability. Both suburban sprawl and informal settlements are challenges to climate-resilient infrastructure, requiring large, sprawling networks to reach residents. Low-density sprawl combined with poor public transport means that residents depend on cars to get around and are, therefore, susceptible to climate-induced degradation of roads as well as traffic congestion caused by extreme weather events. The weakness of local economies due to spatial segregation and single-use zoning means that not only are commutes long, but urban economies lack the resilience of a more decentralised system. Similarly, the importance for communities of adaptive capacity (discussed in more detail in section 4.5 below) means that the weakness of urban communities in South Africa is a major source of vulnerability.

This urban complexity presents a challenge to urban planning. A growing, unstable and largely deprived urban population, epitomised by the informal settlements, makes policy implementation particularly difficult. Participants at the two LTAS Phase II workshops repeatedly raised the difficulty of preventing people evicted from climate-vulnerable areas from returning: planners focused on minimising biophysical vulnerability, such as risk of flooding, frequently relocate threatened communities to places with little access to economic opportunities. The phenomenon of people returning to climate-vulnerable areas, or other people taking up residence once the previous residents are evicted, demonstrates the difficulties that face South African urban planners. In this case, adaptation might require a lesser focus on biophysical vulnerability and a greater focus on socio-economic vulnerability.

Climate change and urban economies

Although overall precipitation may either increase or decrease, South Africa is likely to experience increased rainfall variability and increased incidence and intensity of droughts (even, paradoxically, under the wetting scenarios). More variable patterns of precipitation, particularly rainfall that is more vigorous but less frequent, will damage equipment and fixed capital. This will disproportionately impact mining and manufacturing (Golder Associates 2008) and construction (Phalatse & Mbara 2009). Activity in these industries, particularly opencast mining, as well as the activities of informal traders (Phalatse & Mbara 2009) will be disrupted by increasingly inclement weather. Dry spells interposed with more vigorous rain will increase the frequency and severity of urban floods, which will not only destroy assets and livelihoods (Mukheibir & Ziervogel 2006), particularly in informal settlements, but will damage infrastructure crucial to economic activity. Mines and industry are both particularly vulnerable to extreme weather events (Golder Associates 2008) and particularly important to South Africa's urban economies. Increased climactic risk will in turn result in higher insurance prices and thus increased cost of investment, which will dampen urban economic growth (Golder Associates 2008). Those activities that are not insured, primarily those of small-scale and informal businesses, will suffer even more.

The health implications of climate change will result in increased lost working days and decreased productivity. A less-healthful climate will deter tourists: for example as malaria has become more prevalent in Durban, tourists have already diverted to other coastal venues (Naidu et al. 2006; Turpie et al. 2002). Tourists from colder countries may also find that they need not travel as far as South Africa, as their home climates warm, and parts of South Africa that become uncomfortably hot may also see fewer tourists (Golder Associates 2008).

Environmental goods and services on which cities depend (Durban's alone are valued at R3.1 billion per annum) are also vulnerable to climate change, through loss of biodiversity and environmental degradation and leading to loss of ecosystem services. Some examples of these ecosystem services include:

- The role of wetlands in mitigating flood risks, replenishing ground water, stabilising shorelines, water purification and retaining and exporting nutrients.
- The role that urban forests play in contributing to human health through regulating temperature and absorbing air pollutants, as well as reducing stormwater runoff.

Furthermore, the sustainability of cities depends on the integrity of the ecosystem services in rural areas that underpin agricultural production and the provision of fresh water for industry and human consumption.

Water and waste

In the context of generally exacerbated water scarcity, discussed above, South African cities are particularly vulnerable. Urban water supplies are already strained, particularly during the spring drought in much of the country (City of Johannesburg 2009) and they face increasing water demand due to urbanisation, expansion of access to water, and rising living standards. Metros such as Johannesburg and Cape Town compete for water with other areas (Golder Associates 2008; Mukheibir & Ziervogel 2006) and thus most adaptations focusing on increasing supply could simply export vulnerability to elsewhere in the country. Furthermore, in all areas biodiversity loss and changing climate will lead to an increase in the prevalence of invasive alien species with high water demands. "This could greatly reduce mean annual runoff and further affect the availability of water in Durban" (Mukheibir & Ziervogel 2006; Naidu et al. 2006, 68 citing UNEP 2000). The same holds for many cities or towns in a similar position.

Furthermore, inappropriate land use practices such as over-grazing and industrial effluent discharges will continue to exacerbate the already serious impacts on water quality due to soil erosion and pollution, which lead to increased sediment loads in water bodies that increase water treatment requirements and dredging requirements in harbours, as well as impacting on the health of estuaries and in-shore fisheries.

Waste is another challenge presented by climate change. Urban flooding will damage stormwater drains and sanitation infrastructure (Mukheibir & Ziervogel 2006). This is a problem in itself but will also lead to greater pollution of surface water (Golder Associates 2008) and resultant effects on health. Higher ambient temperatures will cause refuse to decay faster, both representing a hazard to public health and necessitating more frequent collection. The resultant strain on facilities is likely to lead to leakage and pollution. Changes in groundwater levels could also lead to leakage and pollution.

Transport and communications infrastructure

Extreme weather will damage roads, railways, bridges, airports, tunnels, and other transportation infrastructure incurring delays and maintenance costs. Extreme weather will also prevent repairs to damaged infrastructure. In addition groundwater changes will damage structures and foundations of the transportation system and higher temperatures will cause stress to construction materials, in particular steel (Golder Associates 2008). Extreme weather will also result in increased traffic congestion and collisions.

Cities are particularly vulnerable to disruption of transport, highly dependent as they are on the movement of people into and around them. For a variety of reasons South African cities are overwhelmingly dependent on private motorised transport and informal public transport – that is, cars and minibus taxis. This is both a cause and an effect of ever-expanding urban sprawl. These forms of road-based transport are particularly vulnerable to climatic disruption, as evidenced by the extreme traffic that results from even routine thunderstorms in Johannesburg. Urban transport disruption also leads to knock-on disruption of urban economies.

Human health

Extreme weather events also pose a threat to human health. This includes floods, heat waves, storms and fires, all of which are expected to become more prevalent due to climate change. The health system will come under increasing strain due to the health effects of climate change, which include increased temperature-related morbidity and mortality, increased exposure to diseases and problems with the water supply.

Climate change is expected to change the range and breeding season of a number of disease vectors such as mosquitoes (DEDEA 2011). This, with increased water pollution, will result in the spread of a number of diseases. Durban, for example, will see an increase in the prevalence of malaria (Naidu et al. 2006). However malaria predominantly affects rural areas, whereas dengue fever and bilharzia are more likely to affect urban areas, particularly those with poorly managed water and waste systems (Golder Associates 2008, citing Githeko et al. 2000). Thus these diseases will also disproportionately affect informal settlements.

Climate change is likely to result in diminished air and water quality. Higher temperatures cause temperature inversions, which trap existing pollution in cities, ultimately causing “headaches, dry eyes, nasal congestions, nausea, fatigue, respiratory problems, health care utilisation and even mortality” (Golder Associates 2008, 22 citing Campbell-Lendrum & Corvalan 2007; Dawson et al. 2007). Damage to water and sanitation infrastructure, combined with urbanisation and increasing population density, will lead to leakages, pollution and ultimately increased rates of water-borne diseases. Both declining air and water pollution will disproportionately affect areas with inadequate services, especially informal settlements (Golder Associates 2008).

Increased food insecurity will lead to malnutrition, which is closely linked to other health problems. Cities are also subject to the heat-island effect, whereby the built environment increases ambient temperatures by several degrees; urban residents are therefore especially vulnerable to temperature-related illness or death, particularly during heat waves (City of Johannesburg 2009).

Finally, disaster response services and emergency services will come under increasing strain as a result of climate change, particularly during extreme weather events (Cartwright 2008). This and the aforementioned infrastructure vulnerabilities will feed back into increasing vulnerability, because the most socially vulnerable – the poor – are also the most dependent on government services.

Peri-urban settlements

Due to rapid urbanisation combined with organic growth, South African metros and towns are characterised by extensive peri-urban development as urban centres expand into formerly rural areas in a phenomenon referred to as urban sprawl. The resulting settlement patterns may feature a diverse range of social classes and generally continue to reflect the dynamics of apartheid spatial planning.

- Affluent residential areas: In general these are the result of gradual organic urban growth, often on land that has high agricultural potential or scenic value and they are a result of lifestyle choices by high net worth individuals and families. Such residential areas are often lucrative targets for high-end property developers and there are strong market pressures to exclude low cost housing or social housing developments on this land. These areas are likely to have excellent public and private infrastructure, high levels of consumption of utility services such as water and electricity, and relatively low population densities. Generally, infrastructure within these areas complies with building codes and is resilient to extreme weather.
- Gap, low cost and social housing estates: These are often a legacy of apartheid town planning guided by the Group Areas Act, No. 41 0f 1950 and ensuing legislation and tend to have racial or ethnic identities, but also include many new RDP housing estates dating from the post-1994 era. In general, land use for low cost housing developments continues to be dictated by market pressures, despite state policy in terms of the National Housing Code (DHS 2009), to promote more mixed communities and create low cost and social housing opportunities in closer proximity to economic hubs in the urban centres. Leasing of informal or semi-formal structures (shacks) in backyards of low cost or gap housing is widespread.
- Informal settlements: These unplanned, and in many cases illegal, developments are driven in large part by migration to the metros by the rural poor and (to a much lesser extent) by inward migrations from neighbouring countries. The majority of vacant land occupied in this way is on the urban periphery. A significant percentage of the backlog in service delivery is associated with informal settlements. Informal settlements often have the highest population densities in urban settlements, with the exception of those few South African metros that have high-rise residential developments in and adjacent to their CBDs, such as Hillbrow in Johannesburg.

Informal settlements are especially vulnerable to climate change for a number of reasons. By their nature they are unplanned, without extensive service or infrastructure coverage. They feature construction using "materials of diverse origin and quality, and not always following accepted techniques. These houses rarely comply with official safety standards and there are no controls in place" (Hardoy & Pandiella 2009, 211). They are usually located in peri-urban areas that were not previously settled or developed, often either because of distance from economic centres or because the location is vulnerable to weather events: the former is a source of social vulnerability; the latter a direct source of climate vulnerability. Furthermore informal settlements are often overcrowded, and their residents are typically the most socially vulnerable groups in society for various reasons.

Ahmed et al. (2009) found that the urban poor, many of whom in South Africa live in informal settlements, are the most vulnerable social group to climate volatility, especially through food price volatility. Thus not only are informal settlements typically more exposed to climate hazards than other urban areas by virtue of their location, but they also lack adaptive capacity due to the poverty of their residents. Nonetheless, despite being the locus of extreme social and climate vulnerability, informal settlements are neglected in the majority of climate vulnerability assessments. Residents of informal settlements have unique vulnerabilities that do not always correspond to those of other urban residents. For example, residents of informal settlements have been known to respond differently to disaster management: the high risk of looting in informal settlements means that people are reluctant to leave their homes even when under imminent threat (Hardoy & Pandiella 2009).

Informal settlements can be even more vulnerable than other urban areas of comparable poverty, as they are underserved by formal services and generally have little institutional capacity. Their adaptive capacity can be limited by community disorganisation, lack of government support, and individualistic investment by households (Wamsler 2007). Sometimes government actively reduces the adaptive capacity of informal settlements, inadvertently or not. For instance, residents of informal settlements might be discouraged from leaving their homes during extreme weather events by concern that government will not allow them back (Hardoy & Pandiella 2009). Even when this is not the case, informal settlements are often unable to mobilise behind political demands, either due to lack of resources or because local government is oriented towards other citizens (Ribot 2010). Residents of informal settlements may also lack reactive adaptive capacity, lacking the funds to replace or repair damage to houses in the face of disasters (Alam & Rabbani 2007).

Case study: Ruimsig

Ruimsig lies on the borders of the City of Johannesburg and Mohale local municipality in Gauteng. It was inhabited by farm workers in the 1980s and bought from a farmer by the City of Johannesburg in 1998, and rezoned from a peri-urban agricultural zone to a residential zone. As middle-class housing estates developed around it job-seekers in the construction industry settled on the land resulting in rapid informal growth from 2006. The city provided about 70 ventilated improved pit (VIP) toilets for the settlement and three standpipes, but no electricity. Due to increased shack densities, some of the VIP toilets became inaccessible for servicing. The eastern and southern areas of the settlement are located on a now-degraded wetland and are prone to flooding.

The community has been working with the Federation of the Urban and Rural Poor (FEDUP) to establish savings schemes and develop community projects, which led to a partnership with the University of Johannesburg's Department of Architecture on a re-blocking project. This involves relocating shacks and re-demarcating boundaries to improve the layout of the settlement by:

- reducing congestion and shack density
- reducing flood and fire risks
- improving access to facilitate provision of future basic services

- creating safer communal play areas for children.

The ongoing success of the project hinges on the active participation of community members as "community architects" and builds on the existing social cohesion within the settlement. Obstacles that needed to be overcome included:

- opposition from some shebeen owners and shack-lords
- conflict with neighbouring ratepayers associations.

Source: Shack/Slum Dweller's International (SDI) South African Alliance website: http://sasdialliance.org.za/

It is clear that informal settlements are not only among the most vulnerable settlements in South Africa; they also have unique vulnerabilities that are not adequately documented in existing vulnerability assessments. This is partly attributable to the frequent bias towards biophysical vulnerability over the social and economic components of vulnerability in existing studies. More and better research is needed to better implement community-based adaptation responses in informal settlements.

3.3. Rural settlements

Rural economies are primarily dependent on agriculture, herding, and tourism, all of which are directly or indirectly vulnerable to climate change.

Rising temperatures, reduced rainfall, water scarcity and bush encroachment would all damage agriculture, particularly rangelands. Less land would be available for these activities and the growing season would be shorter and yields smaller (Madzwamuse 2010). The nearly 5 million small-holders, of whom almost none use irrigation, are at the highest risk (Gbetibouo & Ringler 2009; Madzwamuse 2010). Maize, a major subsistence crop, could see yields reduced by as much as 10–20%, and some parts of the west of South Africa may become entirely unsuitable for maize production, although this may be partly offset by higher yields in the eastern part of the country (Kiker 1999). This is a serious threat to food security, as well as the incomes of those smallholders who sell their surplus. It is also a threat to commercial agriculture, which will also suffer from reduced availability of water for irrigation (FAO 2011), and this will in turn threaten rural employment.

Livestock are an important commercial product and an important source of food, capital and draft power for smallholders. Livestock ownership measurably reduces vulnerability compared to small farms relying on rainfed agriculture (Shewmake 2008). Cattle numbers could decline by as much as 10% due to drought, bush encroachment, malnutrition and disease (Madzwamuse 2010), but not on industrial feedlots. Therefore poor herders who rely on rangelands will be disproportionately affected. Livestock are both affected by, and a cause of, environmental degradation, particularly through overstocking and resultant overgrazing (Bourne et al. 2012). An increase in pests and diseases due to higher temperatures and heat stress will also reduce livestock production, and the combination of droughts and thicker grass (due to greater concentrations of atmospheric C02) could lead to a 20% increase in the intensity of veld fires (Madzwamuse 2010).

Diminished biodiversity and environmental degradation is a source of rural vulnerability for a number of reasons. Poor rural communities rely on informal resource use for survival (Madzwamuse 2010) as well as on jobs provided by biotourism. Rural tourism relies on biodiversity, both of flora and fauna, which will experience a reduction in both species and range (Rutherford et al. 2000). This includes damage to current biodiversity hotspots. There will thus be greater conflict between conservation and other land use. Ecosystem services on which farmers depend will also be further exacerbated by climate change such as soil loss through erosion, pollination from species loss or shifts and so on. In addition, rural tourism is vulnerable to many of the effects discussed in **Section 3.2**, Climate change and urban economies, above.

Rural areas also experience greater concentrations of social vulnerability than their urban equivalents, which compounds climate vulnerability. In many areas employment is low and declining, and poverty is pervasive (Bourne et al. 2012). Communities are correspondingly more vulnerable. According to the IPCC "it appears that possible negative impacts of climate change pose risks of higher total monetary damages in industrialised areas (namely, currency valuations of property damages) but higher total human damages in less-developed areas (namely, losses of life and dislocations of population)" (IPCC 2007, 365).

Much of rural South Africa, particularly outside large-scale industrial agriculture, functions with formal or informal systems of commonage. Commonage is both "an invaluable adjunct to the low wages and general insecurity of wage employment" and a source of insecurity (Madzwamuse 2010). Recently the commons has seen an increasing influx of people following mass retrenchments from mines and industrial farms. Commonage frequently suffers from inadequate municipal support due to low budgets and capacity constraints, and from the unaccountability and lack of resources of users. In particular ineffective group structures threaten the sustainability of commonage (Bourne et al. 2012). These factors mean that commonage (and the communities that rely on it) is particularly vulnerable to the effects of climate change, including aridification and bush encroachment (Bourne et al. 2012).

As in urban areas, water is "a key medium through which climate change impacts" rural areas (Bourne et al. 2012, 68). In many areas water is the limiting resource for development (Madzwamuse 2010). Much of rural South Africa is arid or semi-arid, and thus "highly sensitive to changes in rainfall because only a small fraction of rainfall is converted to runoff and groundwater recharge is minimal" (Madzwamuse 2010, 8). Climate change will result in increased evaporation, changes in rainfall, damage to infrastructure from floods and storm surges, and reduction in groundwater recharge (Bourne et al. 2012). The west of the country is particularly vulnerable to these impacts.

This water vulnerability, as discussed in **Section 3** under climate change hazard exposure, will primarily affect agriculture. This applies to both irrigated agriculture, which depends on ground and surface water, and non-irrigated agriculture directly dependent on rainfall. Apart from agriculture, rural towns will also be negatively affected as many depend on groundwater for consumption and economic activity (Bourne et al. 2012). A perverse effect of increasing water scarcity is to turn many existing adaptations into maladaptations: for example irrigation and the piping of water for settlements, both historic adaptations to water scarcity, are likely to become maladaptive, limiting water for downstream users (Bourne et al. 2012; Madzwamuse 2010). Apart from diminishing water *quantity*, climate change is likely to damage water *quality* (Bourne et al. 2012), exacerbating the vulnerabilities discussed here. Finally, there may be a knock-on effect of water scarcity: access to water is one major success of service delivery in democratic South Africa (Madzwamuse 2010) and, as access to water becomes more difficult to guarantee even for those who already enjoy it, there may be unpredictable consequences for social stability.

Transport and basic services are uniquely challenging in rural areas. Transport infrastructure largely takes the form of gravel roads which are vulnerable to climate-linked erosion and flooding (Bourne et al. 2012). Apart from making travel difficult (and limiting access to markets) this adversely affects the provision of basic services as police, fire services and ambulances all depend on these roads. Thus rural service provision, which is already poor due to great distances and limited budgets (Bourne et al. 2012), is both vulnerable to climate change, and a significant source of vulnerability to climate change. Similarly disaster response services may be expected to become more necessary (due to extreme weather events) and more difficult (due to deteriorating transport infrastructure).

Social grants are vulnerable in rural areas, as they are in urban areas, with two important differences. First, grant recipients are a greater proportion of rural residents than urban, and thus the rural grants system is likely to become even more strained. Secondly, rural livelihoods are more directly vulnerable to climate change due to their dependence on water, and yet more people may come to rely on social grants for income.

Rural communities are subject to many of the same vulnerabilities to human health as people in cities, with a few crucial differences. Food insecurity is likely to be more of a problem in rural areas, particularly for subsistence farmers. The resultant malnutrition would also be a source of vulnerability to other threats to health. As mentioned, diseases like malaria are more prevalent in rural areas, and this is compounded by poor and sparse rural health coverage. Extreme weather events are similarly a problem in rural areas. Veldfires in particular will increase both in frequency and intensity, due to a combination of higher temperatures and thicker but drier vegetation due to higher levels of $C0_2$ and scarcer water (Madzwamuse 2010). In some areas, grasses may grow taller due to carbon fertilisation and wetter rainy seasons, resulting in increased severity of veldfires during the dry season.

Case study: Climate vulnerability in rural KwaZulu-Natal

In their 2011 study, Community-Based Adaptation to Climate Change in Durban, Golder Associates identified the following drivers of climate vulnerability in the rural communities of Ntuzuma and Ntshongweni:

- **Demographics:** It is evident in both communities that there are a significant number of children, with a small majority of elderly people upon whom the majority of the population depend for their livelihoods. There is an obvious and direct correlation to the livelihood strategies, which demonstrated an overwhelming reliance on government grants.
- **Social networks:** Community groups in both Ntuzuma and Ntshongweni exhibited poor participation levels, reinforcing the general feeling of disunity and lack of social cohesion.
- **Water and waste:** Neither community ranked particularly vulnerable due to the water and sanitation service development in the area.
- **Climate variability:** Ntshongweni ranked as having a greater vulnerability to climate variability due to their reliance on food production and communal gardens.
- **Food security:** The predominant vulnerability with food security for both communities remains the high levels of food purchasing and low levels of food production, and considering the vulnerability with livelihood strategies and low income levels, this stands to be an issue of concern (Golder Associates 2011, 18).

It is generally true that rural communities, and particularly poor rural communities in South Africa that are not connected to the electricity grid or municipal water, are more reliant on natural resources for energy, water and food security. As a consequence, impacts on these resources due to climate change and other impacts of human activity are more keenly felt.

Mixed settlements

Under apartheid, there was a systematic attempt to relocate black South Africans to the so-called homelands, which has resulted in settlement patterns and governance arrangements that are both complex and uniquely vulnerable. These settlements can be considered mixed in at least two ways:

- Governance is accomplished both through elected local authorities (within the urban edge) and through traditional authorities (responsible for administration of communal lands).
- Population densities are typically high, resulting in a blurring of the distinction between urban and rural.

Figure 6 below displays the close correspondence between the areas of the country that constituted the Bantustans under apartheid, and the areas of the country under the authority of traditional councils as of 2010.

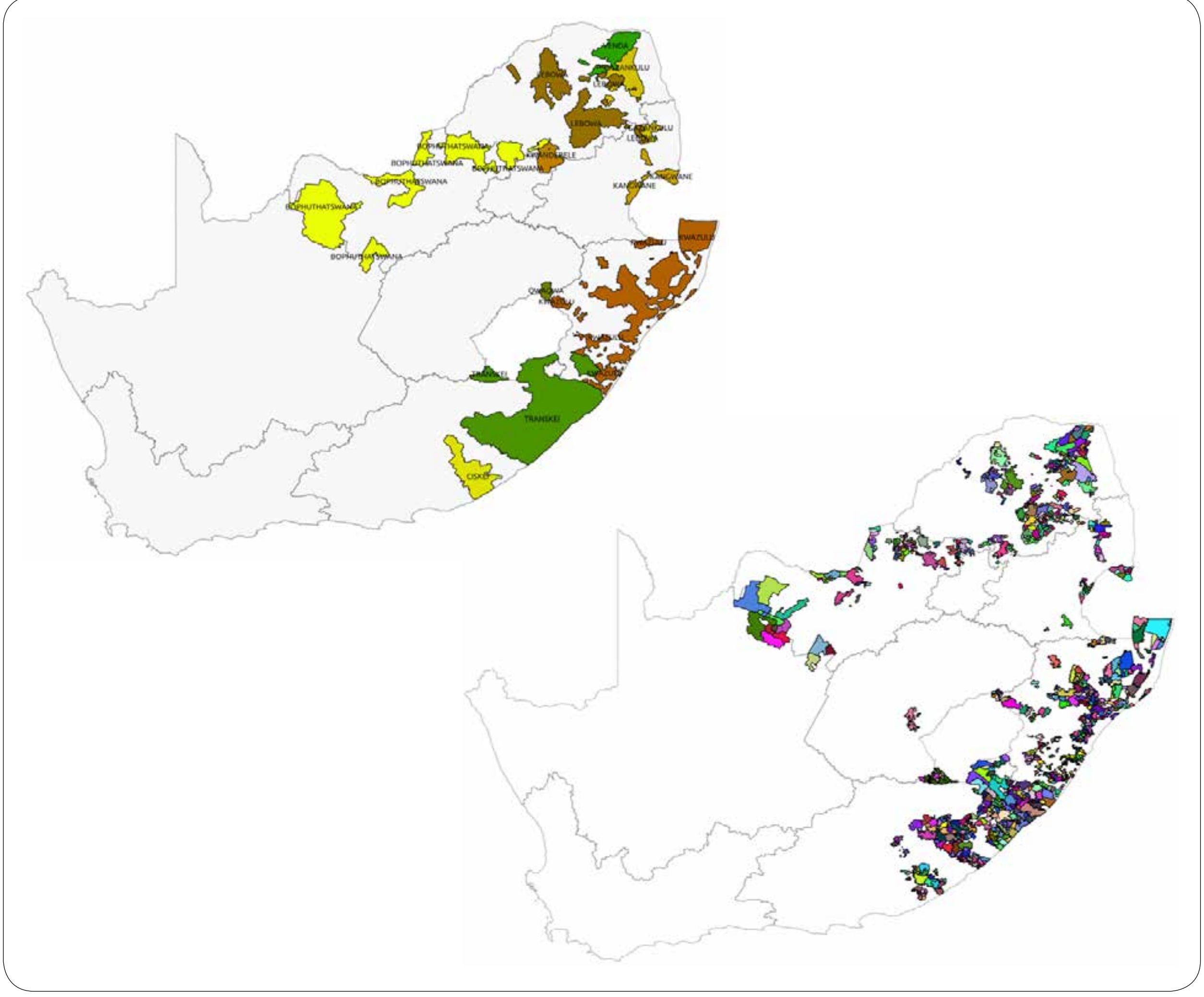


Figure 6: Former Bantustans (top) compared to traditional councils in 2010
Source: Rural Women's Action Research Programme, Centre for Law and Society, University of Cape Town (2014)

Whilst a level of subsistence farming is maintained in these areas, the contribution of farming to household income is typically low. The high population density in these "rural areas" has resulted in extensive land degradation, particularly as a result of deforestation and overgrazing, and resultant soil erosion (Wessels 2005). This creates particular environmental sensitivities to the impacts of climate change, exacerbating the impacts of drought and the extent of soil loss during intense precipitation events, which are likely to increase.

In recent history, the former homelands have been the most food insecure areas in the country. The introduction of social grants has led to improvements in food security in these areas, but subsistence farming and small-scale farming remain important contributors to food security. In these areas, more than 50% of farming households use land allocated by traditional authorities and do not have title deeds to the land they farm (Pienaar & Von Fintel 2013).

Mixed settlements in the former homelands are also socially vulnerable due to their unplanned nature – access roads are seldom tarred and may become impassable when wet, creating a risk for disaster management responses. Penetration and maintenance of basic services is often poor, and the costs of rolling out these services are very high as a consequence of the dispersed settlement patterns, poor access, and distance from urban centres.

While there have been some improvements in the delivery of healthcare and education, there remain significant challenges in terms of infrastructure and human resource capacity that are disproportionately experienced by these communities. As a consequence of the challenges of service delivery in mixed settlements, there is a move towards rural densification around service centres and nodes in these areas, but for this to be successful it needs to be accompanied by careful planning to ensure local economic development creates the economic opportunities needed to sustain this strategy.

3.4. Coastal settlements

The South African coastline is less vulnerable than it could be: "due to the relief of much of the South African coast and the location of existing developments, relatively few developed areas are sensitive to flooding and inundation resulting from projected sea level rise" (Theron & Rossouw n.d., 1). There are important exceptions, however, including northern False Bay, Table Bay, the Saldanha Bay area, the South Cape coast, the stretch from Mossel Bay to Nature's Valley, Port Elizabeth, and parts of the KwaZulu-Natal Coast (Theron & Rossouw n.d., 1).

Coastal economies are vulnerable to climate change primarily through its effects on fishing. On top of already diminished fish stocks, increased water temperatures, ocean acidification and changes to aquatic nutrients threaten marine biodiversity (FAO 2011; Midgley et al. 2005) and the distribution and range of alien invasive species (DEDEA 2011). Extreme weather events will also threaten fishing boats (FAO 2011) and changes in the condition of estuaries will threaten fish reproduction (Lamberth & Turpie 2001). In total South African fisheries' value could be reduced by up to 18% by the effects of climate change (Turpie et al. 2002). Dry spells and droughts will concentrate effluent discharges, further damaging coastal ecosystems and their dependent economies (DEDEA 2011).

As an example of the impacts of increased extreme weather on coastal settlements and shipping, a violent storm in Port Nolloth resulted in six diamond mining vessels running aground and several houses being waterlogged by storm surges. As a consequence, a sea wall has been built by the local municipality (Gosling 2011).

Rising sea levels and extreme weather events will result in partial or total inundation of some coastal areas and damage to others resulting from salt water intrusion, increased erosion, elevated and increasing salination of groundwater (Hughes 1992), greater tidal influence and flooding among other things (Midgley et al. 2005).

Figure 7: Landsat image indicating relative elevation of Cape Flats
Source: Bouchard et al. (2007)

Salination of groundwater is of particular concern: a number of settlement-supporting aquifers are highly vulnerable. The important Atlantis aquifer under the west coast interior is already brak (brackish) and seawater intrusion could threaten its ability to support the settlements that depend on it; similarly the groundwater beneath the Cape Flats already has a relatively high salinity, which further seawater intrusion will exacerbate (Cartwright 2008). Increased groundwater salinity will threaten smallholders who depend on vulnerable aquifers, making some areas "non-arable and possibly uninhabitable even without them being inundated" (Cartwright 2008, 41). Farms or industrial or commercial buildings which are situated in low-lying areas, or which rely on infrastructure situated in low-lying areas, are directly at risk from rising sea levels and extreme weather events, either through inundation or resulting damage (DEDEA 2011; Naidu et al. 2006). Increasingly intense coastal weather will also cause greater erosion and damage to coastal land, wetlands and estuaries, as will greater silt deposits caused by increased rainfall (DEDEA 2011).

Case study: Seasonal flooding on the Cape Flats

Approximately 150 000 Cape Town households are located in informal settlements. Eighty-eight thousand of these households are in areas at risk of flooding during the winter rains, of which more than 80 000 are on the Cape Flats.

Even during a normal winter up to 4 000 homes are affected by floods, and that number is frequently higher: in the winters of 2007, 2008 and 2009 more than 8 000 homes were affected, and in 2001 floods affected 11 000 homes, or about 13% of dwellings in Cape Town's informal settlements.

The particular vulnerability of the Cape Flats is due to a combination of biophysical and social vulnerabilities. The Flats are not only flat but sandy, low-lying and water-logged: the water table is unusually close to the surface and the area was once a wetland. Settlement has been relatively rapid and unplanned due to in-migration, and this has disrupted natural drainage patterns, exacerbating the tendency for the water table to rise above ground level. Flooding in the Cape Flats is thus typically characterised by slowly but inexorably rising water levels, rather than flash floods.

Compounding these biophysical factors is extreme social deprivation. A typical dwelling on the Cape Flats is built from corrugated iron sheets on a wooden frame, offering little protection from rising waters. Residents lack capital or credit to upgrade, protect or repair their homes, and formal and informal institutions of governance are weak. Although the Flats are clearly a dangerous place to live, land is scarce in Cape Town and residents often have no option: "Despite Council's repeated warnings each year, hundreds of families still persist in building their shacks in flood-prone areas. Even after we have offered the latest flood victims an opportunity to relocate to dry ground, they still prefer to stay in their waterlogged homes, out of fear that other desperate home-seekers will occupy their properties" (City of Cape Town quoted in Ziervogel & Smit 2009, 8).

Climate change has the potential to dramatically exacerbate the flood risks of the Cape Flats due to sea level rise and more extreme weather events, but the relationship is not well understood. Further research is therefore necessary.

Source: Ziervogel & Smit (2009)

Much of South Africa's tourism is closely linked with coastal regions. Beaches by definition are low-lying and adjacent to the sea, and are directly threatened by rising sea levels, extreme weather, erosion and other effects of climate change (Cartwright 2008; Naidu et al. 2006; Turpie et al. 2002). Similarly, marine recreational activities, tourism-supporting infrastructure such as beach-access roads and the aesthetic appeal of the coastline are all vulnerable (Cartwright 2008).

Ports are central to South Africa's large coastal urban economies including Durban, Cape Town and Richard's Bay. Ports are also directly vulnerable to climate change: "they are often exposed to a range of climate hazards, including sea level rise, storm surges, extreme wind and waves, and river flooding" (IFC 2011, 12). Adverse climatic conditions can affect shipping movements into and out of ports, with potentially expensive delays. Delays could drive business from more- to less-affected ports, and increase the cost of shipped goods overall. Ports are also dependent on water, electricity, and transportation infrastructure and are thus vulnerable to knock-on effects of disruptions or damage due to climate change. More difficult to predict, ports' business is highly dependent on global trade, and this will be affected in complex ways by climate change: if a wetting climate improves South African agriculture, ports will benefit greatly from expanded exports; however ports are sensitive to diminished exports or imports, which may also result from climate change (IFC 2011). One (limited) potential economic benefit of climate change is rising sea levels causing ports to become deeper, thus accommodating ships with deeper drafts (DEDEA 2011). However increased runoff or sedimentation may result in the need for more frequent dredging. Ports are therefore vulnerable to climate change in complex and difficult to predict ways.

Case study: KwaZulu-Natal coastal vulnerability assessment

The Department of Agriculture, Environmental Affairs and Rural Development in the Province of KwaZulu-Natal has undertaken a coastal vulnerability assessment of the 580 km long KwaZulu-Natal coastline that has provided a relative coastal vulnerability index (CVI). In conjunction with local data on wave run up and projections of sea level rise, the CVI provides a useful tool in helping to identify coastal areas that are likely to be vulnerable to physical hazards associated with climate change.

To generate the CVI, relative physical vulnerability of the coastline was determined for 50 m X 50 m cells by using weightings of parameters such as beach and dune width, distance of vegetation from the beach, slope and orientation, as well as distance to the 20 m isobath.

eThekwini Metro, for instance, has a CVI score that places almost half of its coastline in the high risk category, primarily as a result of low beach and dune width, and little back beach vegetation.

Source: Palmer & Parak (2011)

The infrastructure of coastal settlements is particularly vulnerable to the effects of climate change. Coastal settlements' water supplies are vulnerable to a number of factors above and beyond those already mentioned in **Sections 3.2** and **3.3**. Sea level rise, saltwater intrusion and groundwater rise all threaten to damage water and waste infrastructure, not only threatening provision but leading to leaks and pollution of water sources. For example the Atlantis aquifer in Cape Town is a crucial water source for a number of communities and is directly threatened by rising sea levels (Cartwright 2008). Furthermore salinisation of groundwater will accelerate the leeching of toxins from landfills into the groundwater, threatening the health of communities which rely on it. Rising seas could also backwash through the sewerage and wastewater systems, causing both damage and hazardous pollution. Finally increasing intensity of weather events will erode coastal infrastructure and property.

Coastal transportation infrastructure is also vulnerable to the effects of climate change, including damage to roads and railways (Cartwright 2008; Mukheibir & Ziervogel 2006), delays and congestion due to sea-flooding, displacement of sand onto roads, and increased erosion of coastal infrastructure (Mukheibir & Ziervogel 2006).

Case study: Financial vulnerability to sea level rise in Cape Town

Sea level rise has both direct and knock-on financial implications for Cape Town. A rise of 2,5 m would result in a loss of 25 km^2, and real estate worth approximately R3,25 billion over 25 years. Cape Town would also lose a number of beaches, and access to several more. Tourism is a major growth industry for Cape Town, and is directly threatened by rising seas. In all, a 2,5 m rise could cost the City R5,2 billion in property, lost tourism revenue, and infrastructure over a 25-year period. Although this scenario is the most likely, greater rises could result in losses of up to R54,8 billion over the same period. For comparison, Cape Town's budget for 2012/13 was just under R30,3 billion (Cartwright 2008).

Finally, there are unique risks to industrial infrastructure on the coast. For example, Koeberg Nuclear Power Station is vulnerable to damage to its salt-water intakes, and breakwaters at ports will be damaged by more intense exposure to the sea.

4. CLIMATE CHANGE ADAPTATION RESPONSES

The United Nations Framework Convention on Climate Change (UNFCCC), of which South Africa is a signatory, commits parties to "Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods (UN 1992, Article 4.1(e)). Adaptation can take a number of different forms, be undertaken by a number of different agents, and be of variable effectiveness.

There can be no one-size-fits-all adaptation strategy: adaptation needs vary not only with the particular climate vulnerability experienced by an area or settlement, but with the economic, institutional and socio-economic context as well. The wrong adaptation strategy could be more than wasteful; it could be maladaptive. Some common examples of maladaptive strategies are irrigation of farmlands in response to diminishing rainfall (which can exacerbate surface- or groundwater scarcity) and migration from one climate-vulnerable area to another superficially more attractive one. These strategies for adaptation may actually increase the vulnerability either of those undertaking them or of others affected by them.

This section will cover general principles of adaptation in human settlements, as well as examples of specific adaptation strategies that have been identified for use in South Africa. These examples can only be taken as indicative: taken together they do not apply to all settlements, and nor are they comprehensive for any particular settlement.

4.1. National and provincial planning for climate change adaptation

Climate change adaptation has to happen at local level; however, national government can play a critical role in enabling and supporting effective adaptation.

A strong policy framework at national level can guide local adaptation strategies, including establishing standards of best practice. Local adaptation planners (in the best case) are at an informational advantage due to their closeness to the communities and environments that policy needs to serve, but can be at a corresponding disadvantage in the scale of adaptations they can plan. Therefore provincial and national strategies are necessary to coordinate adaptations at a large scale. This is particularly relevant with regard to water and food security in South Africa. Food security often depends on large, decentralised networks and systems on a regional or global scale, including the market. In urban areas, where domestic food production is relatively minimal, food security depends entirely on markets and linkages with rural areas. Thus adaptations targeting food insecurity will require coordination by provincial, national and even regional actors. Similarly, South Africa has developed extensive water networks in response to natural scarcity, including networks that cross national borders. From a particular settlement's local perspective, increasing access to surface, ground or piped water may be an obvious adaptation measure. However conditions of scarcity may mean that such measures result in a zero- or negative-sum effect on water security. Thus national policy is required to coordinate strategies and mediate between the competing adaptation needs of particular settlements.

Another set of climate vulnerabilities that demand provincial or national coordination centre around population migration. Whereas from the point of view of an urban settlement migration may be an exogenous source of vulnerability, from a provincial, national or regional point of view that same pattern of migration is an internal phenomenon that may respond (to an extent) to policy. Put another way, national government might choose either to reduce the migration by promoting adaptation in rural areas, to influence the patterns or choice of destinations of migration, or promote adaptation that takes account of migration in the ultimate destinations of migrants; or any combination of these.

These policy choices made at national or provincial level must be achievable at local level.

National and provincial government can also help fund, incentivise and capacitate adaptation where local finances or capacity are constrained. Local planners may lack the resources or capacity even for existing policy objectives or short-term plans and national or provincial government may be able to step into the gap. Local planners should build on the adaptation planning frameworks created at national and provincial level to create new funding mechanisms and autonomous adaptation responses. Furthermore where adaptation strategies draw on non-government actors, particularly private companies, provincial government can offer investment or tax incentives. Public private partnerships are a potentially useful implementation tool for adaptation responses, particularly in relation to municipal infrastructure and lands.

National or provincial government can also encourage risk sharing in a way that is not possible without coordination: certain types of insurance might not be economical on a household or local level, but become possible with government mandates. Financial or performance incentives, which link to good adaptation practices at local level, can also be provided.

In general, provincial and national government is capable of planning for climate change adaptation at scales and along timescales that simply are not possible at lower level, and they can also create an enabling environment through resources and policy to support effective adaptation. Local planners often concentrate on familiar technical solutions to environmental problems and may not be aware of ecosystem based adaptation strategies – innovation by local authorities needs to be encouraged and supported by provincial and national government. National programmes such as the Extended Public Works Programme and the Strategic Infrastructure Programme, if implemented effectively, can be used to bring scale to adaption responses and support local adaptation.

4.2. Adaptation and development

The link between social vulnerability, climate vulnerability, and adaptive capacity is related to another general principle, which is that effective adaptation closely resembles non-climate-related development. "Much of what is needed to make cities resilient to climate change within the next few decades is no more than 'good development' in the sense of the infrastructure, institutions and services that meet daily needs and reduce disaster risk" (UN-Habitat 2011, 129). Thus what human settlements in developing countries need, "is not a climate change adaptation programme but a development programme – meeting already existing deficits in provision for water, sanitation, drainage, electricity, tenure, healthcare, emergency services, schools, public transport, etc. – within which measures for climate change adaptation are integrated" (UN-Habitat 2011, 129). A secure home of high quality, served by good infrastructure and services addresses many vulnerabilities including most that are related to climate change. Adaptation, by one definition, is just "development in a more hostile climate" (Stern 2009, 75).

This becomes a potential source of institutional weakness if climate change adaptation is left in the hands of agencies that see their remit as distinct from broader issues of development and service delivery, or if these agencies are given a narrow mandate limited to climate change issues. On the other hand, it represents an opportunity for synergy. Given well-designed institutional arrangements and mandates, development and adaptation objectives can be combined along with the resources necessary for each. Adaptation could be thus be mainstreamed into economic, spatial, and infrastructure policy.

As there is a negative causal relationship between adaptive capacity on the one hand, and income and assets on the other, adaptive capacity can be redistributed down the economic ladder, with progressive taxation and social spending. Furthermore resources expended on building adaptive capacity have a much greater marginal benefit for the socially vulnerable, where any additional capacity will make a big difference, than they have for the already highly-adapted, for whom the difference would be relatively smaller. Thus planned adaptation should primarily target the most socially (and hence climactically) vulnerable parts of society.

4.3. Economy, livelihoods and land

4.3.1. Urban economy and livelihoods

Adaptation for mines and industry can take the form of physical protection from extreme weather conditions. This can be driven either by legislation, such as building codes or by the increasing integration of climate risks into insurance companies' actuarial models. This will not eliminate the costs of adaptation, but will encourage companies to engage in before-the-fact adaptation to keep premiums down. Insurance companies may or may not factor in risk to health and welfare of workers, for example in the case of mine flooding, so this may have to be mandated.

Agricultural climate vulnerability could lead to increasing food prices, increasing the cost of living and decreasing the value of wages. This will lead either to higher costs of doing business or diminished living standards for workers. Possible adaptation measures include direct state intervention in food markets through subsidies or tax reductions, and encouragement and support for domestic food production. Domestic food production can partially protect the urban poor from the vagaries of food markets. The state can also have contingency measures in place for periods of food scarcity or price spikes; India's rice stockpiles are a good example of such a measure.

Urbanisation and immigration are likely to lead to pressure on labour markets and increasing unemployment. This can be addressed by job creation and ameliorated with stronger social protection. Raising living standards either through social protection or economic development will also blunt the impoverishing effects of higher food, energy and water prices, and increase adaptive capacity across the board by reducing social vulnerability.

4.3.2. Rural economies, livelihoods and land

Rural economies are more directly vulnerable to climate change than urban, due to their dependence on agriculture, herding and tourism.

Agriculture is directly threatened by a changing climate, particularly water scarcity. The standard adaptation, irrigation, is in fact a maladaptation, limiting water for downstream needs. Demand reduction and promotion of sustainable water use are better adaptations.

Bourne et al. (2012) detail how rural economies can benefit enormously from careful ecological management. Management and restoration of wetlands and river corridors can limit water runoff, provide grazing fodder, and increase potable water. Furthermore, improving environmental risk management and promoting sustainable development strategies can improve service delivery in urban settlements and enhance rural livelihoods directly while conserving biomes. Participatory land management and monitoring can also increase adaptive capacity.

In many cases, farmers can adapt themselves, given the right enabling circumstances, but there is a role for policy interventions to prevent maladaptation by promoting good practices through incentives and extension support services. Crucial for adaptation are access to credit and to markets. Food aid from the government can decrease the opportunity costs of adaptation by reducing the risk of failed adaptation. Farm support in the form of subsidies and provision of equipment also increases adaptive capacity (Bryan et al. 2009), but it is critical that this is accompanied by agricultural extension services that are used to promote climate smart agriculture – at present, this function is largely provided by NGOs and lacks the required scale.

Land is central to rural adaptive capacity and land insecurity is a source of vulnerability. Uncertain or contested land rights are a source of insecurity (Reid & Vogel, 2006) and can discourage investment in adaptation for fear that the investment will be lost or arbitrarily transferred to someone else. Land reform has the potential not only to reduce land insecurity but also create livelihoods, reduce poverty and address vulnerability. Land reform in South Africa has promised as much (Bradstock 2005). However, tenure reform has been problematic, failing in many cases to establish tenure for the people working the land; land restitution has proceeded slowly and land redistribution has made "extremely slow progress" (Bradstock 2006, 249). Furthermore, land reform in South Africa has provided inadequate support to land recipients (Cliffe 2000) and, by forcing farmers to integrate into the market, undermined many of the practices (such as cooperative farming techniques and animal traction) that characterise viable small-scale farming (Du Toit & Neves 2007).

The adaptive capacity of rural areas could be greatly increased with effective land reform that promotes smallholding, provides adequate support (financial, material and training) for recipient farmers, and does not disrupt traditional farming practices. Promoting the use of traditional knowledge and farming techniques, much of which has developed as a form of adaptation, will also increase adaptive capacity as will designing land reform so as to promote labour cooperatives and other traditional forms of labour (Du Toit & Neves 2007).

4.4. Housing, infrastructure and the built environment

4.4.1. Urban housing, infrastructure and the built environment

Infrastructure represents both a challenge and an opportunity for climate change adaptation. It is an opportunity, because infrastructure, particularly physical infrastructure, is an area that the government already has the mandate and the institutional arrangements to intervene in directly; and the necessary adaptations are in principle reasonably straightforward. It represents a challenge, because in many respects government lacks the capacity to meet even its existing infrastructural projects, and this is one area where non-government intervention (autonomous adaptation) is exceptionally difficult.

Traditionally infrastructure, and especially physical infrastructure, is designed based on historical data. For example a bridge might be designed to withstand a storm of the intensity that has occurred in that area roughly every fifty years. This approach to design was appropriate for a static climate, but is no longer so. As the climate changes, and as climate change accelerates, historical data become less and less useful for predicting the future. Starting now, as fifty-year storms and other extreme weather become increasingly less rare, planning regarding the standards for resilience of infrastructure must be based on worst-case scenarios from climate models (Golder Associates 2008).

This principle of worst-case planning extends further than roads and bridges. All state infrastructure and services must be designed and run on the expectation that the climate will become hostile to human settlement at the best of times, and increasingly erratic.

In terms of specific urban adaptations, water services will require better planning and management (Mukheibir & Ziervogel 2006) and long-term monitoring. Demand will have to be progressively managed and reduced by means of usage restrictions, higher tariffs, leak reduction, pressure management to reduce losses from leaks, awareness campaigns and incentives and regulations to promote efficiency (such as low-flow requirements for toilets). There are also a number of supply-side interventions, but these are by their nature limited and cannot replace demand reduction. Supply-side adaptations include water harvesting (such as rainwater harvesting) and recycling, the exploitation of new aquifers (such as the proposed Table Mountain aquifer), seawater for certain uses such as swimming pools and desalination of seawater for general use. Desalination is extremely energy intensive and will represent a maladaptation under normal circumstances; however, the use of renewable energy can make desalination a viable adaptation.

Of particular importance, and arguably currently receiving inadequate investment, is the need for supply-side interventions that focus on the soft ecological infrastructure that underpins the ecosystem services on which human settlement hard infrastructure depends. These include rehabilitating and protecting wetlands, establishing and maintaining ecological buffer zones for rivers, and creating corridors of indigenous vegetation in agricultural areas.

Improved water infrastructure will itself reduce many health vulnerabilities, particularly vulnerability to water-borne diseases. Further adaptations to reduce the health vulnerability of urban settlements should include the biological control of disease vectors such as malarial mosquitoes, the monitoring and research of diseases, vaccination, improved public health provision and health education. With the reduction of urban air quality that is expected to result from climate change existing regulations regarding air pollution should be more rigorously enforced, additional regulations introduced and air quality actively monitored. The heat island effect can be reduced by reducing the solar heat that cities absorb: "a doubling of the surface albedo or a doubling of vegetative cover were each projected to reduce air temperature by approximately 2°C. Moreover, the study area was projected to experience a decrease in ozone concentration" (IPCC 2007, 381). However, urban greening must be balanced against increased water consumption by plants.

To protect urban residents from extreme weather events, monitoring and warning systems should be upgraded and extended to areas they do not currently cover. Infrastructure for resilience (such as stormwater drains) should be improved and all infrastructure should be made more resilient to accelerated weathering and deterioration.

Case study: Technological adaptation in Western Australia

After a series of major droughts in the first years of the 21st century, a major desalination plant was built to supply drinking water to the city of Perth. The Perth Seawater Desalination Plant produces 45 billion litres of potable water each year, meeting about 17% of Perth's demand (Water Corporation n.d.).

To power the desalination plant the Emu Downs Wind Farm was built to provide 180 GWh/year to the desalination plant, and an additional 90 GWh/year to the city's grid. The cost per kilolitre of the Perth Seawater Desalination Plant is around AU$1,20 (R11,54), which is low by Australian standards but high compared to (for example) Israeli desalination costs (Palmer 2013).

There are limits to the potential of desalination. Not only was the upfront cost of the project high, at AU$567 million (R5,45 billion) for the desalination plant and wind farm together, but the plant quickly fell behind growing demand. Despite the building of a second facility, the Southern Seawater Desalination Plant, yet another plant will be required in the next ten years unless another solution is found (Palmer 2013).

4.4.2. Informal settlements

Informal settlements by their nature lack adaptive capacity compared to other urban areas due to lack of services, infrastructure and well-built dwellings.

The upgrading of informal settlements must be prioritised, in the forms of both the extension of formal infrastructure and the construction of well-built homes. Following the discussion in section 4.4.1 above, many of the adaptations necessary in informal settlements are theoretically already policy objectives. However climate change both lends urgency to the need for informal settlement upgrading, and sets certain parameters for that upgrading.

The location of informal settlements has to be considered with respect to climate resilience, and those settlements that are in climate-vulnerable locations must either be upgraded with additional preventative measures or relocated to more resilient areas. The considerations for relocation are similar, with the additional criterion that a settlement's new location cannot be more economically isolated than its old location: livelihoods are a crucial component of climate resilience and should not be jeopardised by the need for physical adaptation.

The residents of informal settlements are already targeted for housing upgrades, but the RDP housing programme is maladaptive in a number of respects. The houses themselves are frequently of low quality and thus remain vulnerable to extreme weather and climate damage: storms periodically leave poorly-built homes roofless. The low-density suburban-style freehold system limits local economic activity and reduces community cohesion, both necessary for adaptation, and the locations chosen for the houses are usually isolated from industrial and commercial centres, providing few opportunities for economic activity. This land is frequently chosen for housing programmes because it is relatively cheap, which reflects the low desirability of the land. By providing housing in poor locations, government is "trapping" people by means of large, fixed assets in areas offering no chance of economic advancement (Cross 2013, 250).

To be adaptive, housing programmes should aim to produce economically and socially vibrant neighbourhoods in resilient locations with houses of high quality. The apartheid-era approach to urban planning still in use today, which was designed explicitly to discourage community organisation and cohesion (which threatened state authority) and local economic activity (which reduced the dependence on white capital for employment), must be replaced with community-boosting urban forms and pro-social planning, which encourages local economic activity. This includes a shift from low-density residential freehold to medium-density, mixed-use planning. Increased density would also increase the land- and infrastructural efficiency of housing developments. The financial savings of denser settlements are potentially sufficient to compensate for the higher cost of more desirable land (Biermann & Van Ryneveld 2007).

Rental stock is an important area of housing adaptation: high rental prices reflect the scarcity of quality rental stock for low-income households. Renting is often a more suitable option for poor families than ownership, and has the potential to save the state money in the long run through recouped costs. There have been limited pilot programmes of rental stock construction, but quality has been low. For example, the N2 Gateway flats in Langa, Cape Town were contructed in such a way that one key opened as many as 28 units and within months flats were cracking and leaking. The construction of high-quality rental stock could reduce the price of renting for poor families, provide a cost-recoupment revenue stream for the state,and provide sustainable housing for currently unhoused families.

4.4.3. Coastal

Coastal settlements vary tremendously in how much and what adaptation they require as their vulnerability is so dependent on local topography. Nonetheless there are certain general principles of adaptation which they share.

Coastal settlements, particularly cities, need to actively manage their shorelines to guard against inundation and damage by rising sea levels and storms. This includes careful regulation of seashore development including buffer zones and more stringent setback lines (Mukheibir & Ziervogel 2006). Coastal development frequently degrades ecosystems and shorelines, especially where land is reclaimed, and carefully controlling such development would be beneficial even without the threat of climate change. Particular care should be taken with wetlands and estuaries, which are ecologically significant, and dunes, which play an important role in preventing sea encroachment; all of which are frequently damaged by development. Other no regrets adaptations include incorporating sea level rise into future planning processes, infrastructure design and disaster management strategies; maintaining and extending drains and stormwater systems; and decentralising strategic infrastructure. "Under a system of decentralised infrastructure it is not possible that an area becomes entirely cut-off from services and it is much less likely that the impacts of a localised sea level rise event will undermine a large area" (Cartwright et al. 2008, 14). Aggressive poverty alleviation is similarly a no regrets adaptation, as it is something that needs to be done in any case, but it would also improve adaptive capacity in the face of sea level rise by improving people's ability to relocate from affected areas, resettle adequately, build resilient houses and access insurance (Cartwright et al. 2008).

Beyond no regrets adaptations, cities should consider proactive adaptation to the threat of sea level rise. Whereas one might be inclined to think of physical adaptations such as sea walls, groynes, off-shore reefs, water pumps and beach drainage, these are no longer considered best practice. They are of limited effectiveness when they work at all and, in some cases (such as groynes), they actively increase vulnerability. In fact the most effective adaptations are institutional including vulnerability mapping, risk communication, regulation and planning, the prevention of detrimental activities such as sand-mining, early warning systems and research.

Also potentially effective are biological adaptations such as dune cordons, estuary and wetland rehabilitation, and kelp beds, all of which can help protect shoreline settlements from the ravages of the sea.

Table 4: Adaptation options

First resort – no regrets options	Second resort – additional institutional measures	Third resort – additional biological measures	Last resort – additional physical measures
• No further land reclamation from the sea • No further wetland and estuary degradation • No further dune degradation and development • Maintain stormwater infrastructure • Integrate sea level rise into spatial planning • Incorporate with disaster risk management • Decentralise strategic economic infrastructure and services	• Enforce coastal buffer zone – blue line • Early warning system • Correct insurance marker failures and underpricing of sea level rise risk • Managed retreat where necessary • Social and geographic vulnerability mapping • Risk communication • Apply the requisite legislation • Prevent sand mining of coastal dunes • Additional research into rates of change and causes	• Dune stabilisation and planting • Proactive estuary and wetland rehabilitation • Kelp bed protection and ensuring kelp remains on exposed beaches at key times	• Beach and dune replenishment • Sea walls • Barrages and barriers • Raising infrastructure • Revetments, dolosse, rock armour • Beach drainage • Offshore reefs

4.5. Governance and community

4.5.1. Community-based adaptation

Adaptation not only refers to an area of government policy. It also describes a large set of behaviours and strategies by a variety of actors. Good policy and implementation can result in, at best, partial adaptation; there also needs to be **autonomous adaptation** – the people affected by climate change altering their own behaviour and environs.

One the one hand, this is positive – local people are likely to work harder than anyone else to make themselves safer, even without artificial incentives or encouragement, particularly if they are given the necessary information and resources. There is no principal-agent problem here. On the other hand, this must not be taken as a reason to leave adaptation up to the affected communities. As has been explained, those who are least resilient are in this predicament precisely because they lack the resources to adapt effectively. Furthermore there are hard limits to what a community or household can do. They can make contingency plans to prepare for flooding, but they are unlikely to be able to build the stormwater infrastructure that would most effectively mitigate the effects of the flood. Furthermore autonomous adaptation is by nature reactive and unlikely to address the root causes of vulnerability. The answer, then, is a combination of autonomous and planned adaptation, with government, communities, households and others working in partnership.

Households and communities are most capable of building adaptive capacity when organised into community organisations. A strong, representative community organisation can complement planned adaptation in a number of ways. First, community organisations can have direct access to necessary information that might not be available easily to government without extensive research, if at all. This includes the precise vulnerabilities of the community, including variations within them, and hands-on monitoring of climate effects and adaptations.

Case study: autonomous adaptation in India, Kenya and Nigeria

The informal settlements around Indore in India, Nairobi in Kenya and Lagos in Nigeria are all vulnerable to flooding. Residents in each of these areas have developed adaptation strategies.

Many residents of Indore prepare for flooding by building on raised platforms and using flood-resistant materials. They buy furniture that is unlikely to wash away, and lay wiring and build shelving high off the ground. Many people have suitcases ready to quickly rescue valuables and have developed evacuation plans specifying routes and procedures (Stephens et al. 1996).

Half of Nairobi's population lives in informal settlements. Their strategies are more reactive than those in Indore and involve digging dykes and trenches to direct water away from houses, moving to higher ground and putting children on tables (ActionAid International 2006).

Eighty per cent of surveyed residents in Lagos's informal settlements reported being flooded three or four times in 2008. Households adapt by constructing drains, trenches and walls to divert water, and filling rooms with sand or sawdust. Food and many possessions are stored on elevated shelves above anticipated water levels. There have also been some community initiatives to clear blocked drains. Another crucial adaptation takes the form of assistance from family and friends after flood events (Adelekan 2010).

Case study: Community adaptation in India and the Philippines

The Homeless People's Federation of the Philippines, Incorporated (HPFPI) represents 161 community associations of the urban poor, with 70 000 members in total. Along with its member organisations HPFPI builds climate resilience in three areas:

1. By pooling resources HPFPI acquires land and finances construction of resilient structures. This addresses both insecure tenure and inadequate construction, especially in regions where the state has failed to do so.
2. HPFPI represents members at various levels in the state, lobbying for their interests and participating in planning processes. By presenting a unified voice it has motivated government to address climate vulnerabilities in a manner that is directly relevant to communities and cognisant of their needs.
3. Member organisations pool community savings that are then used for pre-event adaptation and disaster relief, among other things. In addition, the trust generated by communal saving enables further

collective action and planning (Dodman et al. 2009; Rayos 2010).

The National Slum Dwellers Federation, India

The slums of Mumbai are particularly vulnerable to flooding, even without the effects of climate change, as they are largely located in low-lying areas and along river banks. What infrastructure they have, such as storm sewers, is frequently clogged by debris.

The National Slum Dwellers Federation (NSDF), based in Mumbai, has more than 90 housing projects completed or underway, housing more than 35 000 families. It also constructs low-cost toilets to improve environmental sanitation, reducing disease outbreaks following floods. For this latter work the NSDF was awarded the UN Human Settlements Programme's Scroll of Honour (De Sherbinin et al. 2007).

Community organisations can operate even in areas where government structures lack the function or capacity to effectively promote adaptation. Although functional local government is key to adaptive capacity, it may not always be a reality. Community organisations can partially fill the gap with risk pooling, savings schemes, information sharing, and even some infrastructural upgrading.

There are difficulties with community-based adaptation, not least of which is building strong and representative community organisations. Many of the sources of climate vulnerability can also prevent effective organisation – particularly migration either into or out of the community. Nonetheless, community-based adaptation is essential as a complement to planned adaptation by government.

4.5.2. The importance of good institutions

Institutional capacity is an essential component of adaptive capacity. Planned adaptation is impossible without strong, capable government with clear mandates. "A strong institutional setting can promote resilience in the face of environmental risk exposure by ensuring appropriate monitoring of the hazard, information dissemination to the public, and the facilitation of emergency preparedness and pre-disaster planning, all of which reduce baseline vulnerability" (Vincent 2004, sec. 4.2.3). Furthermore, as we have seen in South Africa, adaptation in the form of infrastructural upgrading is directly dependent on state capacity. This is an area in which rural municipalities are particularly in need of adaptation: "there are serious capacity limitations in service delivery at the local level … Many of the local level structures suffer from a lack of capacity, are severely under-resourced, and have very little decision-making power" (Bourne et al. 2012, 86–87). The report, Increasing Investment in climate change related projects at the sub-national level, by the Technical Assistance Unit (TAU) and the Western Cape Government (2013) contains useful work on identifying barriers to the implementation of sub-national climate change responses and developing a financing framework to promote these responses. One of the key challenges identified by the TAU is the risk aversion of local authorities, which has inhibited the engagement of private sector finance in adaptation responses. If adaptation strategies are to be settlement-specific, as this report is urging, then the government institutions responsible for specific settlements have to have the capacity, authority and mandates to make adaptation happen.

The State and community organisations: The Homeless Peoples' Federation, South Africa

South Africa's capital subsidy programme for housing construction was designed to provide the funding directly to developers. "Much of the housing developed was located far from income-earning opportunities and was poorly designed, poorly built, and too small. … Many of these contractor-built houses have been abandoned or (illegally) sold for a fraction of their cost." (UN Millenium Project 2005, 40, Box 3.4)

The South African Homeless Peoples' Federation pressured the state to allocate the subsidies directly to the households intended to benefit. Several thousand members of the federation built high-quality homes with four rooms for the same price as contractors charged for tiny, poorly-built homes. The Department of Housing subsequently granted the federation R10 million to expand the programme, and established the People's Housing Process.

The majority of state housing funding, however, remains directed to contractors, and the People's Housing Process remains marginalised (UN Millenium Project 2005).

Autonomous adaptation is similarly dependent on strong institutions. **Section 5.4.1** has already discussed the importance of community organisations, but there is another reason that community organisations are crucial for development: coordination between communities and the state. Government, even when it is focused on the needs of the poor, has a deficit of information about conditions in poor communities and what those communities actually need. Community organisations can feed information into government structures about community vulnerabilities, motivate for communities' needs and pressure government into action. Meanwhile government can provide resources and capacity for community organisations, as well as promoting adaptation at scales and costs that are beyond the reach of the community. The most effective institutional circumstances for adaptation are a combination of strong, effective government and representative community organisations.

Institutional capacity is a major challenge for South African adaptation. Municipalities are, with exceptions, under resourced and under staffed. Rural municipalities which are primarily responsible for environmental issues have "extremely limited staff capacity and no funds at the local level for environmental work of any kind" (Bourne et al. 2012, 96). The TAU diagnostic report on barriers to implementing climate change projects identifies lack of clarity and uniformity in the interpretation of environmental, legal and financial regulations by local authourities as a barrier and suggests that national government issue clarification notes (TAU 2013). Furthermore, government structures are reluctant to engage with community organisations as: "National and local political structures distrust any movement that is not within the ruling party, [and] politicians work through patron-client relationships and do not want to be challenged by community organizations …" (UN Millenium Project 2005, 40, Box 3.4). Moreover, under conditions of corruption, institutional strength can be maladaptive, facilitating rent-seeking and diversion of resources from genuine adaptation (Vincent 2004).

4.5.3. The right to the city

"In every country in the world, significant communities are excluded, whether by active policy or passive acceptance, from fully belonging to the city, its life, and services" (UN Millenium Project 2005, 38). In South Africa this exclusion has been particularly active and acute both under apartheid, where black South Africans were excluded by policy from many urban areas and since, where poor South Africans are excluded from wealthy areas both by policy and by private security, and from official decision-making processes. This exclusion has come to public attention with Operation Clean Sweep, the violent removal by police of informal traders from central Johannesburg in November 2013.

The right to the city is a movement to build inclusive cities. Although the right to the city is a developing concept, its three core principles are:

1. The exercise of **full citizenship**, namely the realisation of all human rights to ensure the collective well-being of inhabitants and the social production and management of their habitat.

2. The **democratic management** of the city through the direct participation of society in planning and governance, thus strengthening local governments and social organisation.

3. The **social function of the city and of urban property**, with the collective good prevailing over individual property rights, involving a socially just and environmentally sustainable use of urban space (Mathivet 2010, 24, emphasis added).

The Right to the City is a rejection of approaches to urbanism that deny the right of poor citizens, particularly people who live in slums, to full access to the city. An approach based on the right to the city, integrating the most vulnerable communities into the adaptation process, would build the formal and informal institutions necessary for climate change adaptation and promote pro-poor adaptive development.

Case Study: Fighting for the right to the South African city

In 2004 the South African government adopted a policy called *Breaking New Ground*, which encompassed a shift to integrate informal settlements "into the broader urban fabric to overcome spatial, social and economic exclusion" using "a phased in-situ upgrading approach" (DHS 2004, 12). Despite the progressive nature of its new policy, in many cases the state turned instead to "slum clearance" (Pithouse 2010, 134).

Abahlali baseMjondolo (Shack Dwellers) movement was formed by community organisations in Durban in October 2005. An "autonomous political project", Abahlali grew steadily and its many achievements include resisting state evictions, expanding existing settlements, winning access to state services, establishing mutual support projects such as crèches, making safe (but illegal) connections to electricity and water for thousands of people and establishing democratic governance of several settlements. In 2008, during the xenophobic violence that was widespread in informal settlements, Abahlali controlled settlements sheltered and defended people born elsewhere in Africa.

These successes were achieved despite the best efforts of the South African state. In September 2007 a lawful Abahlali march was attacked by police. In that same year the KwaZulu-Natal legislature passed the KwaZulu-Natal Elimination and Prevention of Re-emergence of Slums Act, No. 6 of 2007 which "essentially criminalised the unlawful occupation of land, resistance to evictions and any form of shack dwellers' organisation that occupied land unlawfully and raised money via a membership fee" (Pithouse 2010, 138). Abahlali challenged the constitutionality of the Act and in 2009 had it struck down by the constitutional court. Abahlali represents an enormous missed opportunity for the state to engage constructively with community organisations.

5. POLICY RECOMMENDATIONS

South Africa's adaptation responses to climate change need to be considered within the overall context of the developmental state – and more specifically, the framework of policy priorities and planning principles outlined in the National Development Plan. In the short to medium term a number of adaptation responses exist that comprise no regrets actions. Examples of these include activities that promote efficient use of water, such as reducing water losses due to leakages in municipal water supply systems and improving the capacity and operation of water treatment plants. In all likely climate scenarios as described in phase 1 of the LTAS, actions like these promote the resilience of human settlements and have benefits for human health and economic infrastructure and, in the immediate term, they should form the basis of national adaptation planning.

However, there are also a range of adaptation options whose viability depends on the specifics of which climate change scenarios are realised, both in terms of the warmer/hotter axis and the drier/wetter axis of possible futures, and on particular choices in terms of the allocation of scarce resources such as water towards social, economic and environmental ends. This involves the consideration of constraints along timescales that extend beyond the planning horizon of the current National Development Plan (Vision 2030) and which current planning does not necessarily address in a consequential manner.

Water has been identified as the principal vector transmitting systemic climate change costs to the economy and is one of the clearest drivers of option-taking in relation to possible climate futures considering the context of South Africa as a water scarce country. Mutually exclusive options need to be considered in relation to the allocation of water to different economic sectors and these decisions will be critical to shaping the developmental trajectory of the South African state. For example, in a hotter and drier future, expanding agricultural production may place intolerable constraints on water to support the infrastructure required by human settlements and threaten the ecological reserve required to reproduce vital ecosystem services, as well as limiting other forms of economic activity.

The implementation of existing policies and programmes, such as the National Development Plan, National Water Resource Strategy and Strategic Infrastructure Programmes, needs to be guided by the environmental constraints created by climate change to avoid maladaptive development leading to costly investments in stranded assets and unsustainable land use decisions.

5.1. National adaptation planning priorities for human settlements

These planning priorities consist of the adaptation responses for human settlements that are appropriate in all climate scenarios, and that deliver ancillary social benefits, such as creating livelihoods and promoting social equality. They can and should be implemented immediately, and in many cases are aligned with existing government policies and programmes.

5.1.1. Community-based adaptation

A cross-cutting theme in relation to building climate resilient human settlements is the need for policies and programmes that support community-based approaches to adaptation. The current wave of service delivery protests, in many cases sparked by failures in the delivery of water and sanitation to peri-urban settlements, is an indication of conflict risks that will only be heightened by additional stresses on public infrastructure as a result of climate change. Of particular importance is the role of community-based adaptation in relation to:

- **Informal settlement upgrades:** Civil society and community-based organisations need to be seen as key partners in informal settlement upgrades. Insufficient attention is currently paid to this aspect in the design and implementation of the Informal Settlement Upgrade Policy.

- **Rural housing subsidies and tenure reform:** The Rural Housing Subsidy Programme is currently linked to the Communal Land Rights Programme and the Communal Lands Rights Act, No. 11 of 2014, which has been found to be unconstitutional. There is an urgent need for a reformed legal framework for communal lands and for updated policy around land restitution that provides security of tenure in rural settlements, promotes land rehabilitation and small-scale agriculture, and is sufficiently flexible to accommodate the diverse needs of affected communities in a democratic and equitable manner. This is critical for promoting community-based adaptation that results in rural human settlements with productive use and investment in rural land, particularly in the former homelands and in relation to restituted land.

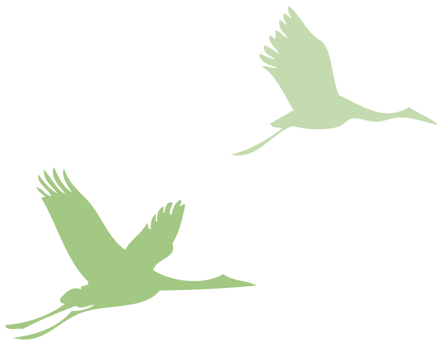
5.1.2. Ecosystem based adaptation

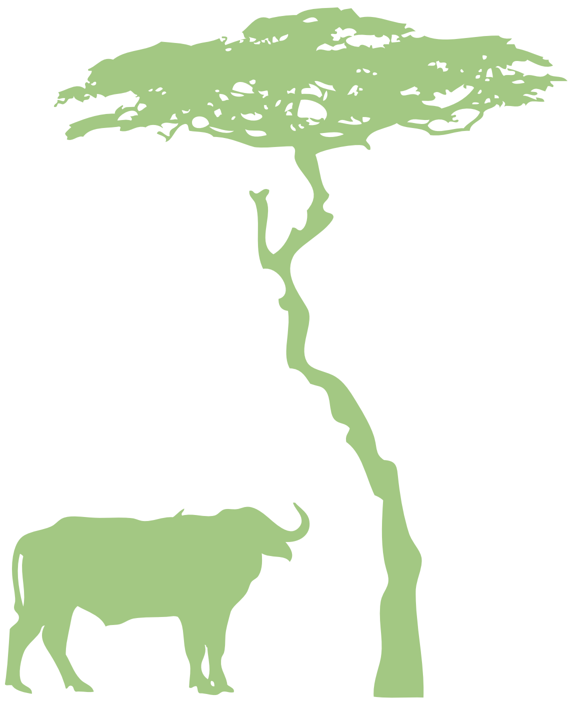
Linked with community based adaptation is ecosystem based adaptation, which should be part of overall adaptation policy and plans. This involves restoring and maintaining ecosystems to help build resilience. Investment in ecosystems can also alleviate poverty and create jobs.

- A number of successful Extended Public Works Programmes, particularly those implemented through the DEA's Natural Resource Management Programme, already exist that maintain and rehabilitate ecosystems. These need to be refined, improved and expanded to address climate change risks and vulnerabilities. In some cases this may involve adapting the indicators monitored during the implementation of these programmes to accommodate climate-specific indicators.

- New opportunities for financing ecosystem based adaptation linked to existing and emerging sources of adaptation finance, and leveraging new mechanisms for investing in ecosystems, including environmental offsets need to be actively developed and explored.

- Ecosystem based alternatives to traditional engineering solutions within human settlements need to be mainstreamed within local government planning and effective administrative frameworks for them promoted to local government officials.





5.1.3. Urban densification and social housing

Densification of the urban environment has a critical role to play in ensuring access to economic opportunities, the cost-effective roll-out of infrastructure and services to the urban poor, managing environmental impacts and the ecological integrity of urban settlements, and reducing encroachment on agricultural land. These represent important determinants of climate resilience in poor urban communities. Many of these imperatives are currently reflected in policy at national, provincial and local level with respect to:

- Promoting diversity of housing and tenure arrangements, including multistorey low-cost rental and sectional title housing and the regeneration and rehabilitation of central business districts in cities.
- Promoting the development of more diverse settlement patterns combining different income categories and ethnic groupings.

However, in practice land use is still predominately dictated by market forces and private sector development agendas, generally resulting in low cost housing development taking the form of single unit housing estates on the urban periphery. There is a need for much more proactive involvement of local authorities in redressing spatial inequalities and in implementing a holistic approach to urban design reflected in policy that:

- While preventing urban creep and encroachment on agricultural land, promotes increased decentralisation of local economic opportunities to improve the sustainability of poor urban communities currently on the urban periphery, including promoting urban food gardens and urban forests.
- Includes public spaces, community facilities, both formal and informal retail and trading opportunities in new housing developments, informal settlement upgrades and retrofitting of existing housing developments.
- Ensures social criteria determine the priorities for vacant municipal land rather than market value, and that this should guide the development of low cost social housing integrated into the urban design.
- Recognises the phenomenon of backyard rental accommodation and provides enforceable legal frameworks to protect the rights of backyard tenants, and policies and programmes to ensure access to free basic services for this vulnerable segment.

5.1.4. Development, inequality and access to basic services

The majority of the backlog in the provision of basic services is located in informal settlements and poor rural communities, although even communities with established infrastructure experience breakdowns in the delivery of basic services. These communities are particularly vulnerable to climate change and the delivery of basic services in terms of the minimum levels of service and free basic allocation for water, electricity and waste collection represents a significant contribution to improving their resilience.

While by global standards the free basic allocations for water and electricity represent a low baseline of consumption, the environmental and resource impact of extending these services to all needs to be considered in the context of consumption by middle and high end consumers, which in many cases is high and wasteful. In the context of natural resource constraints and the need to transition to a low carbon economy, government needs to explore policies that promote a green economy by decoupling development from the consumption of natural resources, carbon emissions, and the destruction of natural assets. This can be accomplished by measures such as stepped tariffs and awareness campaigns targeting those income brackets in which the biggest efficiency gains can be made as well as incentives and performance indicators for local government and provinces that link climate change adaptation to service delivery.

It should also be recognised that providing basic services to informal settlements and remote rural communities poses technological and financial challenges. There needs to be flexibility and innovation in achieving acceptable levels of basic service delivery, and community participation and involvement in decision-making and implementation is central to ensuring acceptance of the service levels provided. In terms of the financial obstacles to electrification in rural areas, full use should be made of current opportunities afforded by commercial renewable energy projects which are required to have a social investment component in terms of existing regulations.

5.1.5. Disaster risk management and human settlements

There is ample evidence of the need to better incorporate disaster risk management in policy and standards around low cost housing and informal settlement upgrades. Disaster risk management must link to national, provincial and local planning so that settlements are designed for reducing risk. In addition to technical engineering specifications being revised to accommodate changes in climate related parameters, such as temperature or flood incidence, ecosystem based responses need to be prioritised. There are many examples of these including the rehabilitation of ecological buffers (wetlands) for floods and the clearing of alien plants to reduce veld fire risks. Existing regulations, such as the onus on landowners to clear alien vegetation, may need to be extended or more effectively enforced.

5.2. Option-taking for future adaptation in human settlements

Not all adaptation options are mutually compatible or appropriate in all possible climate scenarios. The selection of adaptation options needs to be aligned with macro-economic planning and informed by constant monitoring and modelling of climate change and the economy. The key parameters affecting decisions in relation to climate will involve the nature, extent and rate of changes in temperature and rainfall. Linked to this is the extent to which the global economy adopts a low carbon path based on more rigorous international agreements that include carbon as a factor in international trade. This has explicit implications for future policy developments.

Of particular importance to human settlements is the impact climate change will have on urbanisation, population migrations, and the availability of agricultural land, both locally and in the sub-region. In some scenarios and in certain parts of the country, opportunities for agriculture will increase, while in other scenarios any increase in land under cultivation and rangeland will have prohibitive impacts on the availability of water for social and other economic purposes. In particular, these scenarios will determine:

1. The extent to which urbanisation can be slowed and a more decentralised approach to human settlements pursued that focuses resources on regeneration of rural areas. This will require new and additional investment in rural communities and infrastructure on a scale that goes well beyond what is currently the case, but may have significant benefits for climate resilience in terms of food security and sustainable settlement patterns. Key areas of focus might include:
    - Promotion of small-scale climate smart agriculture through agricultural extension support and financing, and improvements to transport infrastructure in rural areas to facilitate access to markets.
    - A focus on renewable energy from solar and wind generation in rural areas and, depending on ecological sustainability being demonstrated, biofuels.
    - A decentralised approach to local economic development that focuses on service centres outside the cities and basic service delivery in rural areas.

2. Alternatively, in scenarios in which South Africa does not experience strong constraints on trade relating to the carbon intensity of its economy, and in which climate scenarios result in a significant increase in marginal agricultural land, the focus of economic development may shift towards extraction and beneficiation of mineral resources and development of a more centralised, service-based economy. Key areas of focus might include:

    - Investments in public infrastructure in cities focusing on urban densification, reducing the environmental impact of basic service delivery, and integrated public transport systems.
    - Investments in industrial research and development and the manufacturing sector, with a focus on developing industrial zones on the urban perimeter.
    - Strengthening diplomatic and trade relations with the sub-region, particularly in relation to population migration, water, energy and food.

In practice, elements of both these strategies are currently being pursued and are likely to be pursued in future. In terms of climate change adaptation the issue is one of relative emphasis in the allocation of scarce public and natural resources, such as fiscal allocations and water use, and the specific mix of measures that are adopted.

In terms of climate resilience, protection of the ecological reserve (that portion of the water resource that is needed to preserve the integrity of ecosystems) and ensuring healthy ecological infrastructure is maintained in urban and rural areas should be a fundamental point of departure. Improving efficiency in water use for social and economic purposes can paradoxically increase vulnerability to climate variability as the limits of water use are approached, and it is therefore vital to maintain an environmental buffer.

6. FUTURE RESEARCH NEEDS WITH LINKS TO FUTURE ADAPTATION WORK AND DOWNSCALING

For the foreseeable future, informal settlements are likely to be a part of the South African landscape with particular vulnerability to climate change. While there is a general recognition of the social vulnerability of informal settlements to climate change, in developing adaptation strategies to inform informal settlement upgrades a much more precise understanding of the environmental vulnerabilities that particular informal settlements face is needed to inform local authority plans. Downscaling of climate change projections to the local scale is an important aspect of this, but this needs to be contextualised through field work in informal settlements involving participatory research models.

Similarly, poor communities in rural settlements are socially vulnerable and exposed to environmental risks associated with climate change. While climate change adaptation in rural settlements has been fairly extensively studied elsewhere in Africa, the historical context and current governance and administrative arrangements pertaining to South Africa's rural communities are both unique and problematic and require further research, particularly to guide policy in relation to tenure reform and land restitution. There are a variety of innovative projects involving delivery of basic services to rural communities both locally and internationally that enhance climate resilience, but these are often not effectively taken up in government programmes and focused research that draws on these projects may improve the situation.

In general, adaptation research is often focused on interpreting the implications of climate change in terms of biophysical impacts on infrastructure and the economy. More research is needed to understand and demonstrate where effective ecosystem based approaches are being used. Behaviour change and social cohesion are critical to community-based adaptation at all levels of society. In relation to HIV, the efficacy of research in relation to identifying strategies for promoting behaviour change is well established, has received extensive financial support, and has had significant impact on decision-makers. There is a need to bring a similar focus and level of research effort to achieving behaviour change and social cohesion in relation to climate change.

Finally, in relation to the impact of macroeconomic and fiscal option taking on human settlements, there is a need for ongoing research and monitoring building on the back of the current scenario planning process, both in terms of updated modelling of climate and in the understanding and quantification of impacts. This will help, for instance, to identify when particular land-use options, such as the expansion of land under agriculture, become maladaptive.

7. CONCLUSION

Urban design and the implementation and planning of human settlements take up substantial public and private resources, and have significant impact on natural resources. Ensuring these investments make sense in the context of a changing climate, by both reducing human vulnerability to climate and minimising human contributions to the causes of climate change, is therefore critical.

Significant progress is being made both locally and internationally in coming to grips with the technical aspects of planning human settlements efficiently in response to the need for infrastructure that is more resilient to high temperatures, rainfall variability, extreme weather and sea level rise. We have a better understanding of the need for spatial arrangements that reduce commuting times and the cost of providing basic services.

However, reducing social vulnerability to climate change as a consequence of poverty and inequality is a critical aspect of climate change adaptation in South Africa's cities, towns and rural areas. State responses of providing low cost housing and access to basic services as quickly and efficiently as possible have sometimes had unintended consequences of increasing both physical and social vulnerability to climate change. South Africa does not have a strong history of democratic and community involvement in the roll-out of infrastructure and services to build upon.

In particular, the existing examples of successful community and ecosystem-based approaches to human settlement planning that promote climate resilience, in South Africa and elsewhere, need to be built upon, as adaptation to climate change requires effective governance and social cohesion as well as an understanding of the technological and environmental challenges.

REFERENCES

ActionAid International (2006). *Unjust waters: Climate change, flooding and the protection of poor urban communities: experiences from six African cities*. Action Aid International, Johannesburg.

Adelekan IO (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization*, 22:2, 433–450. doi:10.1177/0956247810380141

Ahmed SA, Diffenbaugh NS & Hertel TW (2009). Climate volatility deepens poverty vulnerability in developing countries. *Environmental Research Letters*, 4:3, 034004. doi:10.1088/1748-9326/ 4/3/034004

Alam M & Rabbani MDG (2007). Vulnerabilities and responses to climate change for Dhaka. *Environment and Urbanization*, 19:1, 81–97. doi:10.1177/0956247807076911

Babugura A (2010). *Gender and climate change: South Africa case study*. Heinrich Böll Foundation Southern Africa, Cape Town.

Banda K & Mehlwana M (2005). *Equity and Gender in Climate Change*. NOVAFRICA Centre for Innovation in Development, Centurion, Gauteng, South Africa.

Beinart W (2001). *Twentieth-Century South Africa*. Oxford: Oxford University Press, 432 pp.

Biermann S & Van Ryneveld M (2007). Improving the delivery of low income housing in South African urban areas. Paper presented at the Computers in Urban Planning and Urban Management (CUPUM) conference, Iguassu Falls Brazil 15–17 July 2007.

Bouchard B, Goncalo A, Susienka M & Wilson K (2007). Improving Flood Risk Management in Informal Settlements of Cape Town. Worcester Polytechnic Institute. Worcester, MA.

Bourne A, Donatti C, Holness S & Midgley G (2012). Climate Change Vulnerability Assessment for the Namakwa District Municipality. Full technical report. Conservation South Africa, Cape Town.

Bradstock A (2005). Changing livelihoods and land reform: Evidence from the Northern Cape province of South Africa. *World Development*, 33:11, 1979–1992. doi:10.1016/j.worlddev.2005.07.005

Bradstock A (2006). Land reform and livelihoods in South Africa's Northern Cape province. *Land Use Policy*, 23:3, 247–259. doi:10.1016/j.landusepol.2005.01.002

Bryan E, Deressa TT, Gbetibouo GA & Ringler C (2009). Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environmental Science & Policy*, 12:4, 413–426. doi:10.1016/j.envsci.2008.11.002

Buhaug H, Gleditsch NP & Theisen OM (2010). Implications of climate change for armed conflict. In R. Mearns & A. Norton (eds), *Social dimensions of climate change: Equity and vulnerability in a warming world*. Washington D.C.: World Bank, 75–101.

Cartwright A (2008). Global climate change and adaptation: A sea-level rise risk assessment. Report prepared for the City of Cape Town, Stockholm Environment Institute (SEI), Cape Town.

Cartwright A, Brundrit G & Fairhurst L (2008). Sea-level rise adaptation and risk mitigation measures for the City of Cape Town. Report prepared for the City of Cape Town, Stockholm Environment Institute (SEI), Cape Town.

City of Johannesburg (2009). *Climate Change Adaptation Plan*. Johannesburg.

Cliffe L (2000). Land Reform in South Africa. *Review of African Political Economy*, 27:84, 273–286.

Council for Scientific and Industrial Research (CSIR) (2010). A CSIR perspective on water. CSIR Report No. CSIR/NRE/PW/IR/2011/0012/A, Council for Scientific and Industrial Research, Pretoria.

Council for Scientific and Industrial Research (CSIR) (2013). Settlement typology CSIR SACN 2013. Council for Scientific and Industrial Research, Pretoria. http://www.gap.csir.co.za/images/gis-data-layers/settlement-typology/view

Cross C (2001). Why does South Africa need a spatial policy? Population migration, infrastructure and development. Journal of Contemporary African Studies, 19:1, 111–127. doi:10.1080/02589000123491

Cross C (2013). Delivering human settlements as an anti-poverty strategy: Spatial paradigms. In U Pillay, G Hagg & F Nyamnjoh (eds), *State of the nation: South Africa 2012–2013.* Cape Town: HSRC Press.

Crush J & McDonald D (2002). *Transnationalism and new African Immigration to South Africa* (No. 9). Kingston, Ontario: Southern African Migration Project and Canadian Association of African Studies

Dasgupta S, Laplante B, Meisner C, Wheeler D & Yan J (2007). *The impact of sea level rise on developing countries: a comparative analaysis*. Policy research working paper (WPS 4136). World Bank, Washington, D.C.

De Sherbinin A, Schiller A & Pulsipher A (2007). The vulnerability of global cities to climate hazards. *Environment and Urbanization*, 19:1, 39–64. doi:10.1177/0956247807076725

Department of Economic Development and Environmental Affairs (DEDEA) (2011). *Eastern Cape Climate Change Response Strategy*. Department of Economic Development and Environmental Affairs, Bhisho, 83–379.

Department of Environmental Affairs (DEA) (2011). *National Climate Change Response White Paper*. Government Printer, Pretoria.

DEA (2013a). *Long Term Adapation Scenarios Flagship Research Programme (LTAS): Summary for Policy Makers*. Department of Environmental Affairs, Pretoria.

DEA (2013b). *Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Trends and Scenarios for South Africa*. Department of Environmental Affairs, Pretoria. https://www.environment.gov.za/sites/default/files/docs/climate_trends_bookV3.pdf

Department of Human Settlements (DHS) (2004). *Breaking New Ground: A comprehensive plan for the development of integrated sustainable human settlements. Department of Human Settlements*, Pretoria. http://www.dhs.gov.za/sites/default/files/documents/26082014_BNG2004.pdf

DHS (2009). *National Housing Code*. Department of Human Settlement, Pretoria. http://www.nwpg.gov.za/humansettlements/Nationalhousingcode.asp

Department of Science and Technology (DST) (2010). *South African Risk and Vulnerability Atlas (SARVA)*. Department of Science and Technology, Pretoria. http://www.sarva.org.za/

Department of Water Affairs (DWA) (2013). *Strategic overview of the water sector in South Africa 2013*. Department of Water Affairs, Pretoria.

Dodman D, Miltin D & Rayos J (2009). Victims to victors, disasters to opportunities: Community-driven responses to climate change in the Philippines. *International Development Planning Review*, 32:1. doi:10.3828/idpr.2009.10

Du Toit A & Neves D (2007). In search of South Africa's "second economy". *Africanus: Journal of Development Studies*, 37:2, 145–174.
http://ccs.ukzn.ac.za/files/africanus_1.pdf

FAO (2011). *FAO-Adapt: Framework programme on climate adaptation*. Food and Agriculture Organization of the United Nations (FAO), Rome.

FAO/OECD (2012). *Building resilience for adaptation to climate change in the agriculture sector*. Food and Agriculture Organization of the United Nations / Organisation for Economic Co-operation and Development, Rome / Paris.

Gbetibouo G A & Ringler C (2009). Mapping South African farming sector vulnerability to climate change and variability: A subnational assessment. IFPRI Discussion Paper 00885, International Food Policy Research Institute, Washington, DC.
http://www.ifpri.org/sites/default/files/publications/ifpridp00885.pdf

Golder Associates (2008). Assessment of Johannesburg's vulnerability to the global threat of climate change. Report No 10527/10389/1/z, City of Johannesburg.

Golder Associates (2011). Community-Based Adaptation to Climate Change in Durban. Final Report no. 11977-10286-9, Golder Associates, KwaZulu-Natal.
http://www.durban.gov.za/City_Services/development_planning_management/environmental_planning_climate_protection/Publications/Documents/FINAL_Community_Based_Adaptation_Report.pdf

Goodlad R (1996). The Housing Challenge in South Africa. *Urban Studies*, 33:9, 1629–1646. doi:10.1080/0042098966538

Gosling, Melanie (2011). Stormy waters around old wrecks. IOL.
http://www.iol.co.za/capetimes/stormy-waters-around-old-wrecks-1.1093571

Hafiz MA & Islam N (1992). Environmental Degradation and Intra/Interstate Conflicts in Bangladesh. *CSS Environment and Conflicts Project*, 6:1.
http://www.css.ethz.ch/publications/DetailansichtPubDB_EN?rec_id=2836

Hardoy J & Pandiella G (2009). Urban poverty and vulnerability to climate change in Latin America. *Environment and Urbanization*, 21:1, 203–224. doi:10.1177/0956247809103019

Homer-Dixon TF (1991). On the Threshold: Environmental Changes as Causes of Acute Conflict. *International Security*, 16:2, 76–116.

Homer-Dixon TF (1999). *Environment, Scarcity, and Violence*. Princeton NJ: Princeton University Press.

Hughes P (1992). The impacts of sea level rise on the South African coastal environment. PhD thesis, Department of Oceanography, University of Cape Town.

International Finance Corporation (IFC) (2011). Climate risk and business ports: *Terminal Marítimo Muelles el Bosque Cartagena, Colombia*. International Finance Corporation, Washington, DC.

IPCC (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. ML Parry, OF Canziani, JP Palutikof, PJ van der Linden & CE Hanson (eds). Cambridge University Press, Cambridge, UK 976 pp.
https://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

Kahl CH (2006). *States, scarcity, and civil strife in the developing world*. Princeton, NJ: Princeton University Press, 333 pp.

Kiker GA (1999). *South African country study on climate change: Synthesis report for the vulnerability and adaptation assessment section*. UNFCCC, Geneva. https://unfccc.int/files/meetings/seminar/application/pdf/sem_sup5_south_africa.pdf

Lamberth S & Turpie J (2003). *The role of estuaries in South African fisheries: Economic importance and management implications*. WRC Report No. 756/2/03. Water Research Commission, Pretoria.

Madzwamuse M (2010). *Climate change vulnerability and adaptation preparedness in South Africa*. Heinrich Böll Foundation, Cape Town.

Mathivet C (2010). The Right to the City: Keys to Understanding the Proposal for "Another City is Possible". In A Sugranyes & C Mathivet (eds). *Cities for all: Proposals and experiences towards the right to the city.* Habitat International Coalition (HIC), Santiago, Chile. http://www.citiesalliance.org/sites/citiesalliance.org/files/Cities_For_All_ENG.pdf

Midgley G, Chapman R, Hewitson B, Johnston P, De Wit M, Ziervogel G, Mukheibir P, Van Niekerk L, Tadross M, Van Wilgen B, Kgope B, Morant P, Theron A, Scholes R & Forsyth G (2005). *A status quo, vulnerability and adaptation assessment of the physical and socio-economic effects of climate change in the Western Cape*. Report to the Western Cape Government, Cape Town, South Africa. CSIR Report No. ENV-S-C 2005-073, Stellenbosch. https://www.westerncape.gov.za/other/2006/9/wcape_climate_change_impacts_sep06.pdf

Mukheibir P & Ziervogel G (2006). *Framework for adaptation to climate change in the City of Cape Town* (FAC4T). City of Cape Town.

Naidu S, Hounsome R & Iyer K (2006). Climatic future for Durban. Revised Report. Prepared for EThekwini Municipality by CSIR Environmentek.

Palmer N (2013). Cheaper seawater desalination. National Centre of Excellence in Desalination, Australia (website). http://desalination.edu.au/2013/07/cheaper-seawater-desalination/#.UxR95twxGIl (retrieved March 03, 2014)

Palmer B & Parak O (2011). A coastal vulnerability index for KwaZulu-Natal, South Africa. KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development. Pietermaritzburg. http://www.cfoo.co.za/docs/stormsurge/Item%204%20CVI%20for%20KZN%20BP%20et%20al.pdf

Phalatse L & Mbara G (2009). Impacts of climate change and vulnerable communities at the City of Johannesburg (9pp). City of Johannesburg. http://carbonn.org/uploads/tx_carbonndata/PhalatseVulnerability%20study.pdf

Pienaar L & Von Fintel D (2013). Hunger in the former apartheid homelands: Determinants of converging food security 100 years after the 1913 Land Act. Stellenbosch Economic Working Papers: 26/13. Bureau for Economic Research, University of Stellenbosch.

Pithouse R (2010). Abahlali baseMjondolo & the popular struggle for the right to the city in Durban, South Africa. In A Sugranyes & C Mathivet (eds). *Cities for All: Proposals and experiences towards the right to the city.* Habitat International Coalition (HIC), Santiago, Chile. http://www.citiesalliance.org/sites/citiesalliance.org/files/Cities_For_All_ENG.pdf

Presidency (2006). *National Spatial Development Perspective 2006*. Presidency, Republic of South Africa, Pretoria. http://www.thepresidency.gov.za/pebble.asp?relid=514

Rayos J (2010). *Community-driven disaster intervention: Experiences of the Homeless People' s Federation Philippines, Incorporated (HPFPI)*. Human Settlements Programme, working paper 25, 69 p. International Institute for Environment and Development (IIED), London.

Reid P & Vogel C (2006). Living and responding to multiple stressors in South Africa: Glimpses from KwaZulu-Natal. *Global Environmental Change*, 16:2, 195–206. doi:10.1016/j.gloenvcha.2006.01.003

Republic of South Africa (RSA) (1979). Report of the Commission of Inquiry into Legislation Affecting the Utilisation of Manpower (Excluding the Legislation Administered by the Departments of Labour and Mines) (Chairman: P J Riekert) Pretoria: Government Printer.

RSA (1985). Report of the Constitutional Committee of the President's Council on an urbanisation strategy for the Republic of South Africa. Report P.C. 3/1985. Cape Town: Government Printer.

Reuveny R (2007). Climate change-induced migration and violent conflict. *Political Geography*, 26:6, 656–673. doi:10.1016/j.polgeo.2007.05.001

Ribot J (2010). Vulnerability does not fall from the sky: Toward multiscale, pro-poor climate policy. In R Mearns & A Norton (eds), *Social dimensions of climate change: Equity and vulnerability in a warming world*. Washington DC: World Bank.

Rural Women's Action Research Programme (2014). Custom Contested. Website established by Centre for Law and Society, University of Cape Town and Just Communication.
http://www.customcontested.co.za/

Rutherford M, Midgley G, Bond W, Powrie L, Robertson R & Allsopp J (2000). South African country study on climate change: Plant biodiversity vulnerability and adaptation assessment. In *Climate change impacts in Southern Africa: Report to the National Climate Change Committee*. Pretoria: Department of Environmental Affairs and Tourism.

Schulze RE (2005). Setting the scene: the current hydroclimatic "landscape" in southern Africa. In RE Schulze (ed.), *Climate change and water resources in southern Africa: Studies on scenarios, impacts, vulnerabilities and adaptation*. WRC Report no. 1430/1/05, Pretoria: Water Research Commission.

Shewmake S (2008). Vulnerability and the Impact of Climate Change in South Africa' s Limpopo River Basin. IFPRI Discussion Paper 00804, Environment and Production Technology Division, International Food Policy Research Institute (IFPRI), Pretoria.
http://www.ifpri.org/sites/default/files/publications/ifpridp00804.pdf

StatsSA (2011a). *Census 2011*. Statistics South Africa, Pretoria. Online census data retrieved from
http://interactive.statssa.gov.za:8282/webview/

StatsSA (2011b). *General Household Survey 2011*. Statistical release P0318, Statistics South Africa, Pretoria.

Stephens C, Patnaik R & Lewin S (1996). *This is my beautiful home: risk perceptions towards flooding and environment in low-income urban communities: A case study in Indore, India*. London School of Hygiene and Tropical Medicine, London 51 p.

Stern N (2009). *Blueprint for a safer planet: How to manage climate change and create a new era of progress and prosperity*. Oxford: The Bodley Head.

Technical Assistance Unit (TAU) & Western Cape Government (2013). Increasing investment in climate change related projects at the sub national level, Project No. 662, Phase 2: Towards a financing framework for implementing climate change projects. National Treasury, Technical Assistance Unit & Western Cape Government, Pretoria.
http://www.e3g.org/docs/FINAL_Finance_Framework_Repor_October_2013.pdf

Theron A & Rossouw M (n.d.). *Analysis of potential coastal zone climate change impacts and possible response options in the southern African region.* Council for Scientific and Industrial Research (CSIR), Stellenbosch.

Turpie J, Winkler H, Spalding-Fecher R, Midgley G, (eds) (2002). Economic impacts of climate change in South Africa: A preliminary analysis of unmitigated damage costs. Cape Town: Southern Waters Ecological Research and Consulting, and Energy and Development Research Centre, University of Cape Town 58 p.

UN-Habitat (2011). *Cities and Climate Change: Global report on human settlements 2011.* United Nations Human Settlements programme, UN-Habitat, Earthscan: London and Washington.

UN Millennium Project (2005). *A Home in the City.* Task Force on Improving the Lives of Slum Dwellers. Earthscan: London.
http://www.unmillenniumproject.org/documents/Slumdwellers-complete.pdf

United Nations (UN) (1992) United Nations Framework Convention on Climate Change. UNFCCC.
http://unfccc.int/resource/docs/convkp/conveng.pdf

Vincent K (2004). *Creating an index of social vulnerability to climate change for Africa.* Working Paper 56, Tyndall Centre for Climate Change Research & School of Environmental Sciences, University of East Anglia, Norwich.

Waller L (2006). Irregular migration to South Africa during the first ten years of democracy. Migration Policy Brief No. 19, Southern African Migration Programme (SAMP), Kingston, Ontario.
http://www.queensu.ca/samp/sampresources/samppublications/policybriefs/brief19.pdf

Wamsler C (2007). Bridging the gaps: stakeholder-based strategies for risk reduction and financing for the urban poor. *Environment and Urbanization*, 19:1, 115–142.

Water Corporation (n.d.). Perth Seawater Desalination Plant. (website)
https://www.watercorporation.com.au/water-supply-and-services/solutions-to-perths-water-supply/desalination/perth-seawater-desalination-plant [retrieved March 03, 2014]

Wessels K (2005). Monitoring land degradation in southern Africa by assessing changes in primary productivity. PHD thesis, Department of Geography, University of Maryland

Ziervogel G & Smit W (2009). Learning to swim: Strengthening flooding governance in the City of Cape Town. University of Cape Town 16 p.

APPENDICES

Appendix 7.1: Case Studies at Different Representative Locations of Climate and Water Related Indicators of Relevance to Human Settlements under Conditions of Climate Change

OVERVIEW

After setting the scene by briefly reviewing types of human settlements and summarising key drivers of vulnerability and impacts which prevail in this sector in South Africa, the methodology adopted in this study is outlined. This involves the selection of eight locations in South Africa chosen for detailed studies of human settlement relevant analyses on 'push' changes (namely slow changes in average conditions resulting from projections of climate change) and 'pulse' changes (namely changes in individual critical weather dependent events associated with climate change conditions) related to temperature, rainfall and runoff indicators. The eight locations were chosen to represent coastal and inland locations, locations in the summer, winter and all year rainfall regions and locations representing arid, semi-arid and sub-humid climates. This is followed by a discussion on the selection of climate and climate change scenarios, on the selection of biophysical indicators of change relevant to South African human settlements and on the way in which results are presented by an explanation of the indicator, an interpretation of results and the implications of the results.

In the section on findings and their interpretations discussions centre around temperature related 'push' events and projected changes to them, followed by the same format for temperature related 'pulse' events, then rainfall related 'push' trends (of mean annual precipitation, rainfall concentration and of days per year with saturated soil), thereafter rainfall related 'pulse' events related to short duration as well as longer duration 'extreme' rainfalls, followed by runoff related 'push' events (regarding surface water and groundwater resources) and finally runoff related 'pulse' events regarding one and three day flooding of low and high recurrence intervals.

A synopsis of findings consisting of a summary of the approach taken, a summary of key implications and an assessment of future research in this field make up the final section of this report.

1. SETTING THE SCENE

1.1. Introduction

The vulnerability of human settlements to climate change is understood as an outcome of their exposure to environmental risks and changes resulting from climate change, and the extent to which the adaptive capacity of affected communities and households is reduced by social vulnerability. These factors are location specific, related to particular local climate, topography and human settlement patterns (8linkd 2014).

1.2. Types of Settlements

Because of their different social vulnerabilities, climate and climate change will impact differently across the range of settlement types typically found in South Africa, with distinctions made between urban settlements, rural settlements and coastal settlements (8linkd 2014). These types of settlements are described briefly below.

1.2.1. Urban Settlement

This category covers city centres, peri-urban settlements and mixed (urban/rural) settlements. These settlements are characterised by urban sprawl and in South Africa contain settlement patterns that include the following features (8linkd 2014):

- **Affluent residential areas.** These are residential areas at the high end of property development. They generally have solidly constructed houses, reliable access to basic services and display high consumption patterns of water and electricity. Typically they have high adaptive capacity while sometimes supporting patterns of water and energy consumption that are not environmentally sustainable.

- **Low cost and social housing estates.** These include pre-1994 housing as well as many post-1994 new RDP housing estates, often on degraded land and with house tenants frequently leasing out informal or semi-formal structures (shacks) in backyards. Such dwellings are not likely to be "climate-proof" because of structural vulnerability to extreme weather, poor insulation against temperature extremes and are prone to leaks and flooding during heavy rainfall.
- **Informal settlements.** Most of the land occupied in this way is on the urban periphery and is frequently located in areas that may be unsuitable for more formal human settlement due to local topographical features such as unstable soils, wetlands and flood risks. In addition to being environmentally vulnerable, informal settlements often have high population densities and their residents are socially highly vulnerable to climate change.
- **Mixed settlements.** These combine features of urban and rural settlements. Characteristic of many settlement patterns of the former homelands, they are typically not as densely settled as urban areas, but are too densely settled to support intensive commercial agriculture. They may include traditional, formal and informal housing types, characterised by settlement layouts that are not formally planned, with access to basic services often both patchy and unreliable.

1.2.2. Rural Settlements.

These include relatively sparsely populated rural areas containing small settlement nodes and denser, spatially distributed rural settlements.

1.2.3. Coastal Settlements.

Here climate change vulnerabilities that are specific to the coastal context of affected cities and towns are considered, such as those driven by sea level rise and storm surges.

1.3. Key drivers of vulnerability and impacts

Urban, rural and coastal human settlements all face particular environmental and social challenges in relation to climate change, particularly in light of South Africa currently experiencing a strong urbanisation trend which will continue into the future. This trend places infrastructural stresses on urban resources and results in a hollowing out of the productive potential of rural areas due to the exodus of working-age adults into towns. Vulnerability to climate change will not only vary (in degree and nature) between settlements, but also within settlements at the individual or household level (8linked 2014).

The key drivers of vulnerability to climate change in South Africa's human settlements consist of environmental factors which are often exacerbated by uniquely South African social drivers.

Environmental factors and their potential consequences for human settlements due to climate change include:

- *Overall increases in temperatures,* (exacerbated by the urban heat island effect) along with declining air quality in cities and increased demand for cooling.
- *Changes in extreme temperature related weather,* with heat stress impacting on human health, loss of

productivity, increased water demand, water quality problems, heat related deaths and reduced quality of life, as well as enhanced food insecurity.

- *Overall changes in rainfall and runoff*, which affect water supplies to human settlements, either from surface flows (from purely local sources or from larger river systems) or from groundwater, as well as affecting water quality and certain water-borne diseases.
- *Changes in more extreme rainfall and runoff related events*, namely violent storms or damaging heavy rainfalls of one to several days' duration, together with associated local and more regional flood risks which can result in damage to infrastructure and the economy, to loss of property, injuries and even deaths, infections and (again) water-borne disease.
- *Sea level rise and coastal storm surges*, with salt water intrusion on freshwater reservoirs, deaths and injuries, forced relocations, property losses, erosion and submersion of land, damage to infrastructure and services.

Social drivers of vulnerability include:

- *Legacies of past and present social engineering* such as Apartheid era spatial planning which largely shaped urban settlements maladaptively, particularly with poor, historically disadvantaged households being relegated to the urban periphery far from economic opportunities (8linkd 2014), or present-day low-cost housing which is not always constructed to rigorous building standards.
- *Access to basic services* such as electricity, water, sanitation and waste management, all of which are more impacted by climatic extremes rather than means.
- *Type of dwelling*, namely quality of construction, location, access to flood and lightning protection, efficient water systems, cool spaces, heat-reflective surfaces or damp-proofing are all sources of climate vulnerability.
- *Health related issues*, climate resilience depends on baseline health and age related susceptibilities to illness, heat stress, food insecurity and malnutrition – all of which are affected to a greater or lesser extent by climate hazards.
- *Economic factors* such as poverty, unemployment and insecure land tenure are all linked to the ability of households to recover from climate shocks.
- *Demographic factors,* including age structure, gender related vulnerabilities and the proportion of working-age adults (8linkd 2014).

The projected impacts of climate change on urban economies are complex and diverse, and both direct and indirect. They include:

- Direct impacts of weather on construction and other industries in terms of loss of production;
- Increases in the costs of water, liquid fuels and electricity as industrial inputs;
- Increased costs of labour linked to food, energy, water and transport costs;
- Potential impacts arising from regulation of carbon emissions;
- Disruptions to water and electricity supplies which reduce productivity.

2. METHODOLOGY

2.1. Selection of representative locations

In order to restrict the number of representative locations for analysis to eight to maintain an overview, while simultaneously capturing the diversity of settlement types and their geographical settings, the selection of representative locations was guided by the following criteria:

- Types of settlements,
    - o urban, rural and coastal, with consideration within the urban category of city centres, the various sub-types of peri-urban settlements (more affluent suburbia, low cost/social housing and informal settlements)
    - o settlements where water supplies could be predominantly from surface water or from groundwater sources.
- Climatic conditions,
    - o different climatic regimes within South Africa, including sub-humid, semi-arid and arid regions
    - o areas within the winter, all year and summer rainfall regions, and/or with predominantly frontal, convective or more general rains
    - o coastal and inland settlements across a range of altitudes
    - o areas where temperature projections are more moderate and more extreme
    - o areas where overall rainfall magnitudes are generally projected to increase, remain more or less the same or decrease.

Based on the above, the eight locations selected to represent a wide range of settlement conditions were Roodepoort, Lephalale, Bloemfontein, Pofadder, Mitchell's Plain near Cape Town, East London, Durban and Bushbuckridge. Table 2.1.1 shows that these locations:

- are in eight of South Africa's nine provinces
- display an altitude range from 24 m to 1380 m with three coastal and five inland locations
- a mean annual rainfall range from 65 mm to 1088 mm
- cover all rainfall regions and rainfall types
- in some cases use mainly groundwater (for example Mitchell's Plain and Pofadder), others use mainly surface water (for example Durban) and others use both surface and groundwater.

Within close proximity to some of the locations selected, mainly the larger towns and cities, there is a cross-section of urban and peri-urban settlement types from central business districts (CBDs) to informal shanty towns, while others are more typical of townships, and yet others are rural in character.

Table 1 Characteristics of the representative settlements selected for climate change analyses (Authors' compilation)

Representative location	Province	Quinary and location	Alitude (m)	MAP (mm) and dominant rainfall type	Rainfall region
Roodepoort	Gauteng	A21E3 Inland	1380	653 Convective	Early summer
Lephalale	Limpopo	A42J3 Inland	861	480 Convective; Tropical	Midsummer
Bloemfontein	Free State	C52F3 Inland	1349	533 Convective	Late summer
Pofadder	N. Cape	D81G3 Inland	627	65 General	V. Late sum/ winter
Mitchell's Plain	W. Cape	G22D3 Coastal	24	864 Frontal	Winter
East London	E. Cape	R20G3 Coastal	71	832 Frontal; General	All Year
Durban	KZN	U20M3 Coastal	83	949 General	Midsummer
Bushbuckridge	Mpumalanga	X32E2 Inland	744	1088 Convective; tropical	Midsummer

2.2. Selection of climate and climate change scenarios

Because different parts of South Africa will experience different patterns of climate change into the future, with unique interactions of rainfall and temperature characteristics, the four working projections for future South African climates suggested in phase 1 of the Long Term Adaptation Scenarios, with temperatures set to rise by either a little (< 3°C) or by more (> 3°C) in combination with average rainfalls either increasing or decreasing, were considered an over-simplification and, therefore, were not used.

Rather, daily values from climate change scenarios at more local level were obtained from the Climate Systems Analysis Group (CSAG) at the University of Cape Town. These scenarios were made available in point format at existing climate stations and included daily rainfall as well as daily maximum and minimum temperatures. In order to apply these values from the climate scenarios in impact assessments, techniques were developed to represent the scenarios at the spatial resolution of small catchment areas of relatively homogeneous local responses, termed quinary catchments, which more closely represented the location of the settlements selected for this study. The development of these techniques has been described in detail in Schulze (2012) and they are merely summarised below.

The climate change scenarios developed by CSAG and applied in this study were derived from global scenarios produced by five global circulation models (GCMs), all of which were applied in the International Panel on Climate Change's Fourth Assessment Report (IPCC 2007). Details of the five GCMs are provided in Table 2.2.1. All the future global climate scenarios downscaled by CSAG to point scale for use in this report were based on the A2 "business as usual" emissions scenario defined by the IPCC Special Report on Emission Scenarios (IPCC 2000). The point scale climate change scenarios were generated by empirically downscaling the GCM simulation output (CSAG 2008).

Regional climate change scenarios were developed for "present", "intermediate future" and "more distant future" climates represented by the following time periods, the latter two of which were defined by the IPCC:

- present climate: **1971 - 1990** (from a possible 1961 - 2000)
- intermediate future climate: **2046 - 2065**
- more distant future climate: **2081 - 2100**.

Table 2 Information on the GCMs used to generate the global climate change scenarios downscaled by CSAG for this project (CSAG 2008; Schulze et al. 2010; 2012)

Institute	GCM
Canadian Center for Climate Modelling and Analysis (CCCma), Canada	**Name:** CGCM3.1(T47) **First published:** 2005 **Website:** http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
Meteo-France / Centre National de Recherch-es Meteorologiques (CNRM), France	**Name:** CNRM-CM3 **First published:** 2004 **Website:** http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
Max Planck Institute for Meteorology (MPI-M), Germany	**Name:** ECHAM5/MPI-OM **First published:** 2005 **Website:** http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
NASA / Goddard Institute for Space Studies (GISS), USA	**Name:** GISS-ER **First published:** 2004 **Website:** http://www.giss.nasa.gov/tools/modelE
Institut Pierre Simon Laplace (IPSL), France	**Name:** IPSL-CM4 **First published:** 2005 **Website:** http://mc2.ipsl.jussieu.fr/simules.html

- All the scenarios included a daily time series of rainfall for each climate period. The period 1971–1990 was selected to represent the present climate, with the period 1961–1980 not considered due to the long time interval (85 years) between the GCM's present climate and intermediate future climate, relative to the shorter interval (35 years) between the intermediate future climate and the more distant future climate. Additionally, the period from 1981–2000 was not considered as this period may already have experienced a strong climate change signal, making it less suitable as a baseline period.
- The daily values were adjusted (for example, in the case of rainfall by month-by-month relationships with altitude, distance from the ocean, windward/leeward side of mountain ranges and so on) for temperatures by regionalised and monthly lapse rates (Lumsden et al. 2010; Lynch 2004; Schulze & Maharaj 2004) to be representative of the relatively homogeneous and hydrologically interlinked quinary catchments (Schulze & Horan 2010).
- In order to undertake hydrological and related impact studies the daily climate output from the GCMs (namely daily rainfall, maximum and minimum temperatures and daily solar radiation and potential evaporation derived by the Penman-Monteith technique using approaches refined by Schulze and Chapman (2008; Schulze et al. 2008) were used either in direct comparative analyses between projected future and present periods or as input either to empirical models (for example Thom 1959) or the daily time-step conceptual-physical Agricultural Catchments Research Unit (ACRU) hydrological model (Schulze 1995 and updates) for comparative analyses of hydrological or human discomfort variables.

Overall changes in future climate scenarios depend strongly on:

- *which* GCMs were used, and
- *how many* GCMs were in the ensemble used.

The five GCMs which were available for use in this study, namely CGCM3.1/T47, CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4 are considered by climatologists to produce rainfall output possibly a little on the wet side of the spectrum (Hewitson 2010, personal communication) and this has to be borne in mind in interpreting any impacts in which rainfall is an input variable. Furthermore, an error in the GISS GCM's rainfall values for parts of South Africa was reported by its developers and results from the model were omitted from all analyses in this study.

2.3. Presenting results of change projections into the future

As a long term climate baseline against which to assess projected changes in climate and their climatic and hydrological derivatives, values from the historically observed daily rainfall and temperature databases for the 50 year period from 1950–1999 created by Lynch (2004) and Schulze and Maharaj (2004), linked and adjusted to a quinary catchments database for the 5 838 quinaries covering the RSA, Lesotho and Swaziland were used.

For typical analyses in this report the historical values for the variables under study were first derived for the quinary in which the representative location was situated. Ratios of intermediate future (namely 2046–2065) to present (1971–1990), and more distant future (2081–2100) to present were then calculated for each of the GCMs used for the variable under analysis. The mean of the ratios was then computed and the resultant mean of the ratios was then multiplied by the historical value to obtain projected estimates for the intermediate future and for the more distant future.

2.4. Selection of indicators of change relevant to human settlements

Two broad categories of climate and water related indicators are of relevance when assessing potential impacts of climate change on the range of human settlements already identified earlier. These are changes in so-called:

- "push" events, namely where a gradual change of a critical climate driven indicator occurs over time, which may place either greater or lowered biophysical stress onto the human settlement and which is a phenomenon with a slowly creeping onset over time, for example, effects of steadily increasing temperatures or of gradually changing water supplies to a town brought about through climate change
- "pulse" events, namely changes over time in critical individual weather driven events with durations of minutes to several days which impact directly on peoples' safety and well-being in human settlements.

These push and pulse events may be related either to temperature derived indicators or to rainfall or runoff related indicators. These distinctions are made when findings are presented below.

3. FINDINGS AND THEIR INTERPRETATION

3.1. Introduction

It has already been stated that environmental factors and their potential consequences for human settlements due to climate change include overall increases in temperatures, changes in extreme temperature related weather events, overall changes in rainfall and runoff, changes in more extreme rainfall and runoff related events, and sea level rise and coastal storm surges (see section 1.3 above for details.

In the findings and interpretations which follow, both the push and the pulse indicators considered relevant to human settlements are discussed under the sub-headings of:

- *explanations* of what the indicators are and why they are considered important
- *interpretations* of the findings which are presented by way of graphs comparing the indicator and its projected changes into the future at the eight representative locations
- *implications;* what the results imply for human settlements, their related infrastructure and the well-being of their residents.

It should be noted that the intermediate future (2046–2065) is sometimes abbreviated as IF and the more distant future (2081–2100) as MDF in the text that follows.

3.2. Temperature related push events and projected changes

Explanations

Broad statements such as a 1°C or 2 or even a 3°C increase in average temperature affecting humans are relatively meaningless as the accumulated effects of those increases are difficult to quantify. Borrowing a concept used in agriculture, the accumulated changes in daily temperatures above a certain threshold, namely changes in so-called "degree days", is a much more meaningful push indicator of rising temperatures. Examples of the calculation of degree days with a threshold of, say, 10°C, would be as follows: A day with an average temperature of 15°C would give 5 degree days (namely 15 – 10), while a day at 22°C would give 12 degree days (22 – 10), with days on which average temperatures are below 10°C being assigned 0 degree days. The degree days at a specific location would then be accumulated over a period of time such as a year or for the summer season (October to March in South Africa) or the winter season (April to September).

Interpretations

Figure 3.2.1 shows that under historical climatic conditions (1950–1999) annual accumulated degree days are generally uncomfortably high at > 4 000 degree days in sub-tropical low latitude and semi-desert areas (for example, Lephalale and Pofadder), somewhat lower at ~ 2 400 to 2 900 degree days at higher altitudes in the interior of South Africa (for example, Roodepoort and Bloemfontein) and lowest at the southerly latitudes (for example, Mitchell's Plain). As expected, accumulated degree days dominate in summer. Changes in degree days into the intermediate future and especially the more distant future are marked (Figure 3.2.2) and when expressed as percentage changes in Figure 3.2.3 it is evident that in relative terms the winter changes are considerably higher than those in summer, especially at the higher altitude stations such as Roodepoort and Bloemfontein, primarily because under present conditions the winter values there are low.

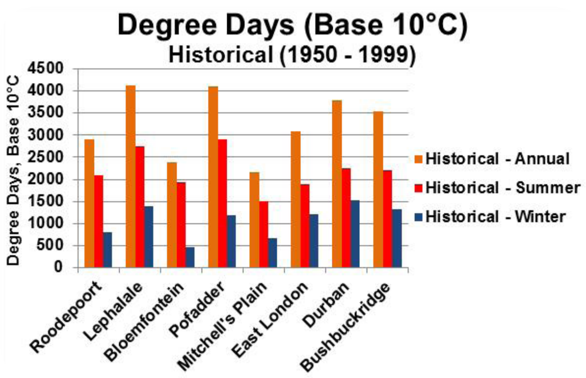


Figure 3.2.1: Annual, summer and winter accumulated degree days (base 10°C) under historical climate conditions.

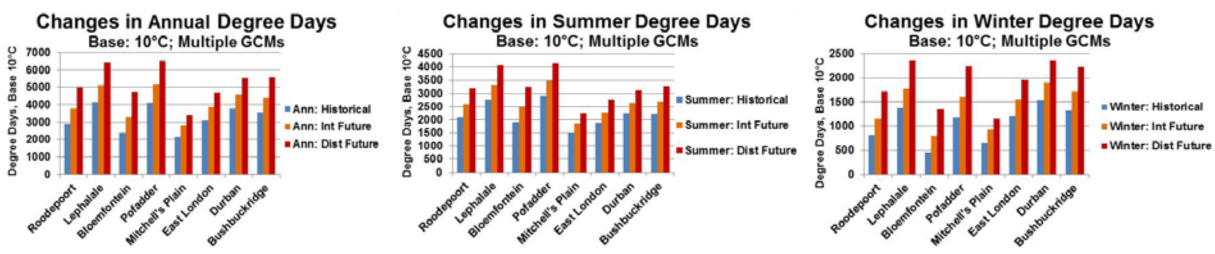


Figure 3.2.2: Changes, from historical climate conditions into the intermediate and more distant future in annual, summer and winter degree days, derived from outputs of multiple GCMs.

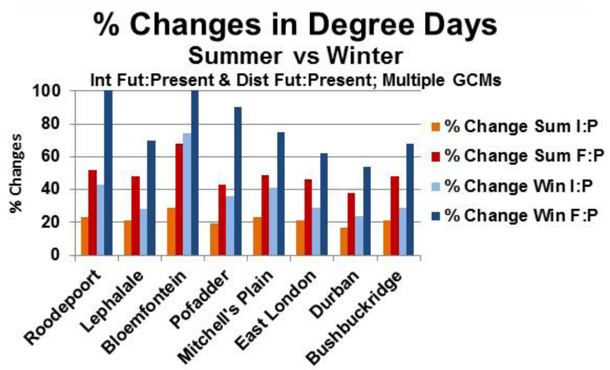


Figure 3.2.3: Percentage changes into the intermediate and more distant future in projected summer versus winter degree days, derived from outputs from multiple GCMs.

Implications

Considerable accumulated warming is projected to take place throughout South Africa both in summer, when more uncomfortable conditions are expected in already warm areas, and in winter, when conditions within the different types of human settlements will become more tolerable, especially in presently cold areas. Using accumulated degree days as a temperature related indicator of a "push" factor, economic implications are for less heating in winter, but with this being offset by a greater need for cooling in summer.

3.3. Temperature related 'pulse' events and projected changes

Explanations

Human comfort in thermal terms is based on the energy balance between the human body and its environment. The human body's thermal balance consists of maintaining the body's temperature between 36.5°C and 37°C, since increases or decreases in the body's temperature produce discomfort, and if the body's temperature exceeds 40°C blood circulation problems appear, while above 41–42°C a coma or total body collapse can occur.

The more significant climatic drivers of comfort/discomfort are:

- humidity, which controls evaporation and plays an important role at high temperatures where perspiration is the cooling mechanism
- temperature, which is the main source of heat gain.

In human settlements the number of days on which humans experience discomfort plays an important role in inter alia:

- productivity, especially of manual labourers
- energy usage
- the health of individuals, especially those with respiratory problems
- the tourism industry.

Of the many indices of human thermal comfort/discomfort, Thom's (1959) Human Discomfort Index (TDI) is one of the most widely used. The TDI is formulated by an equation which combines air temperature T (°C) and relative humidity RH (%) and results are grouped into four classes, namely uncomfortable because it is too cold and dry, comfortable, partially comfortable and uncomfortable because it is too hot and humid. The TDI was computed for hot/humid conditions on a month-by-month basis at each of the eight representative locations for midday conditions, namely for daily maximum temperature and minimum relative humidity conditions, for historical and for projected future climates.

Interpretations

Figure 3.3.1 shows that under present climatic conditions a significant number of uncomfortable days (the blue bars) are only really experienced in arid Pofadder (with an average of 15 uncomfortable days in January and 55 for the whole year) and to a lesser extent in sub-tropical Lephalale (averaging 19 uncomfortably hot/humid days a year and 6 in January), with Durban surprisingly recording only very few uncomfortable days by Thom's criteria. Even into the IF it is still arid Pofadder, with a projected average of 111 uncomfortably hot/humid days and 4 months with > 20 uncomfortable days each, and sub-tropical Lephalale averaging 77 uncomfortably hot/humid days a year, which display significant increases. The big jump occurs in the MDF, especially on the hitherto cooler Highveld (for example Roodepoort and Bloemfontein), with many representative stations showing high numbers of uncomfortable days even in winter months.

Implications

It is the presently already hot areas in the arid and sub-tropical zones which will bear the brunt of additional discomfort over the next 40 or so years through enhanced numbers of uncomfortably hot/humid days. If temperatures continue rising in a "business as usual" scenario, most of the country will experience many unbearably hot/humid days with repercussions for health, economic productivity and energy usage (less in winter, more in summer).

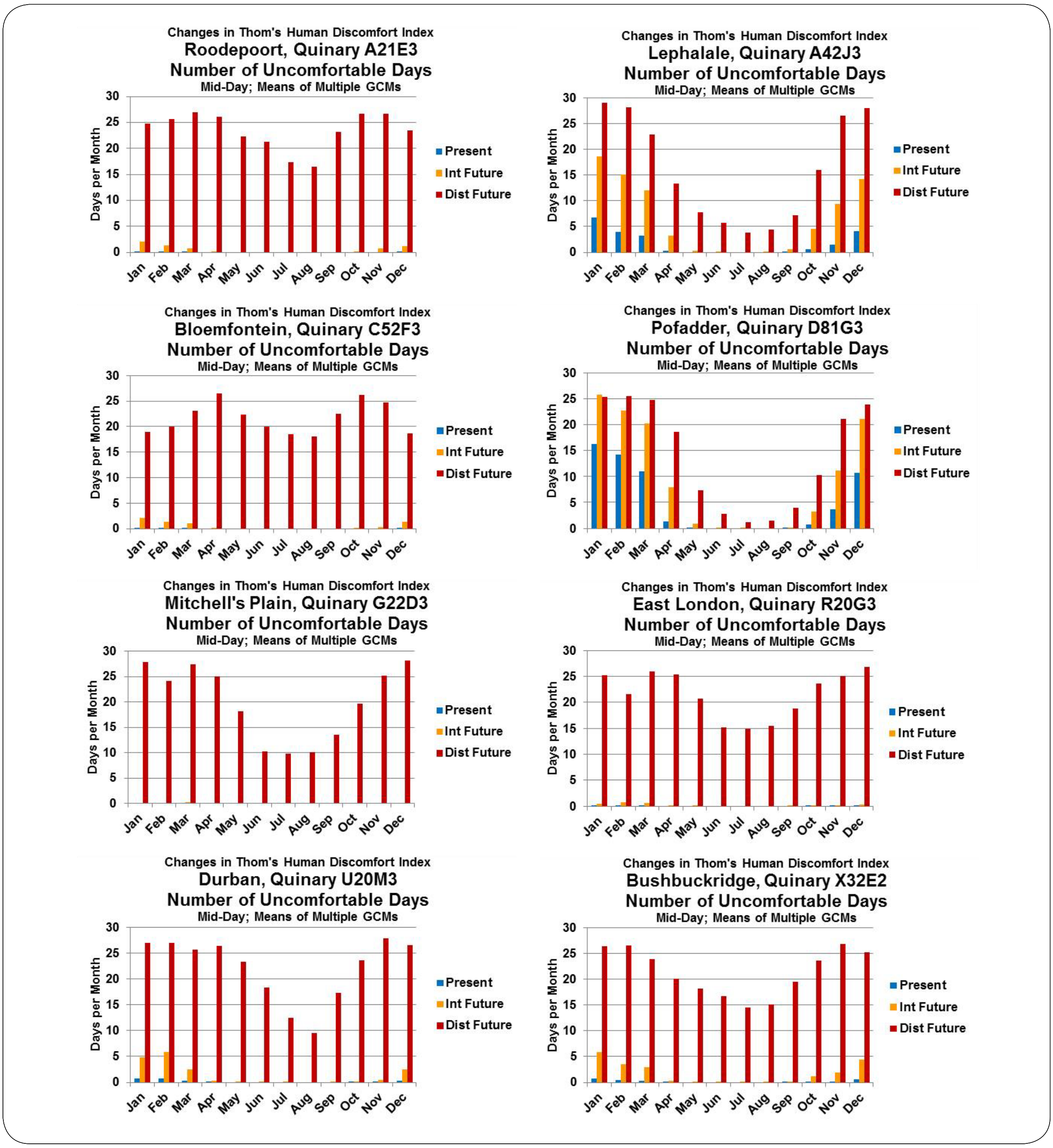


Figure 3.3.1: Month-by-month changes in the number of uncomfortably hot/humid days from the present into the intermediate and more distant future at selected locations, based on Thom's Human Discomfort Index and derived from outputs of multiple GCMs.

3.4. Rainfall related 'push' events and projected changes

3.4.1. Mean annual precipitation

Explanations

The mean annual precipitation (MAP) characterises the long term quantity of water available to a location or region for domestic, hydrological and agricultural purposes. MAP is an important general statistic in its own right, but it is probably the best known climatic variable which can be related to many other things. In the context of human settlement studies it is used more as a broad indicator of contrasts in climates and it is used as a reference indicator for many other assessments.

Interpretations

The range of MAPs under historical climatic conditions from 65 mm at Pofadder to 1 083 mm at Bushbuckridge has already been alluded to. Figure 3.4.1 shows that with the exception of Mitchell's Plain in the winter rainfall region of the Western Cape, all the other locations selected display a projected increase in MAP into the intermediate and more so into the more distant future according to the outputs of the GCMs used in this study.

Implications

While the projected increases in MAP at certain locations are generally viewed as a positive, it should be borne in mind that the non-linear relationship between runoff and rainfall has additional implications for water resources, as discussed later.

3.4.2. Rainfall concentration

Explanations

Not only is it important for human settlements to know whether the average annual rainfall is low or high, or whether the rainfall season is in summer or winter or throughout the year, but the length of the rainy season is important for filling storage dams, watering gardens, or having to irrigate for a few or many months of the year. The rainfall concentration (RC) (Markham 1970) is an index which relates to the concentration, or spread, of rainfall over a year. In essence, a concentration index of 100% will imply that all of a location's rain falls in a single month, whereas a concentration of 0% would mean the rainfall for each month of the year is the same at 8.33% of the annual total. The higher the RC index, therefore, the less the rainfall season is spread over time, irrespective of whether it is a high or low rainfall area or a winter or

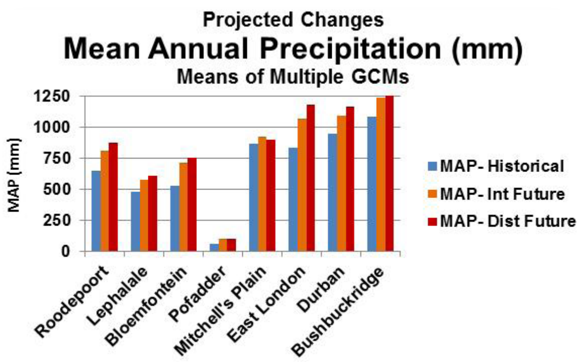


Figure 3.4.1: Historical values of mean annual precipitation at selected locations, as well as projections of intermediate future and more distant future values, derived from outputs of multiple GCMs.

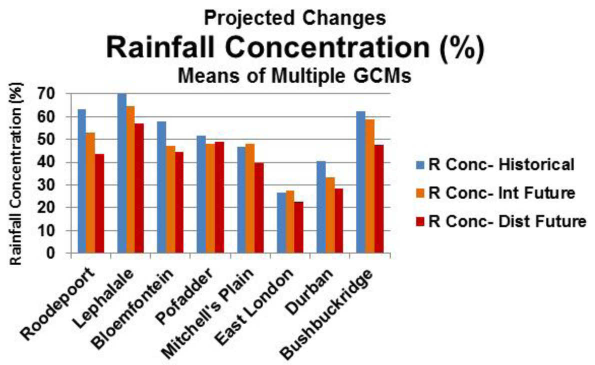


Figure 3.4.2: Historical values of rainfall concentration at selected locations, as well as projections of intermediate future and more distant future values, derived from outputs of multiple GCMs.

summer rainfall region. Under climate change conditions a reduction in the RC would therefore imply a more even spread of rainfall throughout the year, while an increase would imply a shorter rainfall season.

Interpretations

The RC under current (1950–1999) climatic conditions ranges from a short season high of 70% in Lephalale to a low of 27% in East London, where rainfall is experienced over much of the year (Figure 3.4.2). The overall trend into the intermediate future is for the RC to decrease, with the exceptions of the stations representing the winter and all year rainfall areas (Mitchell's Plain and East London). The decrease in the RC continues into the MDF towards the end of the century.

Implications

The projected wider spread of rainfall throughout the year in the future has positive implications for human settlements, as it is expected that runoff will also be generated over a longer period of the year than at present, thus possibly relaxing strict dam operating rules which are currently often in place even in "average" years. A more even distribution of rainfall and runoff may, however, be offset by higher inter-annual variability of rainfall and streamflows.

3.4.3. Days per year with saturated soil

Explanations

It is not only extreme rainfall events or raging floods that cause damage and result in hardship to inhabitants of human settlements. The plight of residents, especially in informal settlements, suffering discomfort, hardship and health problems because prolonged rains cause the soil to become waterlogged and the water level then builds up gradually damaging homes and their contents is a frequent sight on our TV screens.

Various states of water content in soils can exist, for example, soils can be dry, very dry, wet or waterlogged. The focus here is on saturated or waterlogged soil conditions, defined as days when the field capacity of the soil is exceeded. The frequency of such conditions depends on consecutive days with persistent rain (rather than one big event) and on soil drainage properties, with sandy soils draining more rapidly than clayey soils. The frequency of waterlogged conditions was assessed with the daily time step, multi-level soil water budget ACRU model (Schulze 1995 and updates) for current and projected future climates.

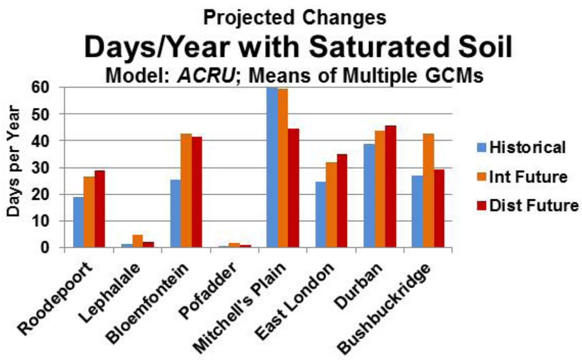


Figure 3.4.3: Historical values of days per year when the soil is saturated at selected locations, as well as projections of intermediate future and more distant future values, derived from outputs of multiple GCMs.

Interpretations

Under current climatic conditions, and with due consideration to soil properties typically found at the respective locations under study, days with waterlogged soils range from an average of ~ 1 per year at Pofadder and 1 at Lephalale to around 20 days at Roodepoort, Bloemfontein and East London to ~ 40 at Durban and 60 at Mitchell's Plain (Figure 3.4.3, blue bars), the last named in a region with multi-day frontal rains in winter when evaporation rates are very low. The figure also shows that the number of days with waterlogged soils is projected to generally increase into the future. The exception is Mitchell's Plain where projections show no change into the IF and even a decrease into the MDF – consistent with projections of an overall decrease in rainfall in the winter rainfall region of South Africa.

Implications

The implications are that urban planners need to take greater cognisance of both soil drainage conditions and the rainfall regime, especially in the winter rainfall region where multi-day rains persist, even into the intermediate future.

3.5. Rainfall related 'pulse' events and projected changes

3.5.1. Short duration 'extreme' rainfall

Both urban and rural areas contain many types of hydraulic engineering structures (such as culverts, dam spillways or stormwater systems) which need to be designed to accommodate peak flows of a certain magnitude in order to function safely at a given level of risk. Should the structures fail, either through breaching or by overtopping, especially where human settlement is dense, there are potential economic, environmental and societal consequences. Hence flood frequency analysis is a major consideration in the functioning of human settlements.

Floods are, however, a consequence of excessive rainfall. So-called "extreme" rainfall, also termed design rainfall, may be expected to occur only very infrequently, for example, with a statistical recurrence (termed a return period) of 2, 10 or 50 years, with the importance of the recurrence interval depending on the size and/or significance of the structure, especially where humans reside next to streams or downstream of structures which could fail.

It is hypothesised that climate change, through an expected "energising" of the earth's atmosphere due to increases of temperature and resultant disturbances to rainfall regimes, could result in increases in the intensity and frequency of extreme rainfall events of both short and long duration with resultant increases in the associated flooding.

Explanations

Short duration rainfall (SDR) is defined as rain falling over durations shorter than 24 hours, and often as short as 10–30 minutes when associated with severe thunderstorms. In this study the indicator SDR is the 2 year 30 minute rainfall, namely the magnitude of rain falling in a 30 minute period statistically every 2 years (or 50 times in a century). SDRs can damage houses (especially inferior structures), other infrastructure and cause excessive soil loss.

Interpretations

Under historical climatic conditions values of the 2 year 30 minute rainfall vary from < 25 mm in low rainfall arid regions represented by Pofadder and in areas characterised by low intensity frontal rains as at Mitchell's Plain, to more than double that at 50–55 mm along the high rainfall eastern fringes of South Africa at Durban and Bushbuckridge (Figure 3.5.1).

Estimations of changes in extreme SDRs into the future involve complex computations and are still associated with many uncertainties (Knoesen et al. 2011), but first estimates indicate increases in the range 6–15% in the interior (Roodepoort, Bloemfontein and Pofadder) where convective storms are a dominant source of rainfall, while along the southern and eastern seaboard (Mitchell's Plain, East London and Durban) projected changes are negligible.

Implications

Some urban areas (eThekwini, Cape Town) already factor in potential increases in SDR in the design of new stormwater systems. While it is still early days, it may be prudent to expect increases in SDR and accommodate for that eventuality in, for example, gutter design, stormwater design and, in rural areas, closer spacing of contour banks.

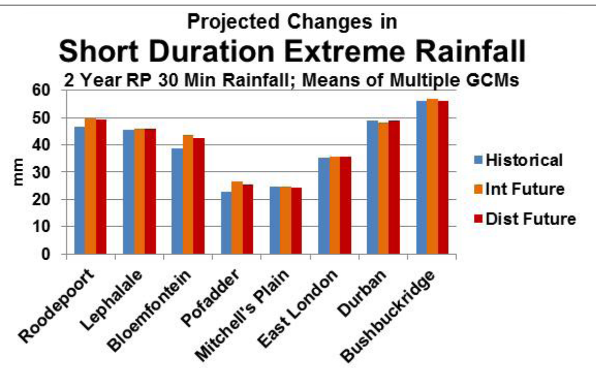


Figure 3.5.1: Historical values of short duration extreme rainfall, expressed as the 2 year 30 minute rainfall, at selected locations, as well as projections of intermediate future and more distant future values, derived from outputs of multiple GCMs.

3.5.2. Longer duration ‘extreme’ rainfall

Explanations

‘Extreme’ (or design) rainfall of longer duration, say 1 or 3 consecutive days, results in regional flooding, saturated soil conditions and structural damage. Magnitudes of such design storms are assessed according to their frequency of recurrence such as the 2, 10 or 50 year return periods, representing occurrences of 50 times per century, 10 times and twice in 100 years.

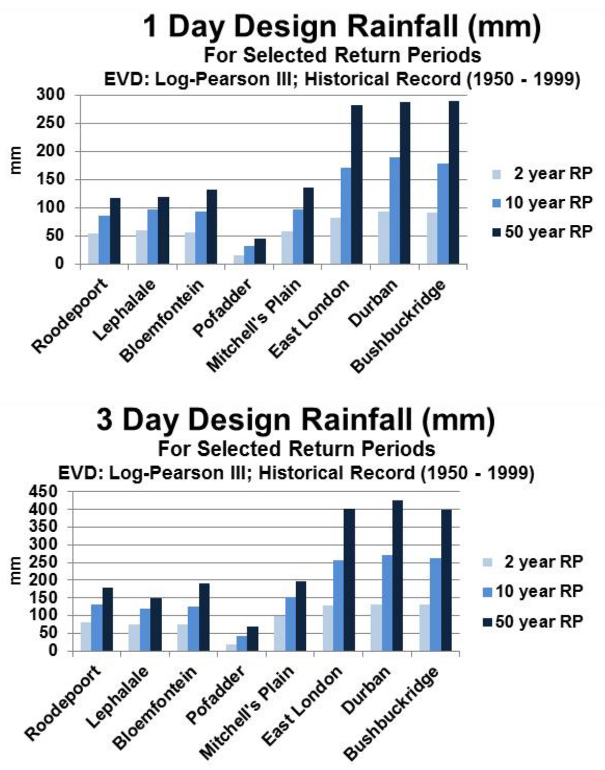


Figure 3.5.2: Historical values for the 1 day (left) and 3 consecutive day design rainfalls for the 2, 10 and 50 year return periods.

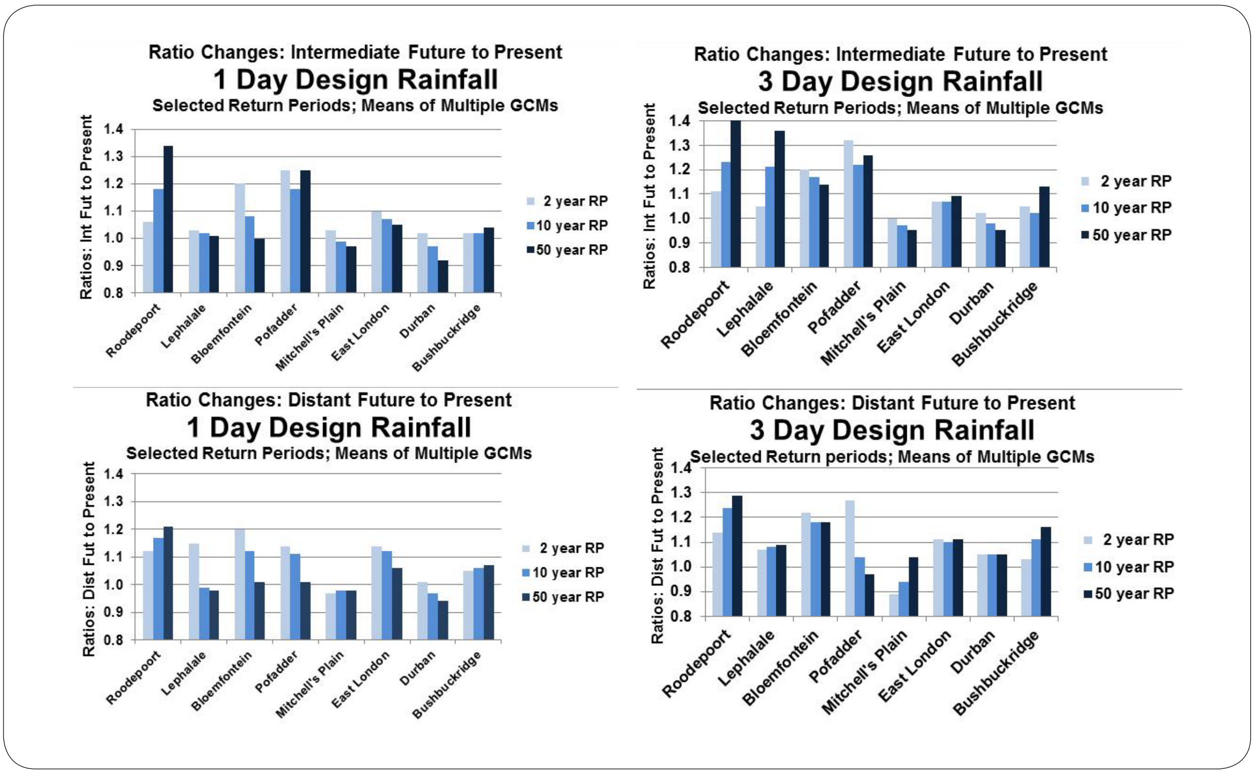


Figure 3.5.3: Ratio changes, for selected locations and return periods, of 1 day (left column) and 3 day (right column) design rainfalls for intermediate future (top row) and more distant future climate scenarios, derived from outputs of multiple GCMs.

Interpretations

Historical values of 1 day and 3 consecutive day design rainfalls shown in Figure 3.5.2 indicate that for many locations the 1:10 year rains are ~ twice the magnitude of the 2 year return period rains, and the 50 year events are ~ 3 times the magnitude of 2 year events. Furthermore, design rainfalls of higher return periods and that recur only very infrequently (namely for the 50 year return period) are extremely high along South Africa's eastern seaboard (East London, Durban and Bushbuckridge) at nearly 300 mm for 1 day events and 400 mm for 3 consecutive day events.

In projections into the future, ratio changes in design rainfalls between the intermediate future and present (Figure 3.5.3 top row) as well as between the MDF and present (Figure 3.5.3 bottom row) are assessed. The key issue in regard to human settlements is whether this ratio is > 1, implying increases in extremes, or < 1, implying more benign extremes in future. Barring assessments at Pofadder, where the base is so low that increases are not really meaningful in practical terms, the following are considered to be of significance:

- for 3 day events the positive ratios tend to be higher than for 1 day extreme rainfall events, especially in the sub-tropics (Lephalale), possibly implying more extreme events of long duration from tropical moisture inflows
- for inland stations the ratio change for the 50 year return period is generally higher than that for 10

years, and that in turn is higher than for the 2 year recurrence interval, while for coastal stations the inverse generally holds, with in many cases the biggest increase being in the 2 year events, indicating a possibility of more convective events than at present

- in the winter rainfall region, represented by Mitchell's Plain, and to a lesser extent in Durban, ratios are frequently < 1, implying projections of extreme rains of lesser magnitude than at present. In the case of Mitchell's Plain this is consistent with projections of lower rainfalls in future.

Implications

Eastern seaboard regions already display exceptionally high design rains of both 1 and 3 days duration for very infrequent events of the 50 year return period, and town and regional planners already factor this into their designs. Planning will also need to consider that long duration events are generally projected to increase, and that for inland locations hydraulic designs with long lifetimes (for example, for the 50 year return period) may have to increase as a safety feature. Despite decreases in ratios between future projections and the present in the winter rainfall region, hydraulic design to cope with long duration rains should, however, not be relaxed as the *frequency* of events (rather than the *magnitude*) leading to saturated soils is still projected to increase.

3.6. Runoff related 'push' events and projected changes

3.6.1. Surface water resources

Explanations

Surface water resources are represented in this study by the median annual runoff (MAR) and by statistics of its inter-annual variability. The median annual runoff from a stream/river is an indicator of the long term availability of surface water, with as many years with accumulated annual flows above the median value as there are years with flows below the median. The median is preferred to the mean, because the latter value is often distorted by years with extreme floods, water from which cannot in any event be used by human settlements.

Daily runoff was calculated with the daily time step, conceptual-physical ACRU hydrological model (Schulze 1995 and updates). For this assessment the local runoff (rather than the accumulated runoff from all upstream catchments) was computed for the locations of interest from daily values of stormflows and baseflows for the middle quinary of three quinaries making up a quaternary catchment (note that the upper quinary is often located in higher lying areas of a quaternary and could give a distorted picture of local runoff conditions, while the lower quinary cannot be used as it is the receiving catchment of all upstream flows). All computations, for both historical and projected future climatic conditions, were undertaken with a baseline land cover representing natural vegetation (Acocks 1988) for which hydrological attributes were derived (Schulze 2004), and with hydrological soil attributes derived by Schulze and Horan (2008).

In the present context the MAR is the most common indicator of water available for storage in dams and for consequent use by human settlements. What is important here for local supplies is the expected yield of water and its reliability from year to year, expressed as its variability in both absolute terms, namely its standard deviation from the mean, and the variability relative to the mean, namely its coefficient of variation (CV).

Interpretations

The wide range of MARs under current climatic conditions at the eight representative locations, varying from < 1 mm to > 365 mm equivalent, is shown in Figure 3.6.1 by the blue bars. With the exception of Mitchell's Plain in the winter rainfall region, where baseflows dominate runoff, the other locations have predominantly surface runoff, with MARs values generally at a low 10–25 % of the mean annual rainfall. Projections into the future, according to the GCMs used in this study, generally display increases, with the exception again of Mitchell's Plain, which is located in the region with projected decreases in rainfall.

The inter-annual variability of runoff is already high under current climatic conditions (Figure 3.6.1 bottom maps), with the variability indicated by the high standard deviations and confirmed by the inter-annual coefficients of variation generally in the order of 50–100 %. In absolute terms the variability of annual runoff is projected to increase into the future at all eight locations assessed (Figure 3.6.1 orange and red bars), but especially into the intermediate future which is only some 40 years hence.

Implications

While the conversion of rainfall to runoff at the locations selected is relatively low at 10–25% (world average is 35%), the general projected increases in MAR in the summer and all year rainfall regions with the GCMs used in this study is positive for assurance of water supply to human settlements. Counteracting this, however, is concern with the already high inter-annual variability of runoff under current climatic conditions, but even more so into the future with projected increases in variability, for this is likely to render water management more difficult and make dam operating rules more complex.

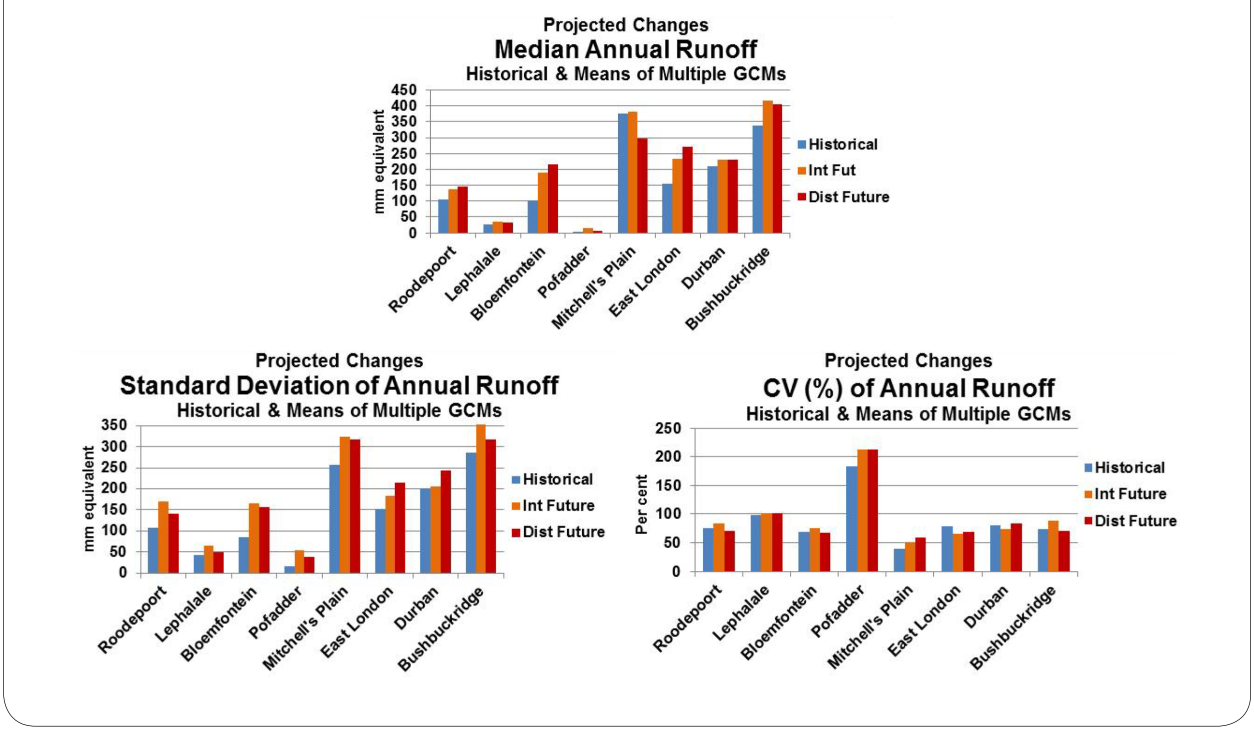


Figure 3.6.1: Median annual runoff at the eight representative locations, for both historical and projected future climatic conditions (top), as well as the inter-annual variation of runoff under historical and projected future climates, expressed in absolute (bottom left) and relative (bottom right) terms.

3.6.2. *Groundwater Resources*

Explanations

Groundwater is the primary source of reliable, safe drinking water supplies in many rural areas and for many towns in South Africa, especially in semi-arid and arid regions. It is also the source for the irrigation of thousands of hectares of valuable arable land around the country and for supporting large numbers of livestock and game. In addition, many mines and industries rely on groundwater for their supplies (DWA 2013). With the over-use of surface water resources in many parts of South Africa, groundwater supply will have to play a major role in the future growth of the region because of its relative cost effectiveness. Reliable assessments of exploitable groundwater resources are therefore essential, particularly for sustainable development in semi-arid areas, which depend more heavily on groundwater than do moister areas. This is important especially during periods of drought when groundwater is often the sole exploitable and reliable water resource for survival. However, the subterranean water stores, which may become depleted through abstractions, have to be recharged (replenished) over a period of time by rainfall in order for groundwater supplies to remain sustainable.

Recharging of groundwater can take place by several means, but in this study it has been calculated with the ACRU model by drainage of soil water through the soil column. Recharge therefore will depend on soil properties (for example, depth and drainage rate) as well as rainfall properties (particularly consecutive days with rain "pushing" soil water to below the soil column). Two indicators of groundwater are assessed, namely:

- the sustained store of groundwater obtained from recharged water and averaged over a year
- the average annual magnitude of recharge through the soil column into the groundwater zone.

Interpretations

The sustained groundwater store from recharged water under historical climatic conditions (blue bars in left map of Figure 3.6.2) is highest where multi-day rainfall events prevail (for example, at Mitchell's Plain, East London and Durban), and lowest in low rainfall areas (for example Lephalale and Pofadder). Higher rainfall magnitudes projected in the east for the IF, coupled with projections of a more even spread of rainfall over the year (see Figure 3.2.2) are probably the prime reasons for a projected general increase in the sustained groundwater store over the next 40 or so years (Figure 3.6.2 left map, orange bars).

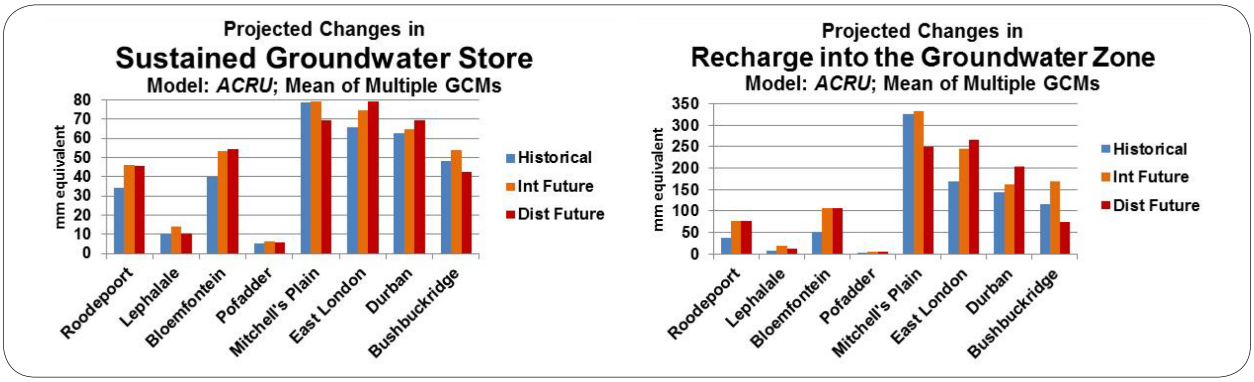


Figure 3.6.2: Historical and future projections of the sustained groundwater store (left) and of recharge into the groundwater store at selected locations, derived with the ACRU model and with future projections based on output from multiple GCMs

Under historical climatic conditions the mean annual recharge of water into the groundwater zone (Figure 3.6.2 right map) varies considerably from location to location, but with high values in the winter rainfall region (Mitchell's Plain) characterised by multi-day rainfall events and at other locations along the eastern seaboard where more general rains are frequently experienced. Again there is a general increase of recharge into the intermediate future, one exception being at Mitchell's Plain where overall decreases in rainfall are projected, especially in the more distant future.

Implications

The status of the groundwater store is highly dependent on rainfall characteristics and is largely dependent on multi-day rainfall events of a frontal or general nature. On the plus side for human settlements in South Africa is that, according to the outputs from the multiple GCMs used in this study, there is a general increase of groundwater recharge especially into the intermediate future, while on the negative side in the semi-arid and arid zones of South Africa (represented by Lephalale, Pofadder and Bloemfontein) where there is a high dependence on groundwater, recharge is presently low and is projected to remain low. This sounds a warning to carefully monitor groundwater abstractions so as to not over-exploit this vital resource.

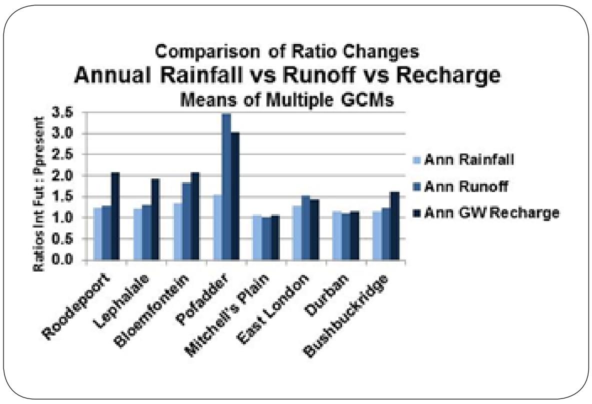


Figure 3.6.3: Comparison, at selected locations, of ratio changes between the intermediate future and present of annual rainfall, runoff and recharge into the groundwater zone, derived from outputs of multiple GCMs.

3.6.3. Comparison of intermediate future to present ratio changes of annual rainfall, runoff and groundwater recharge

Explanations

Up until this point projected changes in rainfall, surface runoff and groundwater recharge have been assessed separately. In this section a comparison is made of projected responses into the intermediate future.

Interpretations

Using the ratio changes between the intermediate future to the present, Figure 3.6.3 shows that projected changes in surface runoff are slightly more sensitive than changes in rainfall and that, in turn, changes in groundwater recharge in the interior of South Africa (for example, at Roodepoort, Lephalale, Bloemfontein, Pofadder and Bushbuckridge) are considerably more sensitive to climate change than changes in surface runoff, while in the coastal areas with more sustained, general rains (for example, at Mitchell's Plain, East London and Durban) this is not the case.

Implications

Town and regional planners, when designing into the future, need to be aware that when considering issues of water resources, projected changes resulting from climate change are important and that anticipated changes are location specific and also depend on whether the source of water is from surface runoff or from groundwater, since their sensitivities to climate change are different.

3.7. Runoff related 'pulse' events and projected changes

Explanations

The background to design floods has already been given in the introduction to design rainfall (see Section 3.5). With regard to human settlements in South Africa, floods do damage especially to informal settlements, which are often located adjacent to streams, and the effects can be devastating to dwellings, with loss of life also frequent. In rural settings floods are associated with large losses of fertile topsoil, and high sediment yields in rivers increase costs of water purification to towns downstream. Note that a 1 day flood usually incurs damage on a more immediate, local scale while the effects of a 3 day flood are often associated with longer periods of inundation, which does damage in different ways and incurs different hardships than a shorter flood.

Unlike extreme rainfalls, the immediate direct effects of which are local and in situ, floods grow in magnitude downstream and the further downstream within a catchment, the more damaging the flood is likely to be. In this study, however, only local flooding is assessed, and for each of the eight selected locations the design floods of the middle quinary of the quaternary in which the location is situated are evaluated. Reasons for selecting the middle quinary are given in Section 3.5.

Interpretations

Values of 1 and 3 day design floods for the 2, 10 and 50 year return periods are given in Figure 3.7.1 for the eight selected locations. Unlike design rainfall, where the magnitude of the 10 year rain was shown to be ~ twice the 2 year magnitude, and the 50 year rain again ~ twice the 10 year rain, design floods are amplified with the return period, with the 10 year flood being 2–5 times the 2 year flood and the 50 year flood in places up to 2.5 times the 10 year flood. Again, the eastern seaboard stations of East London, Durban and Bushbuckridge experience significantly higher local flooding than elsewhere.

Ratio changes of design floods into the future (Figure 3.7.2) display mixed patterns with regard to return periods, but at first glance ratios into the intermediate future appear amplified in relation to the corresponding ones for rainfall (see subsequent analysis). A significant observation is that floods at Mitchell's Plain, representing the Western Cape region with projected decreases in rainfall, generally have ratios < 1, indicating likely reductions in design floods of long duration into the future.

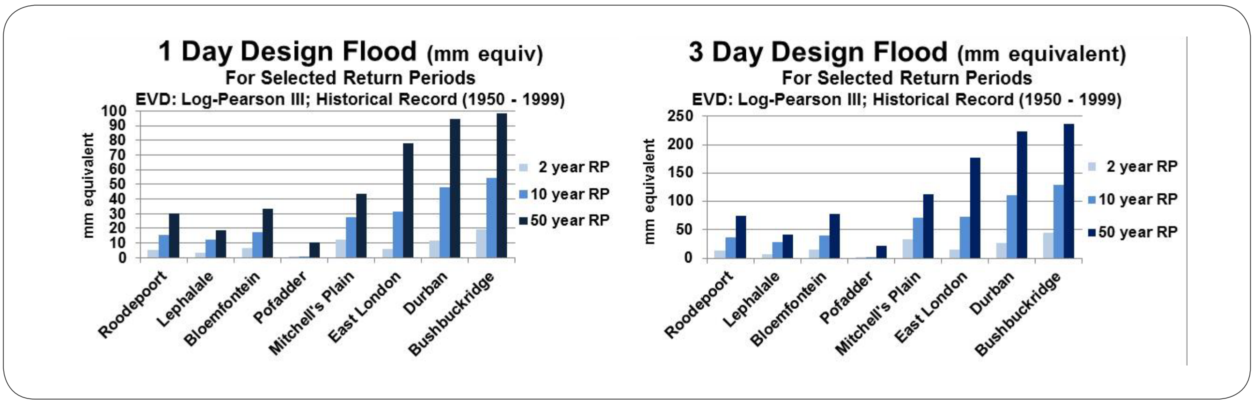


Figure 3.7.1: Historical values for the 1 day (left) and 3 consecutive day design floods for the 2, 10 and 50 year return periods, calculated with the ACRU model and using the log-Pearson extreme value distribution.

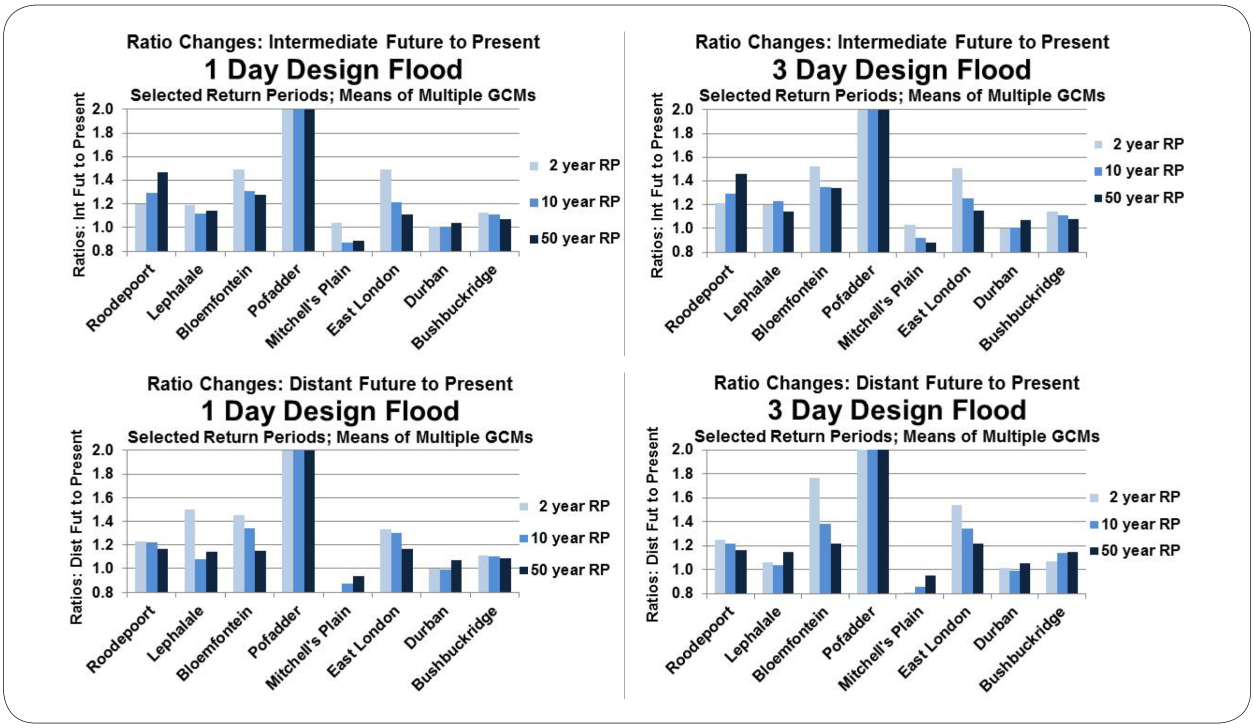


Figure 3.7.2: Ratio changes, for selected locations and return periods, of 1 day (left) and 3 day design floods for intermediate future (top row) and more distant future climate scenarios, derived from outputs of multiple GCMs.

Implications

Projections based on outputs from multiple GCMs indicate that the hydraulic designs of structures and the locations of dwellings adjacent to streams will need to be re-examined in light of climate change, especially with regard to events of higher return periods. Because of the accumulated effects as floods move downstream in a catchment, consideration will also need to be given to where within a catchment design changes should be made.

Design floods have worse impacts than corresponding design rainfalls not only because of flood waters accumulating downstream, but also because of the amplification of effects when rainfall converts to runoff. This amplification is well illustrated in Figure 3.7.3 for both 1 and 3 day extreme events, with ratios of change from the intermediate future to present at virtually all locations and for all three return periods showing that the blue bar, designating a design rainfall, has a lower (but positive) ratio than the corresponding brown bar, which designates the projected change in design runoff.

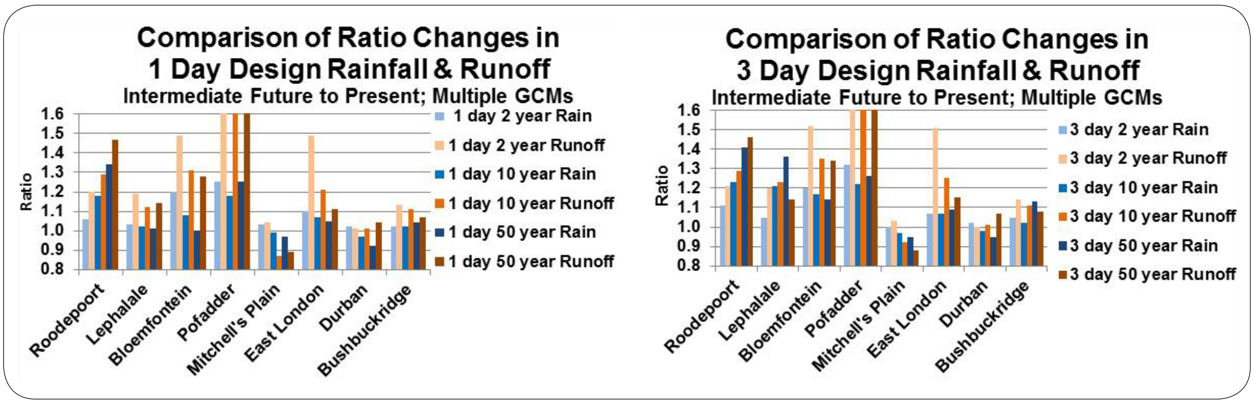


Figure 3.7.3: Comparison of ratio changes in 1 day (left) and 3 day (right) design rainfall and runoff for selected return periods, derived from outputs of multiple GCMs.

4. A SYNOPSIS OF FINDINGS

A summary of the approach taken

Potential biophysical/environment related impacts of climate change were assessed in regard to temperature, rainfall and water indicators considered appropriate to human settlements in South Africa. A distinction was made between so-called push events which are projected to change slowly over time into the future and which impact gradually on human settlements, and pulse events which are short-lived individual weather forced events with more shock implications on human settlements. For the analysis of each selected indicator the scene was set by considering the situation under historical (1950–1999) climatic conditions, which was then compared with the situation under projected climate change conditions, with these expressed for the respective indicators through means derived from multiple GCMs.

Analyses were undertaken at eight locations in South Africa, with these having been carefully selected to represent human settlement situations across a range of arid to semi-arid to sub-humid climates, from low to high altitudes, along the coast and into the far interior, in the summer as well as the all year and winter rainfall regions, and with short and long rainy seasons. For each analysis an explanation of the indicator was followed by an interpretation of findings and an assessment of possible implications for human settlements.

A summary of findings

- Considerable accumulated warming is projected to take place throughout South Africa, both in summer when more uncomfortable conditions are expected in already warm areas, and in winter when conditions within the different types of human settlements will become more tolerable, especially in presently cold areas. Using accumulated degree days as a temperature related indicator of a push factor some implications are that less heating would be required in winter, but this would be offset by a greater need for cooling in summer.
- It is the already hot areas in the arid and sub-tropical zones of South Africa which will bear the brunt of additional discomfort over the next 40 or so years through increased numbers of uncomfortably hot/humid days. If temperatures continue rising as projected, most of the country will experience many unbearably hot/humid days with repercussions for

health, economic productivity and energy usage (less in winter, more in summer).

- The implication into the future of a projected wider spread of rainfall throughout the year is positive, as it is expected that runoff will then also be generated over a longer part of the year than at present, thus possibly relaxing strict dam operating rules which are often in place today even in average years.

- With regard to days per year with saturated soils, urban planners will need to take more cognisance of both local soil drainage conditions and the rainfall regime, especially in the winter rainfall region where multi-day rains persist, even into the intermediate future.

- Some urban areas (eThekwini, Cape Town) already factor in potential increases in short duration (namely minutes to hours) extreme rainfalls in the design of new stormwater systems. While uncertainty remains in the analyses, it may be prudent to expect increases in short duration extremes and accommodate for that eventuality in, for example, gutter design, stormwater design and, in rural areas, closer spacing of contour banks.

- Eastern seaboard regions already display exceptionally high design rains of both 1 and 3 days duration for very infrequent events of the 50 year return period, and town and regional planners factor this into their present designs. Planning will also need to consider that long duration events are generally projected to increase, and that for inland locations designs with long lifetimes (for example, the 50 year return period) may have to increase for safety reasons. Despite decreases in ratios between future projections and the present in the winter rainfall region, hydraulic design to cope with long duration rains should, however, not be relaxed as the *frequency* of events (rather than the *magnitude*) leading to saturated soils is still projected to increase.

- While the conversion of rainfall to runoff at the locations selected is relatively low at 10 to 25% (world average is 35%), the general projected increases in mean annual runoff in the summer and all year rainfall regions with the GCMs used in this study is positive for the assurance of water supply to human settlements.

- Counteracting this, however, is concern for the high inter-annual variability of runoff, already under current climatic conditions, but even more so into the future which shows projected increases in variability. This is likely to render water management more difficult in future and make dam operating rules more complex.

- With many towns and communities in the more arid parts of South Africa depending on groundwater, the status of the groundwater store was found to be highly dependent on rainfall characteristics and is largely dependent on multi-day rainfall events of a frontal or general nature.

- On the plus side for human settlements in South Africa is that, according to the outputs from the multiple GCMs used in this study, there is a general increase in groundwater recharge especially into the intermediate future. However, on the negative side is that in the semi-arid and arid zones of South Africa, where there is a high dependence on groundwater, recharge is presently low and is projected to remain low. This signals a warning to carefully monitor groundwater abstractions to avoid over-exploiting this vital resource.

- Town and regional planners, when designing into the future, need to be aware when considering issues of water resources, that projected changes:

    - are highly location specific

    - depend on whether the source of water is from surface runoff or from groundwater, since groundwater recharge has been found to be considerably more sensitive to projected changes than generation of surface runoff.

- Projections based on outputs from multiple GCMs indicate that the hydraulic designs of structures and the locations of dwellings adjacent to streams will need to be re-examined in light of climate change, especially with regard to projected increases in floods of higher return period (for example, 1 in 50 year events). Because of the accumulation effects as flood waters cascade downstream in a catchment, consideration will also need to be given to designs for specific locations within a catchment.

- • Design floods were found to have worse impacts than corresponding design rainfalls, not only because flood waters accumulate downstream, but also because of the amplification of effects when rainfall converts to runoff. This amplification was well illustrated for both 1 and 3 day extreme events, with ratios of change from the intermediate future to present at virtually all the locations and for all return periods which were considered (namely the 2, 10 and 50 year return periods) showing that a design rainfall has a lower ratio of increase into the future than the corresponding projected change in design runoff.

The road ahead

The biophysical indicator approach taken on projected climate change impacts on human settlements in South Africa needs to be:

- repeated at more locations, especially those with unique or specific problems

- undertaken with a wider range of GCMs in order to reduce uncertainties and also to be able to express uncertainties quantitatively

- linked to drivers of vulnerability specific to South Africa such as legacies of past and current social engineering experiments, access to basic services, types of dwellings, health related factors, economic factors revolving around poverty and unemployment and local demographic uniqueness around age and/or gender.

5. REFERENCES

8linkd (2014). *Climate Change Implications for the Human Settlements Sector of South Africa*. LTAS Phase 2 publication, Department of Environmental Affairs, Pretoria, RSA. 68pp.

Acocks JPH (1988). Veld Types of southern Africa. Botanical Survey of South Africa, Memoir 57, Botanical Research Institute, Pretoria, RSA. *Botanical Survey of South Africa Memoirs*, 57. 146pp.

CSAG (2008). Climate Systems Analysis Group, University of Cape Town, RSA, (downscaled climate change scenarios, personal communication)

Department of Water Affairs (DWA) (2013). *National Water Resource Strategy: Water for an equitable and sustainable future*, Version NWRS2. Department of Water Affairs, Pretoria, RSA.

Hewitson BC (2010). University of Cape Town, (personal communication).

IPCC (2000). *Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Nakicenovic N & Swart R (eds). Cambridge University Press, UK and New York, NY, USA. 599pp.

IPCC (2007). *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change. Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M & Miller HL (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA. 996pp.

Knoesen DM, Schulze RE & Smithers JC (2011). Climate change and short duration day design rainfall: A 2011 perspective. In: Schulze RE (ed.) (2011). *A 2011 Perspective on climate change and the South African water sector.* WRC Report 1843/2/11, Chapter 7.1, 199–205, Water Research Commission, Pretoria.

Lumsden TG, Kunz RP, Schulze RE, Knoesen DM & Barichievy KR (2010). Methods 4: Representation of grid and point scale regional climate change scenarios for national and catchment level hydrological impacts assessments. Chapter 9, 89–100 in: Schulze RE, Hewitson BC, Barichievy KR, Tadross MA, Kunz RP, Horan MJC & Lumsden TG (2010). *Methodological approaches to assessing eco-hydrological responses to climate change in South Africa.* WRC Report 1562/1/10, Water Research Commission, Pretoria.

Lynch SD (2004). Development of a raster database of annual, monthly and daily rainfall for southern Africa. WRC Report 1156/1/04. Water Research Commission, Pretoria, 78pp.

Markham CG (1970). Seasonality of precipitation in the United States. *Annals of the Association of American Geographers*, 60:3, 593–597.

Monteith JL (1981). Evaporation and surface temperature. *Quarterly Journal of the Royal Meteorological Society*, 107:451, 1–27.

Penman HL (1948). Natural evaporation from open water, bare soil and grass. *Proceedings of the Royal Society*, A193:1032, London, UK, 120–146. DOI: 10.1098/rspa.1948.0037

Schulze RE (1995). *Hydrology and agrohydrology: a text to accompany the ACRU 3.00 agrohydrological modelling system.* WRC Report TT 69/9/95. Water Research Commission, Pretoria, 552pp.

Schulze RE (2004). Determination of baseline land cover variables for applications in assessing land use impacts on hydrological responses in South Africa. Chapter 2, 37–50 in: Schulze RE & Pike A (eds) *Development and evaluation of an installed hydrological modelling system*. WRC Report 1155/1/04. Water Research Commission, Pretoria.

Schulze RE (2012). *A 2011 perspective on climate change and the South African water sector.* WRC Report 1843/2/11. Water Research Commission, Pretoria, 366pp.

Schulze RE & Chapman RD (2008). Estimation of daily solar radiation over South Africa (Section 5.2). In: Schulze RE (ed.) (2008). *South African atlas of climatology and agrohydrology*. WRC Report 1489/1/08, Water Research Commission, Pretoria.

Schulze RE & Horan MJC (2010). Methods 1: Delineation of South Africa, Lesotho and Swaziland into quinary catchments. Chapter 6, 55–62 in: Schulze RE, Hewitson BC, Barichievy KR, Tadross MA, Kunz RP, Horan MJC & Lumsden TG (2010). *Methodological approaches to assessing eco-hydrological responses to climate change in South Africa.* WRC Report 1562/1/10. Water Research Commission, Pretoria.

Schulze RE, Horan MJC, Kunz RP, Lumsden TG & Knoesen DM (2010). Methods 2: Development of the southern African quinary catchments database. Chapter 7, 63–74 in: Schulze RE, Hewitson BC, Barichievy KR, Tadross MA, Kunz RP, Horan MJC & Lumsden TG 2010. *Methodological approaches to assessing eco-hydrological responses to climate change in South Africa*. WRC Report 1562/1/10. Water Research Commission, Pretoria.

Schulze RE, Knoesen DM, Kunz RP & Lumsden TG (2010c). General circulation models and downscaling for 2010 South African climate change impacts studies (Chapter 2.1, 25–34). In: Schulze RE 2010. *Atlas of climate change and the South African agricultural sector: A 2010 perspective*. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA, Chapter 2.1, 25–34.

Schulze RE & Maharaj M (2004). Development of a database of gridded daily temperatures for southern Africa. WRC Report 1156/2/04. Water Research Commission, Pretoria, 83pp.

Schulze RE, Maharaj M & Moult N (2008). Reference crop evaporation by the Penman-Monteith method (Section 13.3). In: Schulze RE (ed.) 2008. South African atlas of climatology and agrohydrology. WRC Report 1489/1/06, Water Research Commission, Pretoria.

Smithers JC & Schulze RE (2003). Design rainfall and flood estimation in South Africa. WRC Report 1060/1/03. Water Research Commission, Pretoria, RSA, 156pp. plus CD-ROM.

Thom, EC (1959). The discomfort index. *Weatherwise*, 12, 57–60.

Environment House
473 Steve Biko
cnr Steve Biko and Soutpansberg Road
Arcadia
Pretoria, 0083
South Africa

Postal Address
Department of Environmental Affairs
P O Box 447
Pretoria
0001

Publishing date: March 2015

www.environment.gov.za