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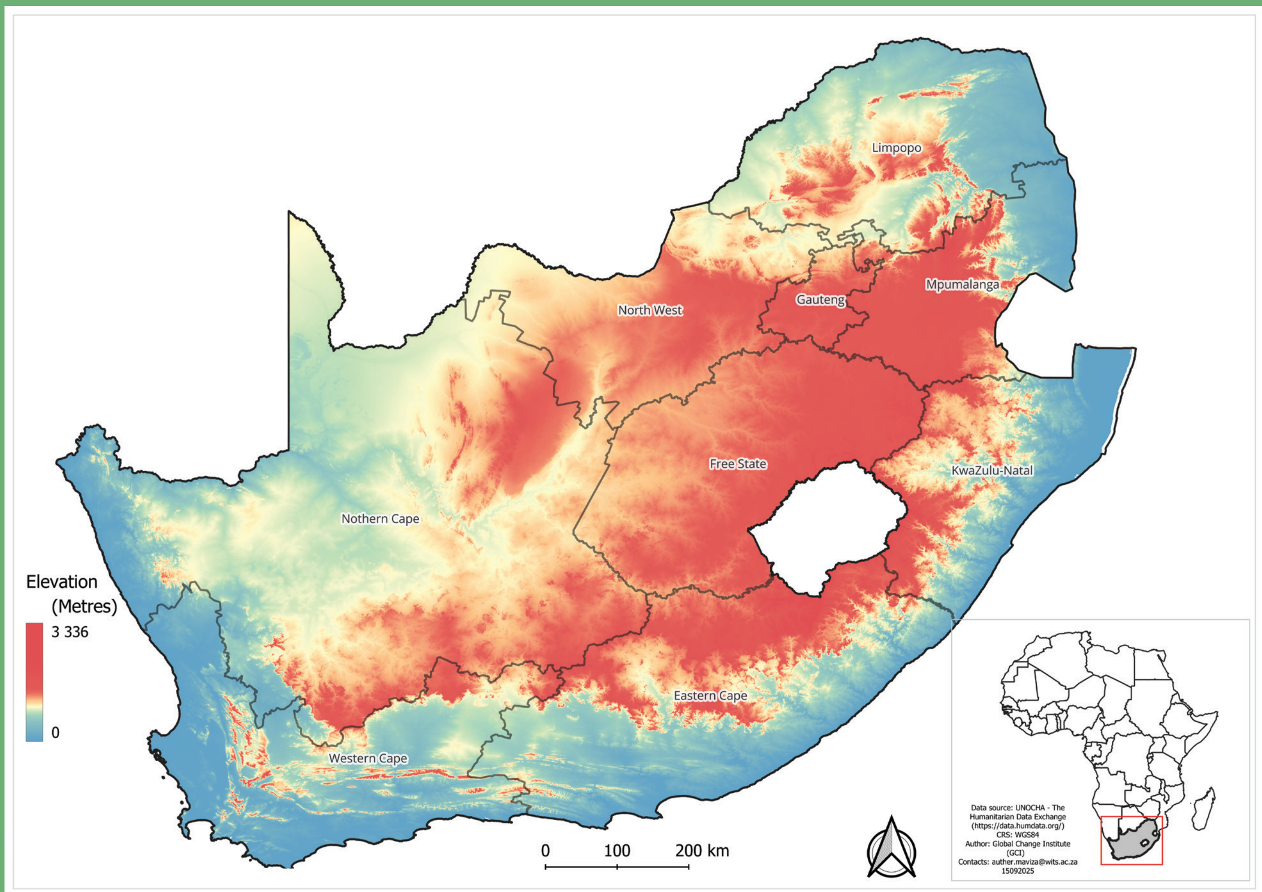

Sub-national climate change fact sheets for South Africa

Credible and policy-relevant climate science to inform climate change responses

INTRODUCTION AND PURPOSE

Southern Africa is one of the world's climate change hotspots. It is a water-stressed region, which under low-mitigation (high emission) climate change futures is projected to become drastically warmer, and likely also drier. When water-stressed regions become drier and warmer, the impacts of climate change are felt more severely and options for adaptation in communities and sectors that are vulnerable to climate change are limited.

In South Africa there is clear statistical evidence of increases in 'warm extremes', such as heat-waves and high fire-danger days, over the last few decades. There is some evidence of decreases in annual average precipitation across the region. At the same time, the more frequent occurrence of extreme rainfall events has been detected across most of eastern and central South Africa. The devastating flooding in Durban in April 2022, and the severe southern African drought of the summer of 2023/24, are examples of extreme weather events made worse by climate change. Their severe impacts were clear reminders of the need for anticipatory planning for climate change impacts. This planning should be based on credible and policy-relevant climate science.

Climate science is often not easily accessible, especially not in sufficient detail to inform adaptation responses at a sub-national and local levels. The sub-national climate change fact sheets (hereafter referred to as the 'Fact Sheets') co-developed by the South African National Biodiversity Institute (SANBI) and University of the Witwatersrand – Global Change Institute (WITS-GCI) aim to address this gap. They present an overview of observed historical and projected future changes in rainfall and temperature and their extremes, at Provincial and District Municipality level. Through a process of distilling multiple lines of evidence of climate change in South Africa, they point towards actionable messages for adaptation at sub-national spatial scales.

The Fact Sheets are intended to be a first foundational step in adaptation planning processes in South Africa. From this foundational step, it is anticipated that more detailed assessments such as risk and vulnerability analyses can be undertaken to enhance effective climate change risk reduction and adaptation, thus informing policy and supporting the implementation of the Climate Change Act (Act 22 of 2024).

GUIDANCE ON HOW TO USE THE FACT SHEETS

- The Fact Sheets provide concise and accessible summaries of current observed trends and available projected changes in climate, with associated confidence assessments, for all of South Africa's Provinces and District Municipalities.
- They are intended to serve as a bridge between scientific knowledge and policy decisions, empowering individuals, institutions and government with information that can be used to strengthen decision making, support risk and vulnerability assessments and identify options for provincial, municipal- and sector-relevant adaptation responses.
- The information in the Fact Sheets is policy-relevant but not policy prescriptive, and to be used effectively, the scientific information that is presented in the Fact Sheets should be contextualised through risk and vulnerability assessments for each Province and District Municipality.
- In order to understand the unique risks and vulnerabilities associated with each area, these assessment processes should consider aspects such as population demographics, socio-economic conditions, governance structures and the natural and built environment. Consideration of these aspects together with the local climate change projections in the Fact Sheets will help reveal more contextualised spatial variation of risk and vulnerability within the Provinces and District Municipalities.

FACT SHEET DEVELOPMENT

- The Fact sheets were developed in the style of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report Six (AR6) regional Fact Sheets, and in this process strongly relied on the outputs of AR6, the IPCC methodology of confidence assessment, available peer-reviewed research outputs relevant to climate change in South Africa and expert knowledge. Refer to the methodology section below for more detail on how the Fact Sheets were constructed.
- Change (IPCC) Assessment Report Six (AR6) regional Fact Sheets, and in this process strongly relied on the outputs of AR6, the IPCC methodology of confidence assessment, available peer-reviewed research outputs relevant to climate change in South Africa and expert knowledge. Refer to the methodology section below for more detail on how the Fact Sheets were constructed.
- Following the initial design, a multi-stakeholder validation process was adopted which informed the final version of the Fact Sheets. Stakeholders engaged included, among others, the national government and public entities, provincial and local government officials, research and science agencies, civil society and non-governmental organisations and independent experts/practitioners. A full list of these contributors is provided in the acknowledgements section.

METHODOLOGY: FACT SHEETS FOR SOUTH AFRICA'S DISTRICT MUNICIPALITIES AND PROVINCES

IPCC regional fact sheets

The IPCC AR6 provided a comprehensive assessment of the latest scientific information on climate change. Summaries of the Working Group I (WG1) assessment of observed trends and projected climate change futures for various regions in the world are provided in the IPCC 'regional Fact Sheets'. The Fact Sheets developed for South Africa's Provinces and District Municipalities follow the IPCC fact sheet style. The underpinning data analysis is based on the latest available multi-model ensembles of projections of future climate change, as generated by the Coupled Model Intercomparison Project Phase 6 (CMIP6) and Coordinated Regional Downscaling Experiment CORE (CORDEX-CORE), consistent with the projections used in AR6.

Climate models and mitigation scenarios

Global climate models (GCMs) have become the main tools to project future climate change. Based on the Laws of Physics, GCMs are used to simulate how the coupled ocean-atmosphere-land system will respond to increasing greenhouse gas concentrations. More than 40 GCMs participated in CMIP6, the most extensive multi-model ensemble of projections obtained to date. GCMs are computationally expensive, and their spatial resolutions in CMIP6 were therefore relatively low, about 100 – 200 km in the horizontal. Regional climate models (RCMs) are used to obtain higher resolution climate simulations over limited areas, through the process of downscaling GCM projections. The highest resolution multi-model ensemble of projections obtained to date for Africa is the CORDEX-CORE experiment, in which the simulations have a resolution of about 25 km in the horizontal. The CORDEX-CORE ensemble consists of the simulations of 3 RCMs that each downscaled 3 GCMs that participated in the second-last global model intercomparison, CMIP5. GCM and RCM projections are undertaken for various greenhouse gas mitigation scenarios. The sheets use CMIP6 and CORDEX-CORE projections for low-mitigation futures, given that such futures hold the highest risks of damaging climate change impacts.

Analysis

Climate model simulations exhibit systematic errors in their representation of present-day climate. Before their application in the Fact Sheets, their raw outputs were thus bias-corrected (that is, the systematic errors were removed) using observations from the Climatic Research Unit (Harris et al., 2020). The Fact Sheets show plots of the projected changes in annual rainfall, temperature, number of very hot days and number of extreme rainfall events. Very hot days are defined as days when the maximum temperature exceeds 35 °C, and extreme rainfall events as occurrences when the daily rainfall total is equal to or exceeding 20 mm, averaged over an area of 25 x 25 km^2. Projected changes are shown for the near-future (2021-2040), mid-future (2041-2060) and far-future (2081-2099) periods, relative to the baseline period 1981-2000. Boxplots are used to investigate model agreement and further assess uncertainties in the projections (see details below).

The use of IPCC confidence language

The Fact Sheets provide assessments of observed trends and projected changes for a number of climate variables known to drive climate impacts. To each of the assessments a 'confidence statement' is assigned, following the methodology and processes originally introduced by the IPCC. The confidence assessment of trends and projections is informed by relevant peer-reviewed research, the degree of model agreement (in terms of the projected climate change signal) and expert knowledge of the weather and climate in each location. Such an assessment was made for southern Africa in 2021 in the IPCC AR6. This IPCC assessment informed the Fact Sheets, and at the regional scale the Fact Sheets are consequently consistent with the IPCC AR6 assessment of climate change in southern Africa (Chapters 4 and 12 of the IPCC AR6 WGI report and the IPCC fact sheet for Africa). The confidence language system applied in the fact sheets is shown in Table 1 and is similar to that used by the IPCC in its Assessment Reports.

Table 1: Confidence language system applied in the Fact Sheets

Term	Associated probability	Confidence level
Virtually certain	99-100%	Very high
Very likely	90-100%	Very high
Likely	66-100%	High
Marginally likely	56-65%	Medium
More likely than not	50-55%	Low
About as likely as not	33-66%	Uncertain
Unlikely	0-33%	High
Very unlikely	0-10%	Very high
Exceptionally unlikely	0-1%	Very high

Understanding the boxplots

Model agreement in the Fact Sheets is illustrated using box plots. These plots consider the spatial-average rainfall and temperature for each model and each period, for each of the provinces and district municipalities. Box plots effectively summarize complex datasets, and show the median (Q2), the interquartile range (IQR), and whiskers extending to represent a broader uncertainty range (Figure 1).

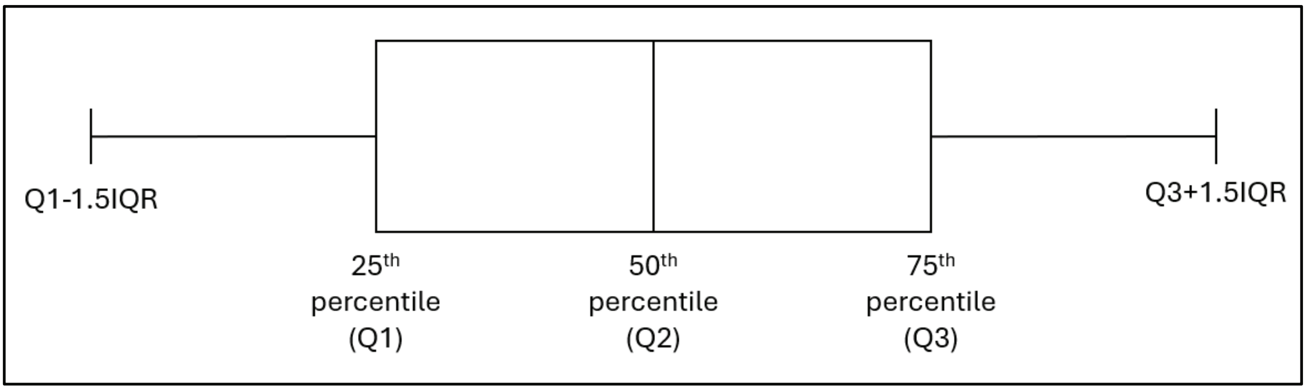

Figure 1: The various metrics displayed in the box plots.

PROJECTED CLIMATE CHANGE IN SOUTHERN AFRICA

It is useful to read and interpret the Fact Sheets against the background of existing insights and an IPCC-style assessment of climate change in southern Africa. In this subsection we provide such an assessment, and we list a number of key references that were prominent in informing our assessment in the Fact Sheets.

Perhaps the most prominent feature of climate change in southern Africa that can already be detected, is the drastic rate of warming (that is, strong positive trends in near-surface temperatures). Over the western and central interior regions of southern Africa, the observed rate of warming is in the order of twice the global rate of warming (Engelbrecht et al., 2015). In South Africa specifically, there are several weather stations with multi-decadal, homogeneous time-series records, and these stations consistently report substantial increases in annual average temperatures (Kruger and Nxumalo, 2017). Clear increases have also been detected in the occurrence of warm extremes (e.g. heat-wave days) in South Africa, with corresponding decreases in cold extremes (e.g. frost days) (Kruger and Nxumalo, 2017). These and a substantial number of additional studies provide strong and consistent evidence that temperatures and warm extremes have been increasing over the last several decades in southern Africa (*virtually certain*), and that these increases are unequivocally the regional consequence of anthropogenically-induced global warming.

When considering climate model projections of future temperatures across southern Africa, all climate models agree that under low-mitigation climate change futures temperatures will continue to increase in the near-, mid- and far-future (Figure 2), consistent with the observed trends. Several studies have documented projections of drastically rising temperatures across southern Africa under low mitigation futures, and these changes can consequently be assessed to be '*virtually certain*' (Engelbrecht et al., 2015; Ranasinghe et al., 2021). Warm temperature extremes such as heat-waves, very hot days and high fire-danger days are similarly projected to increase across southern Africa in all global and regional climate change models (Figure 3; Engelbrecht et al., 2015; Mbokodo et al., 2020; Ranasinghe et al., 2021). Further increases in warm extremes in southern Africa are thus *virtually certain*, already for the near-future, and provide a clear and actionable message for climate change adaptation. For example, millions of people in southern Africa live in informal housing and are exposed to oppressive temperatures during heat-waves, which impact on human comfort, health and mortality (Garland et al., 2015). It is clear that heat-health adaptation plans need to be implemented across southern African cities and municipalities, to build resilience and help protect the most vulnerable communities and people against the increasing impacts of warm temperature extremes.

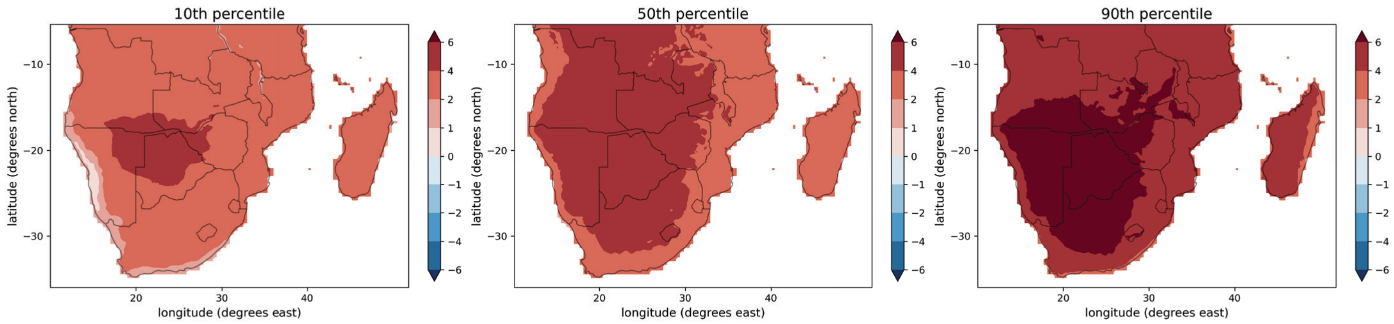

Figure 2: Projected changes in annual average temperature (°C) across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-2099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

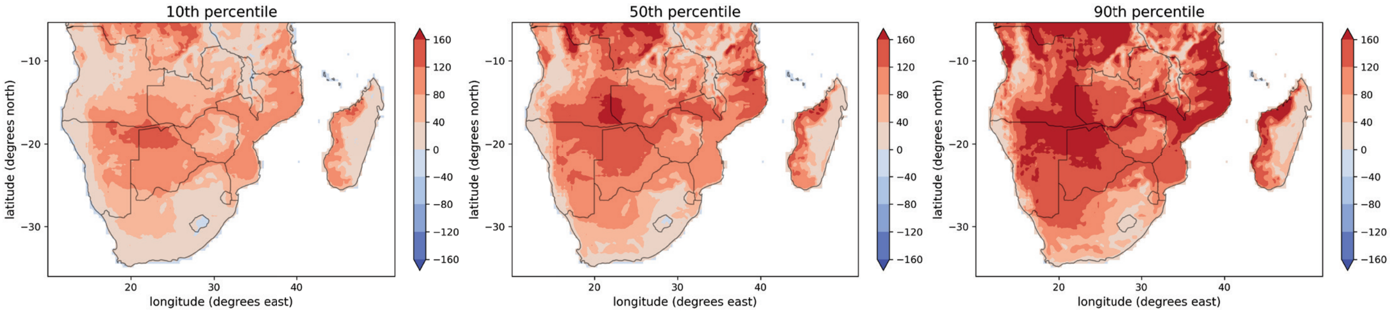

Figure 3: Projected changes in the annual number of very hot days across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-2099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

The IPCC in AR6 has assessed that decreasing trends in annual rainfall can already be detected across the two regional domains of 'Western Southern Africa' and 'East Southern Africa', with associated increases in agricultural and hydrological drought (Ranasinghe et al., 2015). Observed increases in extreme rainfall events have also been observed in recent decades across the southern African region (Ranasinghe et al., 2021). When considering observed trends in extreme rainfall for South Africa specifically, most weather stations in eastern and central southern Africa are reporting general increases in extreme precipitation (McBride et al., 2022), consistent with the AR6 assessment.
There is *high confidence* in this trend and that it is of anthropogenic origin, given the well-known thermodynamic fact that a warmer atmosphere can hold more moisture and potentially produce more intense storm systems. When considering observed trends in annual rainfall totals across South Africa, a more nuanced picture emerges (MacKellar et al., 2014). Pronounced multi-decadal variability may well still be obscuring the anthropogenic signal in terms of systematic rainfall changes, with a large portion of stations reporting trends that are without local statistical significance. There is *low confidence* that general decreases in rainfall can be detected in both South Africa's winter and summer rainfall regions, with associated increases in meteorological and agricultural drought.

Most climate models projected general decreases in rainfall over southern Africa in a warmer world, with associated increases in meteorological and agricultural drought (Engelbrecht et al., 2015; Ranasinghe et al., 2021). This is a signal that strengthens over time, and for the far-future under low mitigations scenarios, general rainfall decreases over southern Africa are *likely* (Figure 4). The eastern escarpment region of South Africa is the one region in Africa south of 10 °S where there is a lack of congruency between climate model projections of future changes in rainfall. Over this part of South Africa, future decreases in rainfall are *about as likely as not*. It is a clear example of model uncertainty, which may be related to the statistical treatment (parameterisation) of convective rainfall in climate models. That is, the GCMs and RCMs applied in the IPCC's AR6 were integrated at horizontal resolutions too low for the dynamic circulation processes working within thunderstorms to be resolved, which forced the need for these effects to be statistically estimated. It is hoped that a new generation of higher resolution 'km-scale climate models', which can to some extent resolve thunderstorm dynamics, will remove some of these structural uncertainties from climate change projections for South Africa's eastern escarpment. Extreme rainfall events are projected to occur more frequently over eastern South Africa in a warmer world by most climate models (Figure 5). It is a signal that can already be detected (McBride et al., 2022) and there is *high confidence* that it will strengthen in the near-future.

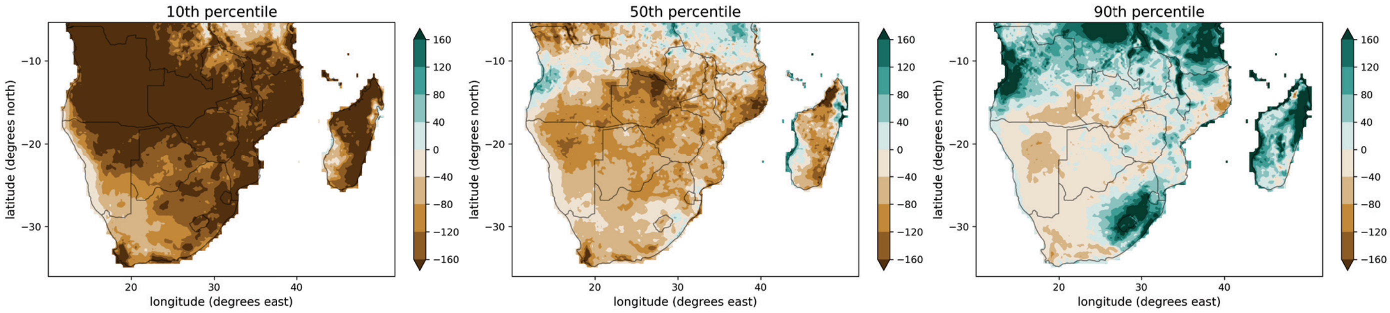

Figure 4: Projected changes in annual average rainfall totals (mm) across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-2099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

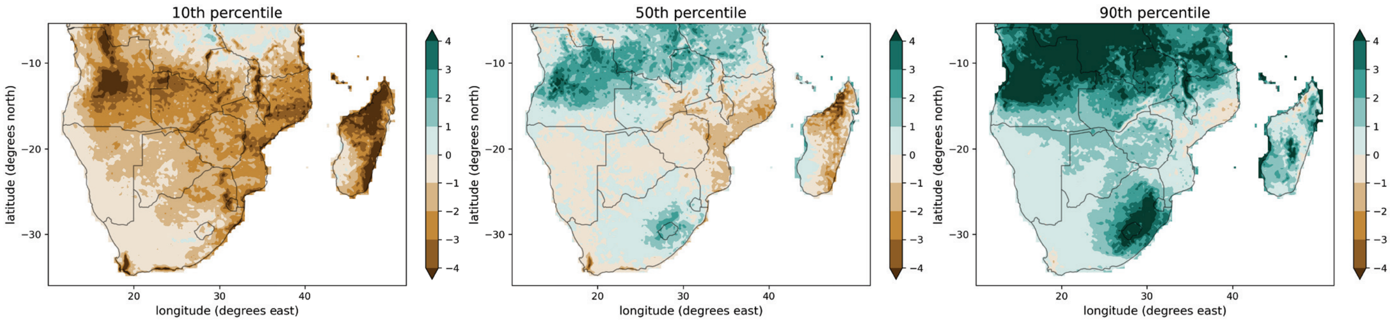

Figure 5: Projected changes in extreme rainfall events (mm) across the CORDEX-CORE ensemble (10th percentile, median and 90th percentile shown), for the period 2081-099 relative to 1981-2000 under the low-mitigation scenario RCP8.5 (Representative Concentration Pathway 8.5).

Decision makers in South Africa's District Municipalities have to formulate adaptation actions with climate science providing various degrees of confidence in terms of the likelihood of future climate change risks. For example, for many District Municipalities large portions of the population are exposed to heat-waves, a risk that is *virtually certain* to get worse and increasingly dangerous. In such a case, the message for adaptation action is clear. In other cases, specifically where rainfall futures are concerned, decision makers may need to simultaneously prepare for very different types of future risks. Model disagreement (model uncertainty) in terms of future rainfall patterns over the eastern escarpment does not imply that no adaptation actions can be taken. In this case the pronounced implications of substantial reductions of rainfall projected for this region by a large portion of climate models (a 3rd of models, or more) needs to be considered given the critical importance of the mega-dams in South Africa's eastern escarpment region to water security in South Africa. As a risk reduction strategy, building resilience for a possible generally drier future, with a general reduction in rainfall and more frequent periods of drought may be appropriate. On the other hand, more than a 3rd of models project increases in rainfall over the eastern escarpment, and there is high confidence of increases in extreme precipitation over this region. Such changes may well result in increased run-off into the mega-dams, but also simultaneously increased sedimentation. This 'alternative future' also requires adaptation action, given the pronounced implications of enhanced sedimentation in the mega-dams. Adaptation options that will be "no regret" regardless of which scenario is correct are therefore the best interventions. Regardless of if there is model certainty or uncertainty (high confidence or uncertainty), climate science is capable of pointing out reasons to take action, rather than to promote inaction.

It is hoped that the Fact Sheets will provide guidance to decision makers in the District Municipalities, provinces, national government and across a range of sectors, in terms of the adaptation actions they may decide to take. As we have discussed in this cover sheet, such actions should always be informed by the expert understanding of the risks and vulnerabilities of the specific communities or sectors where adaptation action needs to take place.

CITATION

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- Department of Water and Sanitation (DWS)
- Development Bank of Southern Africa (DBSA)
- Independent Climate Change Practitioners/ Consultants
- Local Government Association of South Africa (SALGA)
- National Business Initiative (NBI)
- Provincial and District Municipal Representatives from all provinces
- Social Change Assistance Trust (SCAT)
- South African Faith Communities' Environment Institute (SAFCEI)
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