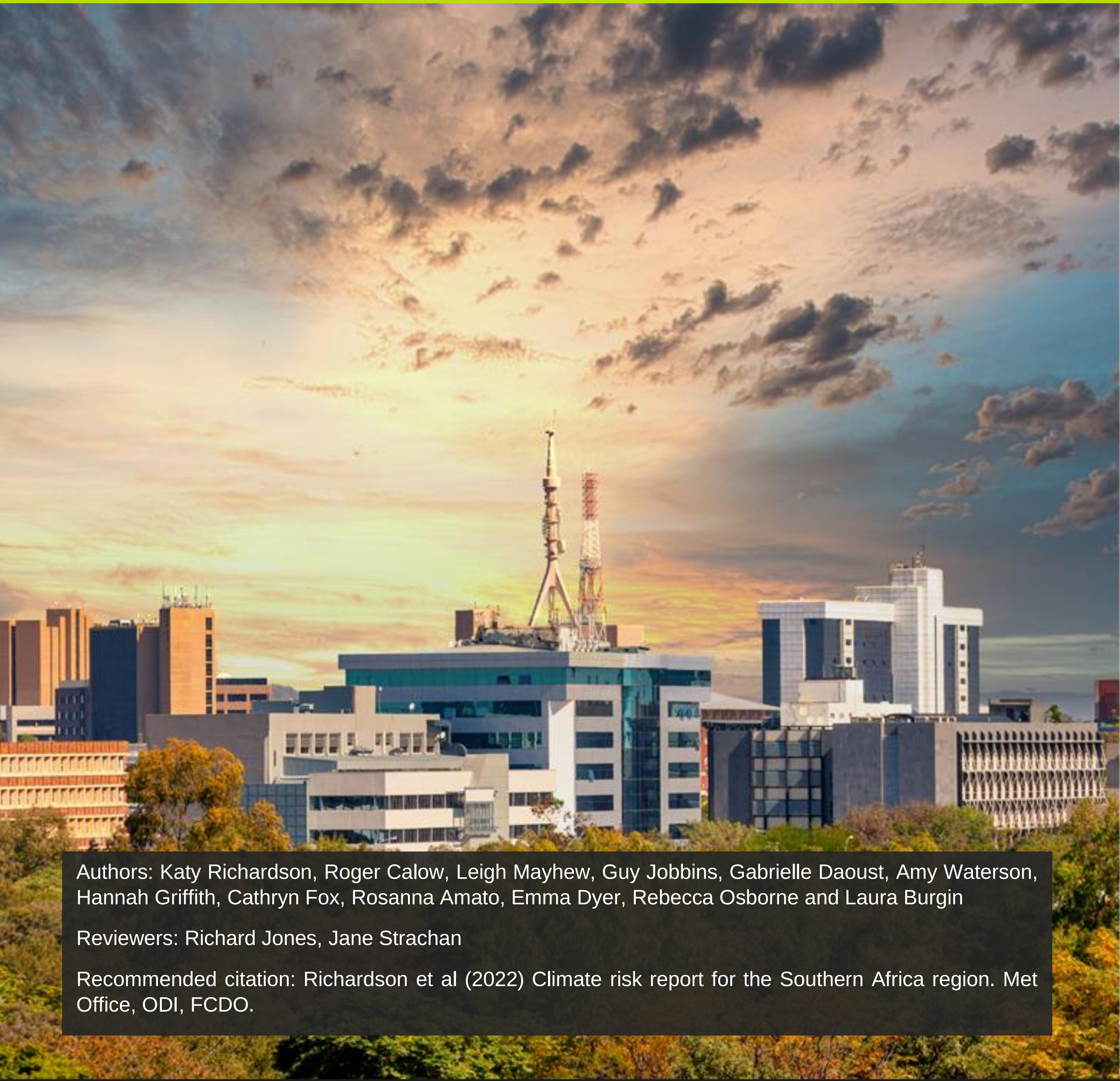
Climate risk report for the Southern Africa region



Authors: Katy Richardson, Roger Calow, Leigh Mayhew, Guy Jobbins, Gabrielle Daoust, Amy Waterson, Hannah Griffith, Cathryn Fox, Rosanna Amato, Emma Dyer, Rebecca Osborne and Laura Burgin

Reviewers: Richard Jones, Jane Strachan

Recommended citation: Richardson et al (2022) Climate risk report for the Southern Africa region. Met Office, ODI, FCDO.

Image location: Gaborone, Botswana

www.metoffice.gov.uk

Source: © Crown Copyright 2022, Met Office

Document history

Version	Purpose	Date
0.1	Review	14/07/2022
0.2	Revised draft	13/12/2022
0.3	Revised draft	10/01/2023
1.0	Final delivery	15/02/2023

Lead authors

Katy Richardson, Senior Scientist
Roger Carlow, Research Officer
Leigh Mayhew, Research Officer
Guy Jobbins, Research Officer
Gabrielle Daoust, Research Associate
Amy Waterson, Senior Scientist
Hannah Griffith, Applied Scientist
Cathryn Fox, Senior Scientist
Rosanna Amato, Applied Scientist
Emma Dyer, Scientist
Rebecca Osborne, Scientific Manager
Laura Burgin, Scientific Manager

Reviewed by

Richard Jones, Science Fellow
Jane Strachan, Head International Applied Science

Authorised for issue by

Cindy Somerville, International Development Delivery Manager

February 2023

© Crown Copyright 2022, Met Office

Contents

© Crown Copyright 2022, Met Office

© Crown Copyright 2022, Met Office

Executive summary

Southern Africa is already exposed to a changing climate and its impacts, and these must be considered to ensure climate resilient development planning. This report analyses key risks across the Southern Africa region under six themes: (1) **agriculture and food security**; (2) **water resources and water-dependent services**; (3) **the environment**; 4) **infrastructure and settlements**; (5) **health**; and (6) the **coastal and marine environment**. These themes are not comprehensive and there are many overlaps between them signposted in the sections that follow.

For this report Southern Africa includes **Botswana, Eswatini, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Zambia, Zimbabwe** and the small islands in the Indian Ocean, including **Comoros, Mauritius, the Seychelles**. Climate change is one of several risks to resources, livelihoods, economies, and ecosystems. Southern Africa is a dynamic region, experiencing rapid population growth, urbanisation and economic transformation, and assessments of climate risks can only ever provide a partial picture of the role climate change plays in shaping development outcomes. Key climate-related risks for Southern Africa have been identified by considering how the current climate interacts with underlying socio-economic conditions, and how further climate change to the 2050s may exacerbate these risks. Seeing the 'bigger picture' where multiple risks compound, interact with one another and drive change will remain important for those charged with designing, monitoring, and evaluating development programmes. Most risks identified in this report are not new for the region, but the frequency, severity and distribution of those risks are changing as the climate changes and economies develop.

Food systems in Southern Africa are vulnerable to climate change because most crops are rainfed, and farming and pastoral livelihoods in poorer countries are subsistence-orientated (Section 3.1). While Southern Africa as a whole is transitioning away from agriculture as a source of income and employment, the population remains predominantly rural (54%) and, in poorer countries (66% rural), agricultural livelihoods still account for most income and employment. Food systems in Southern Africa are particularly vulnerable to climate change because most production is rainfed, based on low productivity, low input subsistence-orientated agriculture dominated by climate sensitive cereal-livestock holdings. Across sub-Saharan Africa, climate change has already decreased wheat and maize yields by roughly 2% and 6% respectively; further increases in temperature and water stress will continue to reduce yields and threaten rangelands (land used for grazing) that support pastoralists. Rangeland productively in Southern Africa is

Southern Africa Climate

The region experiences a diverse range of climates, including semi-arid and desert in the west, temperate climate in the north and areas of high elevation in the south, tropical climate in the north-east and subtropical and oceanic climates in the island nations.

Southern Africa's average annual surface temperatures increased between 1.-1.5°C from 1961 to 2015, faster than the global average. Warming and evapotranspiration will continue to increase in the future. Year-to-year variability in seasonal rainfall amounts and timings will increase, as will the intensity of heavy rainfall events.

There is less confidence about how rainfall has changed in the past though there is high confidence that the drier western part of the Southern Africa region will be drier on average by the 2050s. In the wetter eastern part of the region there is no clear consensus on whether the climate will be wetter or drier, although there is some evidence for a small delay to the start of the rainy season by mid-century in the north-east.

The region has long coastlines with the Atlantic and Indian Oceans. The coastal regions bordering the Atlantic Ocean to the west and Indian Ocean to the east are already exposed to rising sea levels and increasing sea surface temperatures, trends that will continue. The south-eastern coast is also exposed to tropical cyclones, and while their frequency may not change, the most intense will intensify.

© Crown Copyright 2022, Met Office

projected to decline by 37% compared with a 2000 baseline. Higher levels of atmospheric CO_2 which can enhance plant growth may offset some crop losses.

Food security, a broader issue, will become more precarious because food production and food prices will become more volatile (Section 3.1). Some households may benefit – net sellers of food, for example – though much depends on whether rising prices compensate for production losses. Most Southern African households will be harmed because they are net *consumers*. Subsistence-orientated farmers will struggle to meet their food needs in a more variable rainy season. The increasing numbers of urban poor, dependent on informal wage labour to buy essentials, will suffer during times of high food prices.

Many of the impacts of climate change will be felt through the water cycle (Section 3.2). Southern Africa's freshwater resources, providing drinking water, hydropower and many other services, will experience growing pressure as temperatures rise, evaporation increases, river flows become more variable and water quality declines. This makes water management more difficult as demand-side pressures increase. With no perennial, *under*-developed rivers left to exploit, reliance on relatively climate-resilient (and widespread) groundwater resources will increase, particularly for drinking water and small-scale irrigation. Populations lacking safe water and sanitation (26% and 54% respectively in Southern Africa, overwhelmingly poor) are most exposed to water contamination and disease, particularly after heavy rainfall and flood events.

Climate-related hydropower insecurity is already a key source of economic and social risk in Southern Africa, and these risks will increase (Section 3.2). Threats to electrical power are amplified because over 70% of hydropower generation is concentrated in a single basin – the Zambezi - a figure expected to grow over the coming decades. Most big infrastructure projects with a long design life have been planned for historical and poorly characterised climate conditions, not the current or future climates. More resilient energy systems will rely increasingly on multiple options spread across multiple grids – smart, mini, hybrid and cross-border power pool – to mitigate climate risks. Questions remain over whether the region's rich gas reserves (in Botswana and Mozambique especially, including offshore) will be developed alongside renewables as regional and global energy prices rise.

Climate change will also affect the range and composition of Southern African ecosystems and the services they support, already under pressure from human encroachment and degradation (Section 3.3). For example, rising temperatures, greater aridity and the increasing risk of fire weather all affect the range and composition of forests and the services they provide, while rising levels of CO_2 have contributed to the spread of woody vegetation in savannas and grasslands. The fragmentation of forests, savannas and grasslands may reduce the spread of fire and burned areas, though impacts of fire on people and assets may still increase as settlements expand.

Ecosystem loss and degradation threatens food security, flood control and carbon storage among other key services across Southern Africa (Section 3.3). Many poor rural people depend on ecosystems for their base income and as safety nets, and income/food from resource stocks (e.g., timber, fish) helps smooth consumption between seasons and years. Links between climate-related ecosystem changes and poverty have not been systematically assessed but are likely to be significant. The degradation and loss of wetlands in the region from expected drying conditions pose risks to poorer households who depend on 'extractive' use, and threatens flood control, wetland flora and fauna, bird migration and carbon storage. When wetlands dry out, they turn from carbon sinks to emission sources.

Southern Africa's infrastructure deficit in housing, transport, communications, and power acts as a drag on economic growth. Existing infrastructure is vulnerable to climate extremes, particularly heatwaves, floods, and high winds (Section 3.4). Climate risk and poverty increasingly coincide in Southern Africa's rapidly growing informal

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

settlements; over 60% of the urban population in the region's lower income countries already live in informal settlements and are exposed to multiple hazards, especially floods. Floods are the leading cause of damage to transport, and while the severity of natural disasters is often measured in terms of asset loss and damage, it is the secondary impacts on economic activities and output that often explain a larger share of impacts as risks cascade across areas and sectors. In the coastal city of Beira in Mozambique, high winds and floods during Tropical Cyclone Idai in 2019 knocked out 90% of the city's power grid. Southern Africa's southeast coast, where populations and economic assets are increasingly concentrated, is particularly exposed to cyclones, storm surges and sea level rise. Electricity generation and transmission are also affected by rising temperatures, since thermoelectric plants (coal, gas, nuclear) need cooling water to run efficiently, and electricity transmission is less effective at higher temperatures.

Risks to health are closely linked with rising temperatures, extreme events, and associated increases in communicable and non-communicable disease (Section 3.5). By 2060, a further 2.9 million people could be living in areas classified as endemic to malaria, including new areas in northern Zambia, Mozambique and Malawi. Outbreaks of water-borne diseases such as diarrhoea, cholera and typhoid are already common, particularly after floods and in densely populated informal settlements. Outbreaks are likely to increase and carry longer-term risks to health. The non-communicable disease burden is also expected to increase, as rising temperatures and heat extremes, combined with air pollution, exacerbate cardiovascular disease, respiratory illnesses, strokes and type-2 diabetes. People at elevated risk of heat stress include the elderly, infants, pregnant women, those living in cramped conditions and people working outside, especially manual labourers. Higher temperatures and heat extremes also reduce labour productivity. Higher temperatures, heatwaves and fire can also aid the formation of ozone and dust, exacerbating respiratory illnesses.

Southern African coastal fisheries and marine environments are threatened by pollution and dredging (amongst other pressures), but also by climate change (Section 3.6). Marine and coastal ecosystems, including coral reefs, mangroves, sea grasses and saltmarshes, play a vital role in supporting rich habitats for fish and other species, acting as carbon sinks, protecting coasts, and supporting tourism. Ocean warming and acidification (caused by rising levels of CO_2) and marine heatwaves may pose an existential threat to coral reefs off the east coast of Southern Africa. Artisanal fishers are especially exposed to productivity declines of shallow water reef systems. Globally significant coral reefs in the Northern Mozambique Channel, and the reefs off Comoros, Mauritius, and East and South Madagascar are under threat. Rising sea levels and sea temperatures also threaten the other habitats and intense cyclones can devastate mangroves. Fisheries, both commercial and artisanal, provide food, income and jobs. Commercial fishing industries of varying sizes (capture and/or processing) are located in Namibia, South Africa, Mozambique, Madagascar and in the Indian Ocean islands. Evidence linking climate change with changes in productivity and movements of most fish species is minimal. However, periodic declines in tuna stocks off the east coast, and the eastward shift in the sardine fishery off the coast of South Africa, have been linked with ocean warming and marine heatwaves.

There will be negative impacts on the blue economy, including tourism (through degradation of sandy beaches and coral reefs), maritime transportation and port facilities (due to sea level rise and the impacts of storms, storm surges and cyclones) Tourism is a particularly important sector for the small island states. In Mauritius and the Seychelles, the sector employs roughly 20% and 40% of the workforce, respectively. Climate change could also affect Mauritius' role as a shipping hub long term, with Indian Ocean shipping declining in favour of faster routes between Asia and Europe via an ice-free Arctic.

© Crown Copyright 2022, Met Office

Met Office | Foreign, Commonwealth & Development Office | ODI

Southern Africa Climate Risk Report

HEADLINE CLIMATE STATEMENTS

Southern Africa has warmed by between 1.0°C and 1.5°C from 1961 to 2015.

Temperatures in Southern Africa will increase by at least 1.5˚C by the 2050s, with increases of up to 4˚C under high emissions, compared to a 1980- 2010 baseline.

The intensity and number of very hot days will increase in the Southern African region.

Large variations in the timing and intensity of seasonal rains will continue to be experienced over Southern Africa. This variability will increase through to the 2050s resulting in more frequent wetter and drier years and a higher risk of flood and drought events.

The intensity of heavy rainfall events will increase in Southern Africa, even in areas where average rainfall decreases.

The semi-arid and desert regions of Namibia, western Botswana and South Africa will experience a drying trend through to the 2050s.

Sea surface temperatures in the Southern African region will increase by 0.8-1.0˚C on average under very low emissions and by 1.3-1.5˚C under very high emissions by the 2050s, compared to a 1981-2010 baseline.

Around the coast of Southern Africa, sea levels have been rising at a rate of around 3 mm a year between 1993-2018. They will continue to rise, by around 0.2m under very low emissions and 0.3m under very high emissions by the 2050s compared with 1995-2015 levels.

The oceans surrounding Southern Africa will continue to acidify, and the frequency of marine heatwaves will increase.

The total number of tropical cyclones affecting Southern Africa will be similar or fewer. However the proportion of these which will be intense (category 4-5) will increase.

Produced by the Met Office. Met Office and the Met Office logo are registered trademarks. © Crown Copyright 2022, Met Office 02091

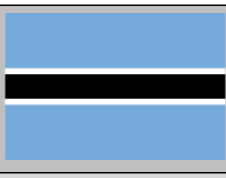
Met Office Hadley Centre | ODI | UKaid from the British people

© Crown Copyright 2021, Met Office © Crown Copyright 2022, Met Office

Country reference tables

Analysis is conducted at the regional level using nine zones. These country summaries are intended to help direct readers towards the relevant sections within the report by country; they are not a complete assessment of the full range of risks at a country level.

Botswana country profile

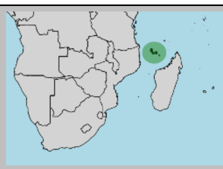


Summary of climate analysis relevant to Botswana	Report section
Botswana experiences a semi-arid climate in the north and east and a hot desert climate in the southwest. Important rivers include the Okavango in the north and the Limpopo in the southeast. Population densities are generally low with higher densities in the east, particularly the capital city of Gaborone. Agricultural livelihoods are predominantly maize mixed in the semi-arid regions and pastoral in the sparsely populated desert regions in the southwest. Botswana has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to rise in the future resulting in an increase in the frequency and intensity of hot extremes. Botswana experiences a rainy season between October and April and a dry season between May and September. Trends in average precipitation indicate an increase in the west and no significant trend in the east in recent decades. The western part of the country will be drier on average in the future, and there is no consensus on whether the eastern part of the country will be wetter or drier on average, although there is some evidence for a small delay to the start of the rainy season in this region. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures.	2.2, Technical Reference Document: Section D, Zones 1, 2 and 6.

Regional risks relevant to Botswana	Report section
Risks to crop production due to changes in temperature and rainfall leading to increase levels of crop disease and pests.	3.1.2
Risks to savannah plains associated ecology and biodiversity due to rising temperatures and changing rainfall patterns.	3.3.5
Risks to water resources due to the drying trend and increased rainfall variability leading to water stress in the Okavango River Basin.	3.2
Risks to livestock production due to increased heat stress and reduced water availability.	3.1.3
Risks to health, including a shift in the areas at risk of malaria, communicable water-borne diseases and heat-related impacts.	3.5
Risks to the Okavango delta wetland system and associated biodiversity and ecosystem services, due to increases in temperatures and drier conditions.	3.3.4

© Crown Copyright 2022, Met Office

Comoros country profile



Summary of climate analysis relevant to Comoros	Report section
The Comoros islands are a group of small islands in the West Indian Ocean. The Comoros Islands experience a tropical marine climate which is strongly influenced by the surrounding ocean. Livelihoods are predominately agricultural production, including both crops and livestock, and fishing based. Comoros has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to rise in the future resulting in an increase in the frequency and intensity of hot extremes. Comoros experiences a rainy season between November and April and a dry season between June and October, with more rainfall in western regions. Most islands in the Western Indian Ocean will become drier in the future, particularly from June to August. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s, exacerbating coastal flooding. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The proportion of intense tropical cyclones will increase with the total number remaining similar or becoming fewer. Though it is important to note the substantial variability in tropical cyclones making landfall with small island regions given projected regional shifts in storm tracks.	2.2, Technical Reference Document: Section D, Zone 9

Regional risks relevant to Comoros	Report section
Risks to already critically endangered coral reefs, which provide important ecosystem services due to warming sea temperatures and marine heatwaves.	3.6.2
Risks to vulnerable marine turtles due to rising temperatures and sea levels.	3.6.2
Risks to mangroves due to rising sea levels, intense cyclones, and coastal inundation.	3.6.2
Risks to coastal artisanal fishing due to warming sea temperatures, marine heatwaves and ocean acidification.	3.6.3
Risks to coastal and marine tourism due to sea level rise, storms and cyclones, and subsequent degradation of natural resources.	3.6.4
Risks to crop production due to changes in temperature and rainfall leading to increased levels of crop disease and pests.	3.1.2
Risks to livestock productions due to increased heat stress and reduced water availability.	3.1.3
Potential risks to the quality and availability of water resources, including for drinking water and sanitation.	3.2

© Crown Copyright 2022, Met Office

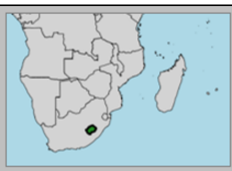
Eswatini country profile

Summary of climate analysis relevant to Eswatini	Report section
Eswatini is a landlocked nation, encircled by South Africa. It experiences a temperate climate and is among the coolest countries in the Southern Africa region due to the high elevation. Agricultural livelihoods are predominantly perennial mixed. Eswatini has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Eswatini experiences a rainy season between September and April and a dry season between May and August. There was no significant trend in average precipitation in Lesotho in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures.	2.2, Technical Reference Document: Section D, Zone 7

Regional risks relevant to Eswatini	Report section
Risks to crop yields, particularly for maize, sorghum and groundnut due to increasing temperatures.	3.1.2
Risks to crop yields due to changes in temperature and rainfall creating more favourable conditions for pests such as fall army worm.	3.1.2
Risks to food security due to increased rainfall variability and droughts.	3.1.5
Risk of increasing water stress due to increasing temperatures and variable rainfall.	3.2
Risks to energy supply due to reliance on energy imports from South Africa leaving it vulnerable to regional energy security dynamics.	3.4.3
Risks to health, including a shift in the areas at risk of malaria, communicable water-borne diseases and heat-related impacts.	3.5

© Crown Copyright 2022, Met Office

Lesotho country profile

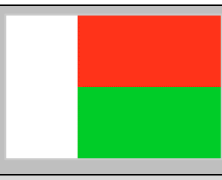


Summary of climate analysis relevant to Lesotho	Report section
Lesotho is a landlocked nation, encircled by South Africa. Lesotho experiences a temperate climate and is among the coolest countries in the Southern Africa region due to the high elevation. The country has a high population density especially to the northwest where the capital city of Maseru is located. Lesotho's north-eastern boundary runs along the western edge of Maloti-Drakensberg National Park in South Africa. Agricultural livelihoods are predominantly highland mixed. Lesotho has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase into the future resulting in an increase in the frequency and intensity of hot extremes. Eswatini experiences a rainy season between September and April and a dry season between May and August. There was no significant trend in average precipitation in Lesotho in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures.	2.2, Technical Reference Document: Section D, Zone 7

Regional risks relevant to Lesotho	Report section
Risks to food security due to dependence on food imports such as cereal to meet national food security demands.	3.1.5
Increasing water stress due to increasing temperatures and variable rainfall.	3.2
Risks to forests, particularly the heat and drought intolerant vegetation of the Afro-temperate forests, and associated ecology and biodiversity due to increased drought conditions.	3.3.2
Risks to livelihoods of rural populations reliant on rainfed agriculture due to increasing rainfall variability.	3.1.2
Risks to health, including a shift in the areas at risk of malaria, communicable water-borne diseases and heat-related impacts.	3.5

© Crown Copyright 2022, Met Office

Madagascar country profile



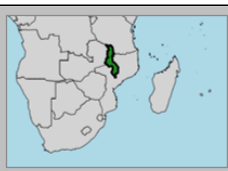
Summary of climate analysis relevant to Madagascar	Report section
Madagascar experiences a mix of climates: the majority of the country experiences a tropical climate, with some temperate climate in the east where there is higher elevation, and some semi-arid climate in the south. Madagascar's population is of high density in the east, especially at the capital and largest city of Antananarivo. Agricultural livelihoods are predominately coastal fishing, agropastoral, maize mixed and tree cropping. Madagascar has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Malawi receives rainfall throughout the year with larger amounts between October and March. There has been no significant trend in average precipitation in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future, although there is some evidence for a small delay to the start of the rainy season. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s, exacerbating coastal flooding. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The proportion of intense tropical cyclones will increase with the total number remaining similar or becoming fewer.	2.2, Technical Reference Document: Section D, Zone 8

Regional risks relevant to Madagascar	Report section
Risks to critical infrastructure due to an increased frequency of cyclones and subsequent flooding.	3.4.5
Risks to health, including a shift in the areas at risk of malaria, communicable water-borne diseases and heat-related impacts.	3.5
Risks to coral reefs, mangroves, seagrasses, and fisheries due to sea level rise, marine temperature and heatwaves, and ocean acidification.	3.6
Risks to livelihoods of rural populations reliant on rainfed agriculture due to increasing rainfall variability.	3.1.2
Increasing temperatures increases the ability of some diseases to spread, particularly in densely populated informal settlements.	3.5.2
Risks to coastal cities due to increasing sea level.	3.4.1
Risks to crop yields due to changes in temperature and rainfall creating more favourable conditions for pests such as fall army worm.	3.1.2
Risks to the quality and availability of water resources, including irrigation and sanitation.	3.2

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Malawi country profile



Summary of climate analysis relevant to Malawi	Report section
Malawi experiences a tropical climate and is among one of the hottest and wettest areas in the Southern Africa region. Key rivers include the Zambezi in the south and Lake Malawi in the northeast. The country has a high population density especially on the southwestern side of Lake Malawi. High population hotspots include the capital city of Lilongwe, as well as other large towns and cities such as Kasungu, Mzuzu, Zomba and Blantyre. Agricultural livelihoods are mostly maize mixed and fishing. Malawi has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Malawi experiences a rainy season between October and May and a dry season between June and September. There has been no significant trend in average precipitation in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future, although there is some evidence for a small delay to the start of the rainy season. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures.	2.2, Technical Reference Document: Section D, Zone 5

Regional risks relevant to Malawi	Report section
Risks to fishing communities due to increases in temperatures and thermal stratification reducing the productivity of Lake Malawi.	3.1.4
Risks to energy security and hydropower production due to increased frequency of drought conditions.	3.2.3
Risks to the quality and availability of water resources, including rural and urban water supplies and sanitation.	3.2
Risks to crop production, particularly maize, sorghum and groundnut due to increased temperatures, rainfall variability and droughts.	3.1.2
Risks to crop yields due to changes in temperature and rainfall creating more favourable conditions for pests such as fall army worm.	3.1.2
Risks to livestock health and mortality due to increased heat stress and livestock disease outbreaks.	3.1.3
Risks to health, including communicable water-borne diseases and heat-related impacts, particularly in densely populated informal settlements.	3.5

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

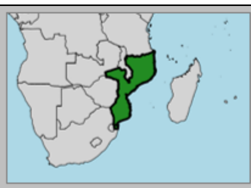
Mauritius country profile

Summary of climate analysis relevant to Mauritius	Report section
Mauritius has a tropical marine climate which is strongly influenced by the surrounding ocean. The main island of Mauritius has several population centres, including the capital Port Louis, which are clustered in the central and north parts of the island on the higher elevation. The main island of Mauritius consists of a coastal plain rising to a higher plateau, with some mountain peaks up to 1000m. Livelihoods are mainly tourism, coastal fishing, agriculture, and livestock. Mauritius has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Mauritius experiences a rainy season between November and April and a relatively dry season between June and September. Most islands in the Western Indian Ocean will become drier in the future, with less rainfall over parts of the Indian Ocean, particularly from June to August. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s, exacerbating coastal flooding. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The proportion of intense tropical cyclones will increase with the total number remaining similar or becoming fewer. Though it is important to note the substantial variability across small island regions given projected regional shifts in storm tracks.	2.2, Technical Reference Document: Section D, Zone 9

Regional risks relevant to Mauritius	Report section
Risks to already critically endangered coral reefs, which provide important ecosystem services due to warming sea temperatures and marine heatwaves.	3.6.2
Risks to vulnerable marine turtles due to rising temperatures and sea levels.	3.6.2
Risks to infrastructure due to an increased frequency of cyclones and coastal flooding.	3.4.5
Risks to mangroves due to rising sea levels, intense cyclones and coastal inundation.	3.6.2
Risks to fish stocks and the fishing sector due to warming sea temperatures, marine heatwaves and ocean acidification.	3.6.3
Risks to coastal and marine tourism due to sea level rise, storms and cyclones, and subsequent degradation of natural resources.	3.6.4
Risks to crop production due to changes in temperature and rainfall leading to increase levels of crop disease and pests.	3.1.2
Risks to livestock productions due to increased heat stress and reduced water availability.	3.1.3
Potential risks to the quality and availability of water resources.	3.2

© Crown Copyright 2022, Met Office

Mozambique country profile

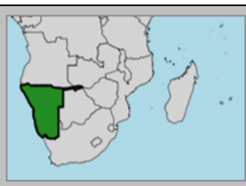


Summary of climate analysis relevant to Mozambique	Report section
Mozambique experiences a tropical climate across most of the country and a semi-arid climate in the south. Key rivers include the Zambezi which runs across the centre of the country out to the eastern coast. The country has low population density, with some higher population centres at cities such as Lichinga on the northeast side of Lake Malawi, Beira on the coast, Nampula to the northeast, and Maputo and Matola on the coast at Maputo Bay. Agricultural livelihoods are predominantly agro-pastoral, coastal fishing and maize mixed in the south. Mozambique has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Malawi experiences a rainy season between October and May and a dry season between June and September, with lower rainfall amounts in the south. There has been no significant trend in average precipitation in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future, although there is some evidence for a small delay to the start of the rainy season in the north. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s, exacerbating coastal flooding. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The proportion of intense tropical cyclones will increase with the total number remaining similar or becoming fewer.	2.2, Technical Reference Document: Section D, Zones 5 and 6

Regional risks relevant to Mozambique	Report section
Risks to critical infrastructure due to an increased frequency of cyclones and subsequent flooding.	3.4.5
Risks to agricultural production, affecting both livelihoods and food security die to extreme weather events and flooding.	3.1.2
Risks to marine turtles, coral reefs, mangroves, seagrasses, and fisheries due to sea level rise, increasing marine temperature and heatwaves, and ocean acidification.	3.6.2, 3.6.3
Risks to coastal communities, port facilities and offshore oil and gas mining due to sea level rise, coastal erosion, storm surges and cyclones.	3.6.4
Risks to food security die to increased severity and/or frequency of drought.	3.1.2
Risks to health, including a shift in the areas at risk of malaria, communicable water-borne diseases and heat-related impacts.	3.5
Risks to crop yields due to changes in temperature and rainfall creating more favourable conditions for pests such as fall army worm.	3.1.2
Risks to the transport network due to increased frequency of flooding.	3.4.2
Risks to energy security and hydropower production due to increased frequency of drought conditions.	3.2.3
Risks to the quality and availability of water resources, including rural and urban water supplies and sanitation.	3.2

© Crown Copyright 2022, Met Office

Namibia country profile

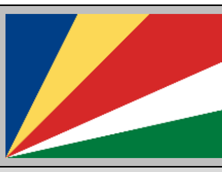


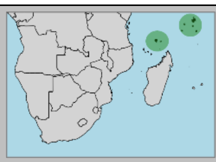
Summary of climate analysis relevant to Namibia	**Report section**
Namibia experiences a hot desert climate across the majority of the country, particularly the Namib desert to the west, and a semi-arid climate in the northeast. Key rivers include the Okavango in the north and the Orange in the south. Population densities are low with some high population centres such as the capital city Windhoek. Agricultural livelihoods are predominantly pastoral, with some arid pastoral-oases livelihoods in the desert regions and fishing livelihoods along the coast. Namibia has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Namibia experiences a rainy season between October and April and a dry season during May to September with higher rainfall amounts in the northeast. There has been an observed increase in average precipitation in recent decades and the country is expected to become drier on average in the future. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s, exacerbating coastal flooding. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification.	2.2, Technical Reference Document: Section D, Zones 1 and 2

Regional risks relevant to Namibia	**Report section**
Risks to grasslands and savannah, and associated ecology and biodiversity due to increased drought conditions.	3.3.3
Risks to fish stocks and industrial fishing due to potential changes to the upwelling Benguela Current System.	3.6.3
Risks to coastal port facilities due to sea level rise and storms.	3.6.4
Risks to food security due to increased severity and/or frequency of drought events.	3.1.2
Risks to cereal crop yields due to higher temperatures.	3.1.2
Risks to water supply due to increased water stress in the Orange River basins due to the drying trend and increased rainfall variability.	3.2.3
Risks to livestock health and mortality due to direct heat stress.	3.1.3
Risks to food security due to the reliance on food imports from surrounding countries.	3.1.5
Risks to health, including a shift in the areas at risk of malaria, communicable water-borne diseases, and heat-related impacts.	3.5
Risks of climate-induced power outages.	3.2.3
Risks to the quality and availability of water resources.	3.2
Risks to the Ephemeral wetland system and associated biodiversity and ecosystem services due to higher temperatures and drier conditions.	3.3.4

© Crown Copyright 2022, Met Office

Seychelles country profile





Summary of climate analysis relevant to the Seychelles	Report section
The Seychelles is a group of islands in the West Indian Ocean. The Seychelles islands experience a tropical marine climate which is strongly influenced by the surrounding ocean. Livelihoods are mainly tourism, coastal fishing, agriculture and livestock. The Seychelles islands have already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. The Seychelles experience rain throughout the year, particularly over higher ground, and the wettest months are December and January. Most islands in the Western Indian Ocean will become drier in the future, with less rainfall over parts of the Indian Ocean, particularly from June to August. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s, exacerbating coastal flooding. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The proportion of intense tropical cyclones will increase with the total number remaining similar or becoming fewer. Though it is important to note the substantial variability across small island regions given projected regional shifts in storm tracks.	2.2, Technical Reference Document: Section D, Zone 9

Regional risks relevant to the Seychelles	Report section
Risks to the fishing sector due to warmer sea temperatures, marine heatwaves and ocean acidification.	3.6.3
Risks to coastal and marine tourism due to sea level rise, storms and cyclones, and subsequent degradation of natural resources.	3.6.2
Risks to already critically endangered coral reefs, which provide important ecosystem services to warming sea temperatures and marine heatwaves.	3.6.2
Rising temperatures and sea levels impact vulnerable marine turtles which nest here, affecting the species and tourism.	4.6.2
Risks to mangroves due to rising sea levels, intense cyclones and coastal inundation.	4.6.2
Risks to vulnerable marine turtles due to rising temperatures and sea levels.	4.6.4
Potential risks to the quality and availability of water resources.	4.2

© Crown Copyright 2022, Met Office

South Africa country profile

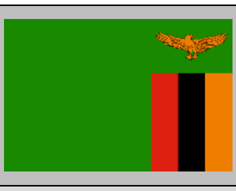
Summary of climate analysis relevant to South Africa	Report section
South Africa experiences a hot desert climate in the northwest, a cool desert and semi-arid climate in the southwest and a temperate climate in the east. Key rivers include the Orange in the west and the Limpopo in the northeast. Population densities are concentrated in cities such as Cape Town in the southwest, Johannesburg and Pretoria in the east. Agricultural livelihoods are predominantly perennial mixed, maize mixed, and pastoral in the more sparsely populated desert regions. South Africa has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. South Africa experiences a rainy season between October and April in the east, and lower amounts throughout the year in the southwest. There has been no significant trend in average precipitation in recent decades. The western part of the country will be drier on average in the future, and there is no consensus on whether the eastern part of the country will be wetter or drier on average. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures. Sea levels will continue to rise by 0.2-0.3m by the 2050s. Sea surface temperatures will increase, resulting in increases in the frequency and intensity of marine heatwaves and ocean acidification. The proportion of intense tropical cyclones affecting the eastern coast will increase with the total number remaining similar or becoming fewer.	2.2, Technical Reference Document: Section D, Zones 2, 3 and 7

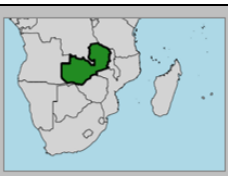
Regional risks relevant to South Africa	Report section
Risks to regional food system due to a decline in cereal production and exports.	3.1.5
Risks to livestock health and mortality due to rising heat stress.	3.1.3
Risks to crop production due to the spread of pests such as the corn leafhopper as temperatures increase.	3.1.2
Risks to forests, particularly the heat and drought intolerant vegetation of the Afro-temperate forests, and associated ecology and biodiversity due to increased drought conditions.	3.3.2
Risks to the quality and availability of water resources, including rural and urban water supplies, sanitation and irrigation.	3.2, 3.4
Risk of climate-induced power outages.	3.2.3
Risks to charismatic marine species, coral reefs, saltmarshes, and fisheries due to impacts from sea level, marine temperature and heatwaves, and ocean acidification.	3.6
Risks to coastal and marine tourism.	3.6.4
Risks to coastal and offshore industries including shipping, oil and gas extraction.	3.6.4

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Zambia country profile





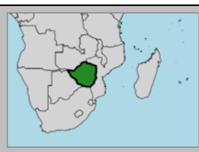
Summary of climate analysis relevant to Zambia	Report section
Zambia experiences a temperate climate. Key rivers include the Zambezi in the west and the northeast is part of the Congo River Basin. The country has low population density, with the exception of some higher population centres such as at the capital city of Lusaka. Maize mixed livelihoods dominate over most of the country, with agropastoral livelihoods being more dominant in the south-west. Zambia has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Zambia experiences a rainy season between October and April and a dry season between May and September. There has been no significant trend in average precipitation in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future, although there is some evidence for a small delay to the start of the rainy season. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events and increased evapotranspiration resulting from rising temperatures.	2.2, Technical Reference Document: Section D, Zone 4

Regional risks relevant to Zambia	Report section
Risks to energy security due to downturns in hydropower production as a result of droughts.	3.4.3
Risks to water supply due to an increase in frequency of urban flooding, contamination of drinking water and outbreaks of water borne diseases.	3.4.4
Risks to the quality and availability of water resources, including rural and urban water supplies and sanitation.	3.2
Risks to hydropower production and energy security.	3.2.3
Risks to food security due to increased severity and/or frequency of drought events, extreme weather and flooding.	3.1.2
Risks to crop production due to changes in temperature and rainfall continuing to create more favourable conditions for pests such as the fall army worm and locusts.	3.1.2
Risks to livestock health and mortality due to changes in temperature and rainfall impacting the risk of livestock disease outbreaks, such as East Coast fever.	3.1.3
Risks to health, including a shift in the areas at risk of malaria.	3.5.2
Risks to the Kafue flats wetlands and associated biodiversity and ecosystem services due to higher temperatures and greater rainfall variability.	3.3.4

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Zimbabwe country profile



Summary of climate analysis relevant to Zimbabwe	Report section
Zimbabwe experiences a temperate climate in the northeast and a semi-arid climate in the southwest where. Key rivers include the Zambezi in the north and the Limpopo in the south. Agricultural livelihoods are predominantly maize mixed in the northeast and agro-pastoral in the southwest. Zimbabwe has already experienced more than 1˚C of warming between 1961 to 2015. Temperatures will continue to increase in the future resulting in an increase in the frequency and intensity of hot extremes. Zimbabwe experiences a rainy season between October and April and a dry season between May and September. There has been no significant trend in average precipitation in recent decades and there is no consensus on whether the country will be wetter or drier on average in the future, although there is some evidence for a small delay to the start of the rainy season. Flood and drought events are likely to be more frequent and intense due to increased year-to-year rainfall variability, increased intensity of heavy rainfall events, and increased evapotranspiration resulting from rising temperatures.	2.2, Technical Reference Document: Section D, Zones 4 and 6

Regional risks relevant to Zimbabwe	Report section
Risks to food security and livelihoods due to vulnerability of regional food system as well as an increase in frequency of drought events, extreme weather, and flooding.	3.1.5
Risks to hydropower production and energy security.	3.2.3
Risks to the quality and availability of water resources, including rural and urban water supplies and sanitation.	3.2
Risks to crop production due to changes in temperature and rainfall continuing to create more favourable conditions for pests such as the fall army worm and locusts.	3.1.2
Risks to livestock health and mortality due to rising heat stress.	3.1.3
Greater risk of fire weather resulting in increased frequency of forests fires which are already a major risk in the country.	3.3.2
Risks to dambo wetlands and associated biodiversity and ecosystem services due to higher temperatures and greater rainfall variability.	3.3.4

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Image locations
Top: Windhoek, Namibia
Middle: Zimbabwe
Bottom: Cape Town, South Africa

©Crown Copyright 2022, Met Office

1 Introduction

1.1 Purpose of this report

This report provides an evidence base on the Southern Africa region's changing climate and how these changes could impact socio-economic development across the region. The aim is to inform development programming and policy dialogue for Southern Africa. It forms part of a series of climate risk reports commissioned by the UK Government's Foreign, Commonwealth & Development Office (FCDO) which interpret climate, socio-economic and environmental information to support FCDO regional development planning.

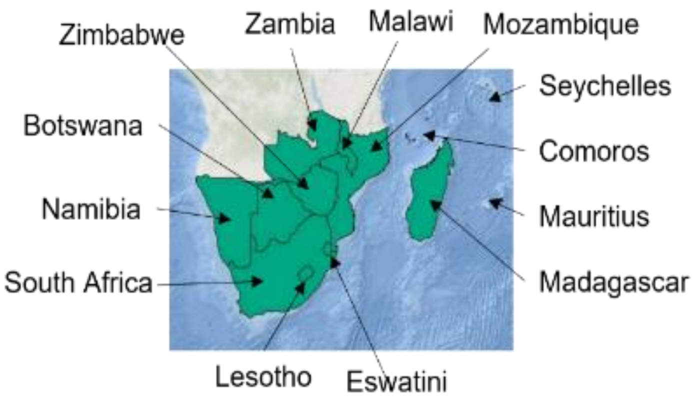


Figure 1: Countries included in the Southern Africa region for this report.

Southern Africa includes **Botswana, Eswatini, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Zambia, Zimbabwe** and the small islands in the Indian Ocean, including **Comoros, Mauritius and the Seychelles** (Figure 1). Key aspects of the region also included in the analysis, such as the topography of the region and population densities, are also shown in Figure 2 (second and third panels).

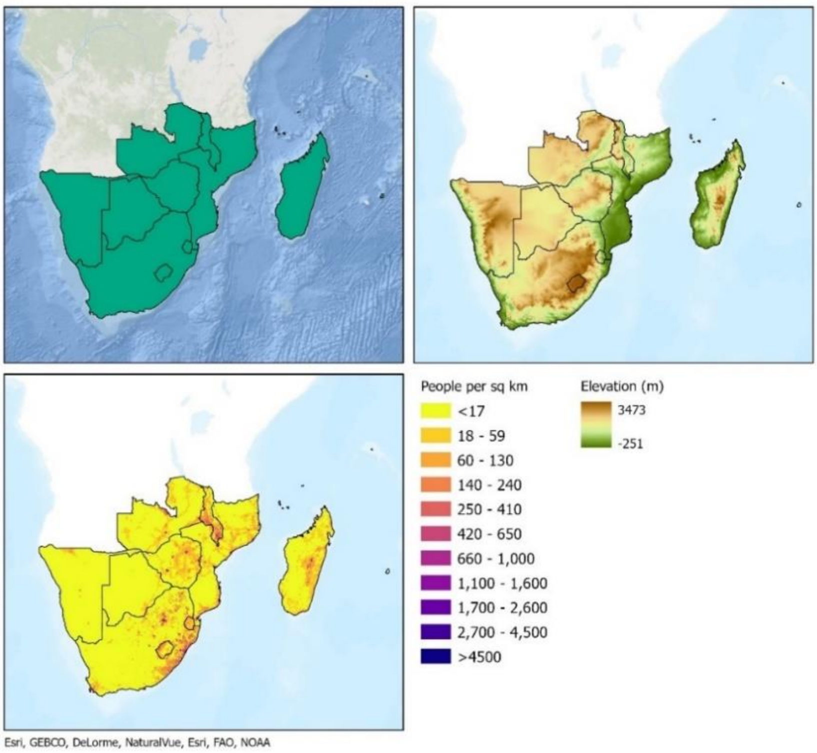


Figure 2: The Southern Africa region considered in this report. Top left panel: countries included in the analysis, top right panel: topography of the region, bottom left panel: population density.

© Crown Copyright 2022, Met Office

1.2 Methodological approach

This report presents an analysis of climate risk in the Southern Africa region, combining climate with social and economic analysis to identify key threats to production systems, resources, economies, services and livelihoods. The report aims to guide development planners to areas requiring attention, providing an overview of key risks and uncertainties, bringing prominent regional risks to the fore.

Current climate has been analysed for geographical regions which share similar climate characteristics, such as the timing of rainy seasons or similar seasonal temperature ranges. This climate analysis is brought together with regional socio-economic information to contextualise our knowledge of future regional climate change.

The interpretation of knowledge of future climate in this report is informed by six issues that run through analysis of several themes:

- Economic growth and infrastructure, including disparities in income/wealth distribution.
- Capacity and human capital, including ways in which climate risks are shaped by gender and differences in power, rights and opportunities.
- Population and demography, including rapid urbanisation and the growth of informal settlements where climate risks are amplified.
- Livelihood systems and key crops, with a focus on more exposed (rainfed) agricultural and pastoral systems, but also including marine and freshwater fisheries.
- Disaster risks, given recent and future projected increases in the frequency and magnitude of extreme events such as storms, floods and droughts.
- Conflict and migration in a region where political instability and violence undermines efforts to build resilience.

Further information regarding the data used and detailed methodology can be found in Section A of the Technical Reference Document and on the Met Office website[1].

Focus Box 1 summarises the need for considering both exposure and vulnerability to climate hazards, and the need for an interdisciplinary approach when interpreting compound risks associated with, or exacerbated by, climate change.

[1] https://www.metoffice.gov.uk/services/government/international-development/climate-risk-reports

© Crown Copyright 2022, Met Office

Focus Box 1: Exposure, vulnerability, response and development

A climate or disaster hazard does not in itself create risk. Risk is a function of both an individual's or community's exposure and vulnerability to a hazard, and also its ability to respond (Figure 3, Begum et al., 2022). Exposure and vulnerability are separate, yet both emerge from socio-economic contexts and are exacerbated by uneven development dynamics such as: rapid urbanisation and demographic change, environmental degradation, weak governance, and lack of economic opportunity. IPCC AR6 also now considers response as an important component of risk and examines the effectiveness of adaptation solutions, the management of risks at higher levels of warming if climate change mitigation is unsuccessful and the benefits of mitigation and emissions reductions (Begum et al., 2022).

The components of risk (hazard, vulnerability, exposure and response) interact in complex ways (Figure 3, Begum et al., 2022). They can compound in single or multiple directions, cascade (e.g., with one event triggering another) and aggregate (e.g. more than one component occurring simultaneously).

Climate vulnerability and poverty are often mutually reinforcing; a growing body of evidence highlights the role of climate risk in persistent poverty and poverty traps (Hansen et al, 2019; Sachs et al., 2004). This is a challenge exacerbated by the political marginalisation of many poor and climate vulnerable people (Wisner et al., 2003).

Climate change is interwoven with development challenges across the Sustainable Development Goals (SDGs). As factors such as economic inequality, education, gender, nutrition and health shape the risk profile of individuals and communities, supporting sustainable development indirectly supports their capacity for managing climate risk (Wisner et al., 2003; Schipper and Pelling, 2006).

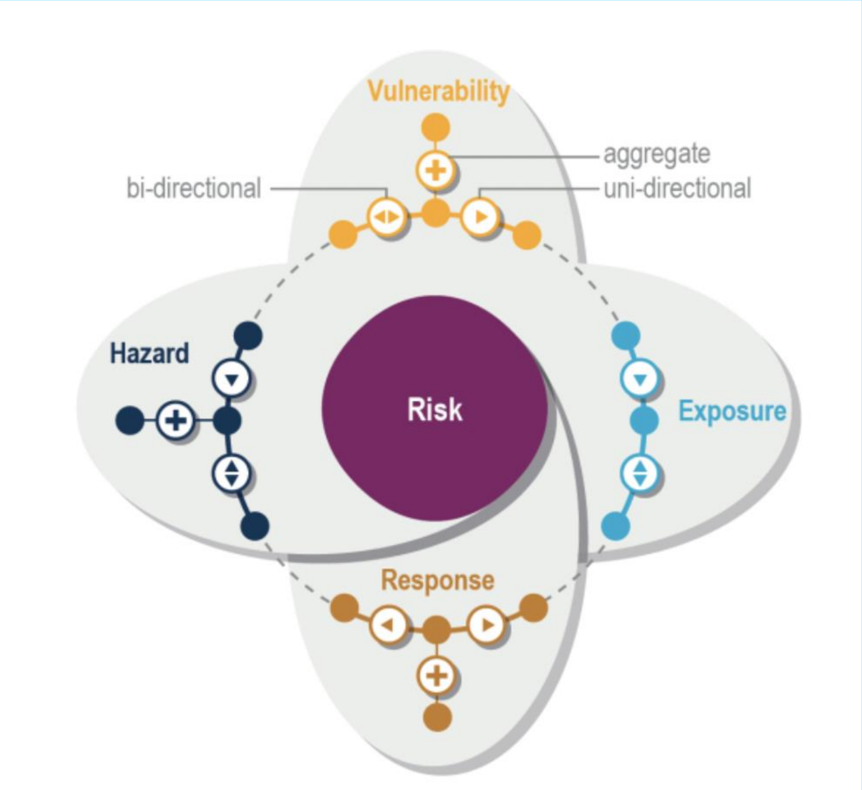


Figure 3: Climate risk is the product of the hazard, vulnerability and exposure to the hazard and the response to the hazard which interact in complex ways: compounding in single or multiple directions, cascading and/or aggregating. Image adapted from IPCC AR6 Working Group 2 (Begum et al, 2022).

© Crown Copyright 2022, Met Office

1.3 Report Structure

The current climate already includes significant changes to which some aspects of human and ecological systems are not well adapted. Section 2 provides an assessment of the current climate resilience and vulnerability across the Southern Africa region, as well as a summary of our knowledge about the current climate and its future evolution at the regional scale. This information is brought together to present assessments of the current and future climate in the context of the prevailing socio-economic conditions in newly identified zones defined by their main climate characteristics. Section 3 interprets this knowledge on future climate presented in Section 2 in terms of risks across six key themes: biodiversity, ecology and forests; agriculture and food security; water resources and water-dependent services; infrastructure and settlements; health; and coasts, fisheries, and the marine environment.

Country summaries have been provided in Appendix A to outline prominent climate risks for that location within the regional context. The summaries do not provide a national level analysis and there will be additional climate risks pertinent at a national scale that should also be considered in a national or subnational development plan. Where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis would be required.

The Technical Reference Document accompanies this report to provide more detail on the methods, data and analysis that supports the assessment presented here.

© Crown Copyright 2022, Met Office

2 Current and future climate in the Southern Africa region

2.1 Climate resilience and vulnerability overview for the Southern Africa region

Southern Africa has witnessed strong economic growth over the last 20 years or so, buoyed by economic reforms and, in some countries, rising commodity prices. However, wealth is very unevenly distributed between and within countries and the region still experiences persistent poverty and food insecurity. Zambia, Malawi, Mozambique, Lesotho and Madagascar all fall into the low-income category defined by the World Bank for 2022-23[2], and have a combined population of 99 million – roughly 55% of the regional total (World Bank data for 2020 – see Technical Reference, Section E). The direct and indirect impacts of COVID-19 pushed most countries into recession in 2020 (World Bank, 2020), and even though health impacts were less severe than expected, the economic and social fallout has been severe. Regional economies are now rebounding, albeit patchily, with rising food prices now threatening those countries heavily dependent on cereal imports[3] – Botswana, Namibia, Eswatini, Lesotho, Mauritius, Comoros and Seychelles (Raga and Pettinotti, 2022; Wiggins, 2022).

Climate-related shocks have also had major consequences, with floods and droughts a recurring (and growing) risk throughout the region. In March 2019, Tropical Cyclone Idai swept across Southern Africa causing widespread damage and a humanitarian crisis in Mozambique, Zimbabwe and Malawi (see Section 3.4). In April 2022, flash floods and landslides in the eastern coast provinces of KwaZulu-Natal and Eastern Cape, South Africa, killed over 400 people and forced 40,000 people from their homes (PreventionWeb, 2022). Droughts in 2015-16, 2018-19 and 2021-22 have caused widespread food insecurity in Malawi, Zambia, Mozambique, Zimbabwe and Eswatini, with impacts that have rippled across rural and urban areas (Relief Web, 2022).

The link between increasingly erratic rainfall and poverty remains a key source of vulnerability, especially in the low/lower-middle income countries of Zambia, Malawi, Mozambique, Zimbabwe, Lesotho and Madagascar (69% rural – World Bank data for 2020). Those engaged in low intensity, low input rainfed farming, disconnected from markets and with few opportunities to adapt cropping patterns or diversify, are among the most vulnerable to climate change (Ellis, 2013; Hallegatte, 2016). For rural smallholders, the climate determines the harvest, and the harvest determines the ability to meet most staple food needs (Derereux, 2009). Pastoral and agro-pastoral livelihoods, significant across the more arid lowlands, are similarly climate-sensitive, as rains (and heat) affect forage and water availability, as well as livestock health (Hallegatte, 2016).

---

[2] Low income (<USD1085/person/year); lower-middle (USD1086-4255); upper-middle (USD 4256-13,205); high-income (>USD 13,205). In Southern Africa, no countries fall into the high-income category (World Bank: https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2022-2023

[3] Botswana, Lesotho, Mauritius Comoros and Seychelles all have cereal import dependency ratios of over 75% based on a 2016-18 average. Namibia (69%) and Eswatini (67%) are also heavily dependent on food imports (FAOSTAT, 2022 – see Technical Reference, Section E).

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

Rapid urbanisation is changing the exposure and vulnerability landscape, however. The region has the highest urbanisation rate in sub-Saharan Africa, and infrastructure provision (safe water and sanitation, drainage, housing) typically lags behind urban expansion. In low income Zambia, Malawi, Mozambique, Lesotho and Madagascar, over 65% of urban residents live in poorly served informal settlements, and new migrants often have little choice but to settle in riskier places exposed to multiple hazards (World Bank data for 2018-2020 – see Technical Reference, Section E).

© Crown Copyright 2022, Met Office

2.2 Climate overview for the Southern Africa region

The Southern Africa region contains a diverse range of climates including semi-arid, warm and cold desert, temperate, tropical savanna, subtropical and oceanic. Situated at the junction of the South Atlantic, Indian and Southern Oceans, variability in sea surface temperatures around the coastlines influences the region's climate. Elevations above ~700m are found across the majority of Southern Africa, excluding areas in Mozambique and along the coast. The areas of highest elevation and coolest average annual temperatures are found in Lesotho in the south-east, with parts of the Thaba Tseka, Mokhotlong and Butha Buthe Districts reaching above 3000m (Figure 2). Major river basins in the region include the Zambezi, Limpopo, Okavango and Orange.

2.2.1 Regional climate overview and observed trends

Arid climates of West Southern Africa (WSAF)

WSAF encompasses semi-arid climate in Namibia and Botswana, hot desert climate in Namibia, Botswana and South Africa, and cold desert climate in western South Africa (see Figure 4). Warmest average annual temperatures are found in the north in Namibia and Botswana (between 22 – 24°C), with cooler average temperatures found in regions of high elevation close to Namibia's eastern coastline (~18°C) and in eastern South Africa (~16°C). Highest maximum temperatures, which occur during austral summer (December to February), are found in the north of region in northwest Namibia (between 32 - 34°C). During the winter season (June to August), average temperatures fall below 20°C in much of the region.

WSAF experiences the driest conditions of the Southern Africa region, with some areas in Namibia and western South Africa receiving very little rainfall (less than 200mm) per year (Figure 4). The seasonal cycle of rainfall is characterised by a wet season during summer and a dry season during winter, with the exception of the Western Cape along the south-western coast of South Africa, which experiences a winter rainy season (Figure 5).

Tropical and temperate climates of East Southern Africa (ESAF)

ESAF includes temperate climates in the north in Zambia and Zimbabwe, and in the south in South Africa, Lesotho and Eswatini. Tropical climate is found in Zambia, Malawi and Mozambique and semi-arid climate is present in central and eastern parts of the region. Average annual temperatures are warmest in the centre of the region (see Figure 4) in Botswana and Zambia and along the eastern coast in Malawi and Mozambique (~25°C). Highest maximum temperatures, which occur during austral summer (December to February), are of around 30 – 32°C are found in the centre north of Botswana and the regions of low elevation in Mozambique. During the winter season (June to August), average temperatures fall below 20°C in much of the region. The region's highest elevations and coolest average annual temperatures (12°C and lower) are found in Lesotho, with parts of the Thaba Tseka, Mokhotlong and Butha Buthe Districts reaching above 3000m (Figure 2).

ESAF experiences greater annual average precipitation compared to WSAF, with Mozambique and Malawi receiving more than 1500mm of rainfall per year (Figure 4). The seasonal cycle of rainfall is characterised by a wet season during summer and a dry season during winter (Figure 5).

© Crown Copyright 2022, Met Office

Climate of Madagascar, Mauritius, the Seychelles and the Comoros Islands

The island of Madagascar is primarily tropical savanna, with monsoon and equatorial climates found along the eastern coast. An area of humid subtropical and warm oceanic climate occurs in central Madagascar and a warm semi-arid climate characterises the southwest. Highest elevations are found in the north and centre of Madagascar, with some mountainous regions ~ 2500m above sea level. Average annual temperatures are warmest on the western coast of Madagascar, particularly in the north (~26°C) and are cooler in the mountainous regions (~18°C). Highest maximum temperatures, which occur during austral summer (December to February), around 32-34°C occur in the north-west low elevation regions of Madagascar. Madagascar currently experiences 0-10 days per year exceeding 35°C on average and no days exceeding 40°C on average. Madagascar experiences annual average rainfall totals of more than 1500mm per year (Figure 4). The seasonal cycle of rainfall is characterised by a wet season during summer and a dry season during winter (Figure 5).

There is little climate information published for Mauritius, the Seychelles and the Comoros Islands. These islands consist of forests, lagoons, reefs, estuaries, mangroves and saltwater wetlands. They experience a tropical climate with warm temperatures year-round with a dry season from June to September and a wetter season from November to April, with October and May as transition months (Figure 5). Annual rainfall totals in these islands are greater than 1500mm per year (Figure 4).

Observed trends in regional climate for Southern Africa

Observational records show that Southern Africa's average annual surface temperatures increased by between 1°C and 1.5°C from 1961 to 2015. Minimum temperatures have increased more rapidly than maximum temperatures in inland areas. The frequency of hot extremes has increased, and the occurrence of cold extremes has decreased (IPCC, 2021).

Across the Southern Africa region, WSAF currently experiences the greatest number of days exceeding 35°C and 40°C on average per year. On average, 50-100 days exceed 35°C per year, with lower values around 0-30 days occurring in the far north (north Namibia and Botswana), far south (southwest South Africa and Cape Town) and along the west and southwest coast (Namibia and southwest South Africa). WSAF experiences 0-4 days exceeding 40°C per year on average, with higher occurrences of 10-12 days in south Namibia and 2-4 days in north Namibia and west Botswana. ESAF currently experiences 30-80 days on average per year exceeding 35°C in the central areas (south and mid-Mozambique, south and west Zimbabwe, southernmost Malawi), with large areas seeing lower values at 0-20 days to the north (northern Mozambique, east Zambia, mid-Zimbabwe), south (east South Africa, Lesotho, Eswatini), and along the east and south coasts. The majority of ESAF experiences 0-2 days on average per year exceeding 40°C, and slightly higher values of 2-8 days in central regions (southernmost Mozambique, Zimbabwe, and Malawi).

Over recent decades (1980-2015) there has been an increasing trend in precipitation averaged over West Southern Africa, no clear trend for East Southern Africa and a drying trend for Madagascar in the two observational datasets available in the IPCC Interactive Atlas (IPCC, 2021). However, over a longer time period (1961-2015) available for one of these datasets, the increasing precipitation trend in West Southern Africa is no longer statistically significant but there is a decreasing trend over East Southern Africa. This demonstrates that care is needed when using information on precipitation trends in Southern Africa due to its

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

variable nature. Observations since the 1950s show that heavy precipitation events and the occurrence of agricultural and ecological drought have increased (IPCC, 2021).

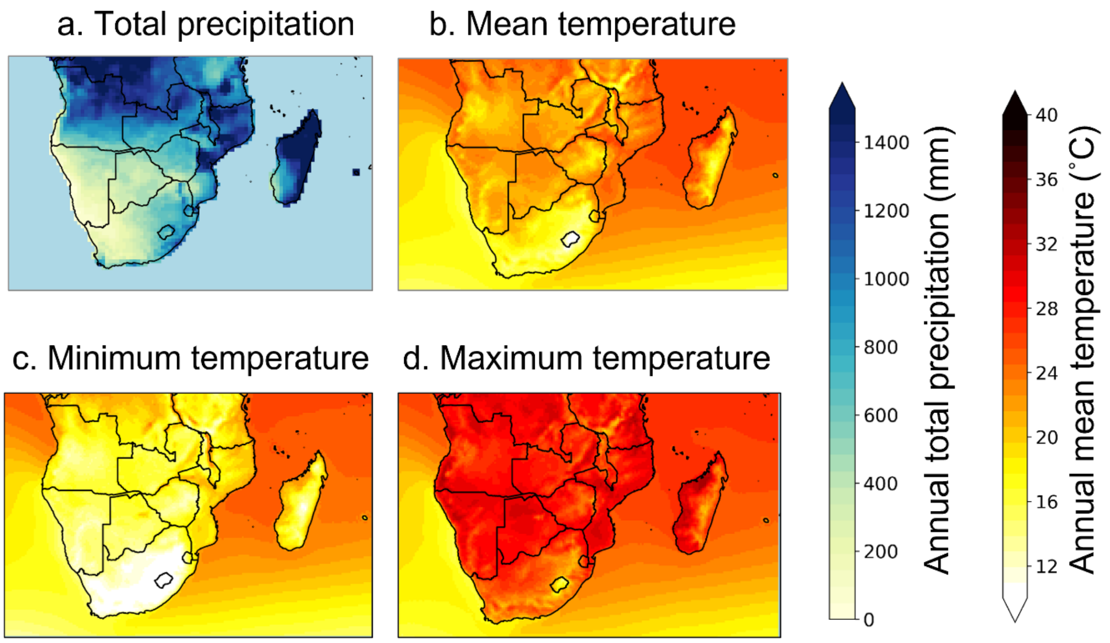


Figure 4: Baseline climate for the Southern Africa region for the period 1981-2010. Maps show climatological average values of annual mean a) total precipitation (mm/year), b) mean temperature (°C), c) minimum temperature (°C) and d) maximum temperature (°C). Temperature and precipitation data come from the ERA5 and WFDE5 reanalysis datasets respectively[4]. These maps represent the average annual values over the 30-year baseline climate period (1981-2010).

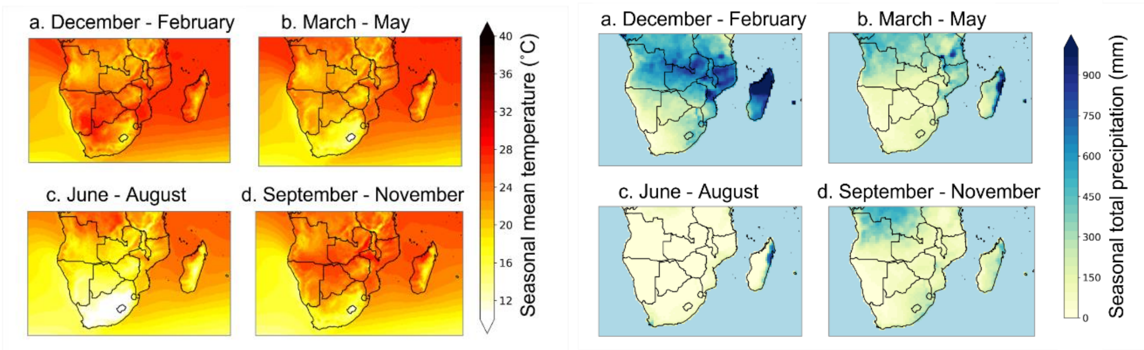


Figure 5: Seasonally averaged mean temperature for the Southern Africa region over the baseline period (1981-2010) from the ERA5 reanalysis (left). Seasonal total precipitation for the Southern Africa region over the baseline period (1981-2010) from WFDE5 reanalysis[4] (right).

[4] Temperature data are from the ERA5 reanalysis (Hersbach et al., 2020) which includes air temperature values over the oceans. Precipitation data are from the WFDE5 reanalysis product which has been bias corrected using observations from the GPCCv2018 full data product and includes land-based data only (Cucchi et al., 2020).

© Crown Copyright 2022, Met Office

2.2.2 Future climate over Southern Africa

Average annual temperatures will increase across Southern Africa and rise faster than the global average (IPCC, 2021). By the 2050s, temperature increase relative to 1981-2010 under a very high emissions scenario is expected to range from 2 - 4°C in the north and centre of WSAF, and 1.5 – 3.5°C in South Africa, and range from 1.5-4°C in ESAF. As temperatures increase, evaporation rates will also increase. Areas in the south-west of the region covering South Africa and parts of Namibia and Botswana are projected to experience the greatest increases in temperature. At 1.5°C, 2°C and 3°C global warming, average annual surface temperature increases in Southern Africa will be higher than the global average (IPCC, 2021). Daily minimum and maximum temperatures are projected to increase at roughly the same magnitude as the daily mean.

The intensity and frequency of hot extremes, including heatwaves, will increase, whereas the intensity and frequency of cold extremes will decrease (IPCC, 2021). In WSAF the number of days with temperatures exceeding 35°C may increase up to 150-190 days per year, with the highest values in the far north and south of Namibia and west Botswana. The Namibian and southwest South African coasts show lower values, with the number of days ranging from 20-50 days. Projections for days exceeding 40°C show an average increase in the central parts of the region (southeast Namibia, northeast Namibia, west Botswana) to 25-45 days. The rest of the region (South Africa, Namibian coast) shows lower values of 0-15 days. In ESAF, days exceeding 35°C show an average increase to 30-80 days per year for the majority of the region with higher values ranging from 100-150 in southernmost Mozambique, south Zimbabwe, north-eastern South Africa, and southernmost Malawi. Days exceeding 40°C are projected to increase to 25-35 days in southern and central Mozambique, southern Malawi and southern Zimbabwe. The rest of the region is expected to see lower occurrences at 0-10 days (north Mozambique, northeast Zimbabwe, south-eastern South Africa, Lesotho, Eswatini).

By the 2050s it is expected that the south-west of Southern Africa will get drier, especially under scenarios of greater global warming (IPCC Interactive Atlas, 2021). Projections show that the north-east of the Southern Africa region may see a small delay to the start of the rainy season (Dunning et al., 2018). There is less confidence in projected trends in precipitation compared to temperature and it is less clear whether the remainder of the region will become wetter or drier on average in the future, with some areas showing a clearer trend than others. At higher levels of global warming there is more agreement across model projections that the region will get drier (IPCC Interactive Atlas, 2021). Areas which see a drying trend in future, along with increasing temperatures, will experience more severe agricultural and ecological droughts, even if global warming is stabilised in a range of 1.5 – 2°C above pre-industrial levels. There is less confidence about the projected changes in hydrological droughts, but the risk of these increases at higher levels of warming (IPCC, 2021). Whilst the frequency of heavy rainfall events in western South Africa is projected to decrease, the intensity is expected to increase, increasing exposure to flash flooding (Engelbrecht et al., 2009; Pinto et al., 2018). At the river basin scale, reductions in river flow are projected in the south-west (Orange, Okagvango) (Hamududu and Killintveit, 2016; Trisos et al., 2022). Reductions in river flow are projected in river basins in the east (Limpopo, Zambezi) although there is greater uncertainty around whether these will see an increase or decrease in flow (Hamududu and Killintveit, 2016; Trisos et al., 2022). Increases are projected in the Congo River basin in the north of the region (Doherty et al., 2022).

© Crown Copyright 2022, Met Office

Around the Southern African coast, including Madagascar, Mauritius and the Comoros and Seychelles Islands, average sea level has increased at a rate of around 3mm per year between 1993-2018 (Allison et al, 2021) and will continue to rise under all greenhouse gas emissions scenarios and globally these are committed to rise for centuries to millennia (IPCC, 2021). By mid-century under a very high emissions scenario, a 0.3m median rise is projected, increasing to 0.7-0.8m by the end of the century, relative to 1995-2014 levels. Projected increases in sea level rise are lower under a very low emissions scenario (SSP1-2.6), with a 0.2m median rise for mid-century, and a 0.4-0.5m rise by the end of the century (IPCC Interactive Atlas, CMIP6). For small islands, storm surges and waves will exacerbate coastal inundation and shorelines will retreat along sandy coasts of most small islands (IPCC, 2021).

The risk of coastal flooding in low-lying areas and erosion along most sandy coasts will increase in the future as a result of continued relative sea level rise across the region (IPCC Interactive Atlas). Between 1984 – 2015, the continent as a whole has experienced net erosion and shoreline retreat. While ESAF has experienced a shoreline growth rate of 0.1m per year (IPCC, 2021) and specific locations in Oranjemund in Namibia and the south coast of Madagascar represent some of the highest sandy beach accretion hotspots globally (Luijendijk et al. 2018), the eastern coast of South Africa, with low coastal plains and sandy beaches, is recognised as vulnerable to flooding and erosion caused by cyclonic weather events and large waves (Mather and Stretch, 2012).

Sea surface temperatures will increase in the coming decades around Madagascar, Mauritius and the Comoros and Seychelles Islands as well as the Southern African coast. Average SSTs, which range from 22-26°C around the northern and western coasts of Madagascar, and for Mauritius, the Comoros and Seychelles islands (OSTIA climatology[5]) during austral summer. By the 2050s and under a very high emissions scenario, SSTs around Madagascar are projected to increase by 1.4°C, by 1.3°C for Mauritius and the Comoros Islands, and by 1.5°C for the Seychelles, relative to 1981-2010. SSTs, which are around 15°C along the western coastline during austral summer (OSTIA climatology), around 20°C along South Africa's eastern coastline, and around 26°C along Mozambique's coastline during austral summer (OSTIA climatology), are projected to increase by 1.4°C by the 2050s, under a very high emissions scenario, relative to 1981-2010 and to continue to increase in the coming decades. The ocean will continue to acidify, a process which causes changes in seawater chemistry, with negative implications for a variety of marine organisms. The frequency of marine heatwaves (periods of extremely high ocean temperatures which negatively impact marine ecosystems) doubled and increased in intensity along the southern African coastline from 1982-2016. These will further increase in frequency, intensity, spatial extent and duration for all coastal zones (IPCC, 2021).

For eastern Southern Africa and Madagascar, there is medium confidence that the number of intense tropical cyclones (category 4-5) will increase over the 21st century, with higher wind speeds and more intense rainfall. These projections apply to the small island regions but are associated with substantial variability due to the projected regional shifts in storm tracks. The overall frequency of tropical cyclones making landfall over eastern Southern Africa and Madagascar is projected to decrease (IPCC, 2021).

---

5 https://ghrsst-pp.metoffice.gov.uk/ostia-website/index.html

Met Office Hadley Centre ODI UK aid from the British people
© Crown Copyright 2022, Met Office

2.3 Climate analysis by zone

To assess the magnitude and direction of projected climate trends at a sub-regional scale the region is divided into nine sub-regional spatial analysis zones that reflect the different climate types, as shown in Figure 6. The projected trends in these zones are summarised in

Table 1. Further detail on the selection of zones and the zonal climate analysis is provided in Section D of the Technical Reference Document.

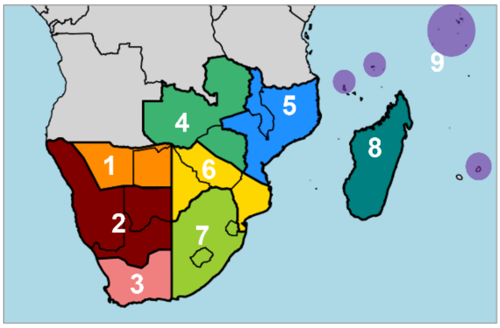


Figure 6: The nine spatial analysis zones across the Southern Africa region

Table 1: Summary of the zonal analysis for Southern Africa. More detail is provided in Section D of the Technical Reference Document.

Zone	Countries included	Current climate type	Future projections for the 2050s: headline messages
Zone 1	North-eastern Namibia and north-western Botswana	Semi-arid climate	• Annual mean temperatures will increase. • Some evidence that the zone will become drier on average. • Droughts likely to be longer and more frequent. • Heavy rainfall events will become more intense.
Zone 2	North-western and southern Namibia, south-western Botswana and northern South Africa	Hot desert climate	• Annual mean temperatures will increase. • The zone will be drier on average. • Droughts likely to be longer and more frequent. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase.
Zone 3	South-western South Africa	Semi-arid climate	• Annual mean temperatures will increase. • The zone will be drier on average. • Droughts likely to be longer and more frequent. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase.
Zone 4	Zambia and north-eastern Zimbabwe	Temperate climate	• Annual mean temperatures will increase. • Some evidence for a decrease in seasonal rainfall at the start of the rainy season. • Heavy rainfall events will become more intense.
Zone 5	Malawi and northern Mozambique	Tropical climate	• Annual mean temperatures will increase. • Some evidence for a decrease in seasonal rainfall at the start of the rainy season.

© Crown Copyright 2022, Met Office

			• Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase. • Tropical cyclone wind speeds and associated heavy rainfall likely to increase.
Zone 6	Southern Zimbabwe, western Botswana and southern Mozambique	Semi-arid climate	• Annual mean temperatures will increase. • Some evidence for a decrease in seasonal rainfall at the start of the rainy season. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase. • Tropical cyclone wind speeds and associated heavy rainfall likely to increase.
Zone 7	Eastern South Africa, Lesotho and Eswatini	Temperate climate	• Annual mean temperatures will increase. • Some evidence for a decrease in seasonal rainfall at the start of the rainy season. • Heavy rainfall events will become more intense. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase.
Zone 8	Madagascar	Mostly tropical climate with some temperate climate in the east and some semi-arid climate in the south	• Annual mean temperatures will increase. • Some evidence for a decrease in seasonal rainfall at the start of the rainy season. • Heavy rainfall events will become more intense • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase. • Tropical cyclone wind speeds and associated heavy rainfall likely to increase.
Zone 9	Comoros, Seychelles and Mauritius	Tropical maritime climate	• Annual mean temperatures will increase. • Medium confidence for less rainfall particularly from June to August. • Sea levels, sea surface temperatures, marine heat waves and ocean acidity will increase. • Tropical cyclone wind speeds and associated heavy rainfall likely to increase. Future storm track and landfall locations are uncertain.

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Image location: Lesotho

© Crown Copyright 2022, Met Office

3 Climate risk impacts and interpretation for the Southern Africa region

This section examines some key climate risks relevant to development themes. The themes analysed include agriculture and food security (3.1), water resources and water-dependent services (3.2), environment, terrestrial forests, ecosystems and biodiversity (3.3), infrastructure and settlements (3.4), health (3.5) and coastal fisheries and the marine environment.

3.1 Agriculture and food security

<u>**Summary of risks relevant to agriculture and food security**</u>

- Greater rainfall variability, more extremes and rising temperatures will have broadly negative impacts on agricultural yields, output variability, prices and food security. Pest populations may also increase, with adverse effects on output variability and yields as well as the costs of control.
- Increasing average and extreme temperatures will increase periodic heat and water stress for important staples such as maize and wheat, reducing yields, while increases in heavy rainfall may damage crops, cause waterlogging and threaten storage and processing.
- Projected increases in average temperatures and heat extremes will affect pastoral and agropastoral systems through heat stress to animals, impacts on pasture and fodder, water needs and access, disease vectors and livestock mobility. Vulnerabilities will be intensified and possibilities for adaptations limited by land use changes that restrict mobility and access to water and pasture.
- Rising water temperatures and changing seasonal flood patterns will reduce the productivity of inland fisheries. Vulnerabilities will be intensified by other pressures on lakes and rivers such as deforestation, agricultural and urban development, and pollution.

3.1.1 Context

Agricultural production (including forestry and fishing) is an important source of employment across Southern Africa, but accounts for a relatively low proportion (an average of 12% in 2020) of national GDP (World Bank, 2022). Contribution to national GDP from the agriculture ranges from 2-3% in Botswana, Seychelles, Zambia, South Africa, and Mauritius to 8-9% in Zimbabwe, Eswatini and Namibia, to 23-26% in Malawi, Madagascar, and Mozambique, and 37% in Comoros (World Bank 2020 data – see Technical Reference, Section E). However, agriculture as employer or source of income means it is a significant sector impacting on substantial numbers of people. In many countries in the region – especially Malawi (76%),

© Crown Copyright 2022, Met Office

Mozambique (70%), Zimbabwe (66%), Madagascar (64%), and Zambia (50%) – rates of agricultural employment as a proportion of total employment in the region highlight the sector's importance to peoples' livelihoods (World Bank, 2022).

Southern Africa is characterised by a diverse range of agricultural systems: agropastoral, pastoral, and maize-mixed systems cover the largest areas of the region (see Figure 7) (Dixon et al., 2020a). Inland fisheries in lakes and rivers also play a key role in providing food and income, particularly for poorer households (Dixon et al., 2020a,b). Projected climatic changes will present different types of risks across these different systems, across the region and within individual countries.

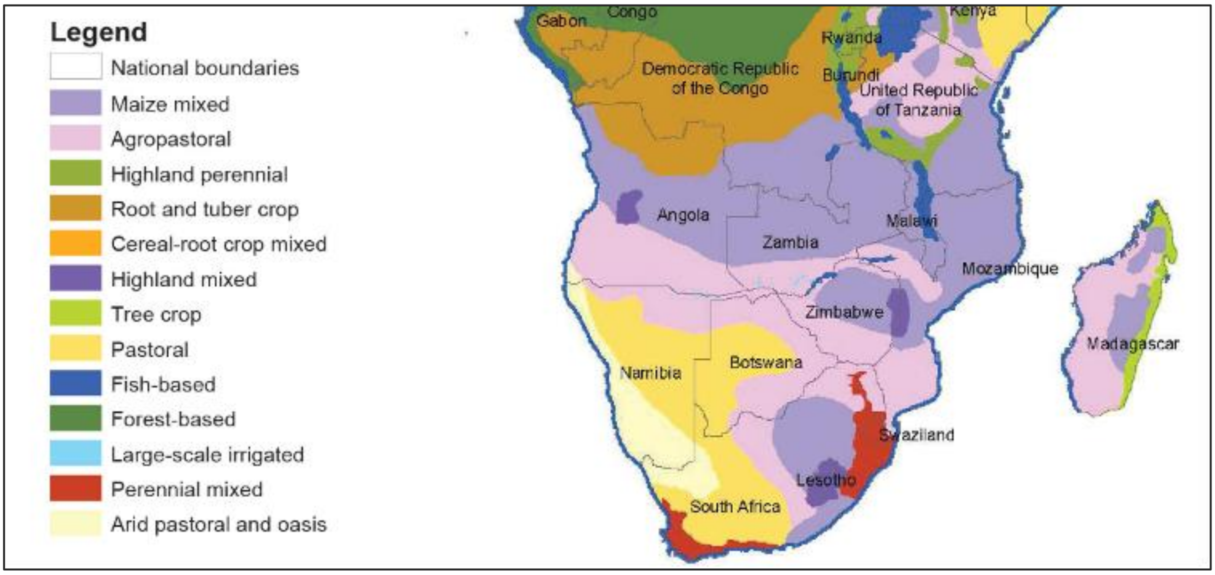


Figure 7: Agricultural systems in Southern Africa. Source: Dixon et al., 2020a.

3.1.2 Farming systems and livelihoods

Detrimental effects on cultivation, including important food crops, are already occurring in Southern Africa due to increases in temperature. Agriculture in Southern Africa is predominantly rainfed, making it vulnerable to climatic variability and change. Climate change poses risks to farming systems and livelihoods via increasing average and maximum temperatures, water stress and changing rainfall patterns. Climate change has already reduced total agricultural productivity growth in Africa by 34% since 1961, more than in any other region (Ortiz-Bobea et al., 2021). In sub-Saharan Africa, maize yields have decreased 5.8% and wheat yields 2.3%, on average, due to climate change in the period 1974–2008 (Ray et al., 2019). Rising levels of atmospheric CO_2 may mitigate some of these losses over the coming decades by promoting plant growth, but there is considerable uncertainty about the exact nature of the CO_2 response (Hasegawa, 2021).

Declines in areas suitable for cereal production and further reductions in cereal productivity are likely to continue due to rising temperatures across Southern Africa (Mapfumo et al., 2014; Adhikari et al., 2015; Stevens and Madani, 2016; Chapman et al., 2020). Wheat and maize are particularly sensitive to rising temperatures (Adhikari et al., 2015), and where temperatures exceed 30-35°C for long periods, maize will fare worse than more heat-tolerant staples such as millet and sorghum (Thornton and Cramer, 2012; Adhikari et al.,

© Crown Copyright 2022, Met Office

2015; Hadebe et al., 2017). Warming and elevated CO_2 may also reduce the nutritional content of some crops. By 2050 under a high emissions scenario overall wheat yields and grain protein content may decrease by over 15% in Southern Africa (Asseng et al., 2019).

Crop production will vary *within* countries as an impact of climate change. For example, north-eastern Namibia could see a 20% reduction in cereal yields while the north-central region could see a reduction of 50% (World Bank, 2021d). Irregular rainfall and droughts already affect crop production and have contributed to food security crises via declining cereal production in Zambia, Madagascar, and Eswatini, where cereal production declined by nearly 20% in 2019-2020 (USAID 2016d; World Bank 2021b; FSIN and GNAFC, 2021). The 2015 El Niño drought in Southern Africa severely affected maize and wheat production, contributing to a regional cereal deficit of nearly eight million tonnes in 2015-2016 (Davis-Reddy and Vincent, 2017).

Root crops (e.g., sweet potato, cassava) may be less affected than grain crops by temperature increases (Jarvis et al., 2012; Adhikari et al., 2015; Adjei-Nsiah et al., 2020). However, cassava is not well-adapted to excess water, so projected increases in flooding across Southern Africa present risks to production, and prolonged drought may result in reduced yields (Thornton and Cramer, 2012; Adhikari et al., 2015).

Regional cash crops (e.g., tobacco, cotton, tea, sugarcane, sunflower) are also likely to be negatively impacted by rising temperatures. Cotton can tolerate high temperatures, but yields may decline if those temperatures are sustained over long periods (Adhikari et al., 2015). Tea yields are expected to decline as rising temperatures reduce areas suitable for production, especially in lowlands, driving shifts toward higher altitudes (Adhikari et al., 2015; Davis-Reddy and Vincent, 2017). Sugarcane yields may also decline as rising temperature reduces areas suitable for cultivation, with temperatures above 35°C detrimental to plant growth (Adhikari et al., 2015). Sunflower production in Botswana is also likely to be negatively affected (Trisos et al, 2022).

Growing seasons are likely to be affected by increased water stress as a result of rising temperatures and changing rainfall patterns across Southern Africa**.** Higher temperatures lead to increased evapotranspiration and reductions in soil moisture, increasing plant water requirements and irrigation needs. Projected drier conditions in semi-arid and desert regions of Botswana, Namibia and South Africa will increase the likelihood of longer and more frequent droughts. Increases in year-to-year variability in rainfall in all zones will affect planting seasons and crop development and lead to less predictable growing seasons. Decreases in seasonal rainfall at the start of the rainy season in Zambia, Zimbabwe, Malawi, Mozambique and Madagascar may negatively impact cultivation systems by shortening growing seasons and increasing water requirements (USAID, 2016b; World Bank 2021b; Trisos et al., 2022).

Irrigation can help buffer rainfall variability, but its high water consumption can bring unforeseen risks. Flood-based farming such as floodplain/flood recession agriculture in the Zambezi River basin (Midgley et al., 2012b, 2012c) is less dependent on local rainfall variability. However, water access will be affected by changes in river flows, lake levels and flood dynamics linked to seasonal rainfall patterns and rainfall extremes. State projects and large commercial schemes that divert water from rivers or tap groundwater storage can increase and stabilise agricultural production and incomes. But they may also end up competing for existing or planned water uses, especially when demand and supply scenarios are based on average water availability that fails to account for variable (peak) demands, and increasingly variable supply (Siderius et al, 2021). Hence the risk that intensive basin

© Crown Copyright 2022, Met Office

development, such as that envisaged for the Shire River in Malawi (more hydropower, more irrigation), creates 'stranded assets' that will not meet performance targets under future climate and development scenarios (Bhave et al, 2020; 2022).[6] Farmer-financed irrigation, often from groundwater storage, is accelerating in some countries (e.g. Zambia, Malawi, Zimbabwe) but remains largely unrecorded and unregulated (Wiggins and Lankford, 2019).

Soil erosion, damage to crops and crop losses will increase as a result of more frequent and intense rainfall events. Different crops have different levels of tolerance to waterlogging. While some (e.g., sorghum) are resilient, others (including maize and millet) are far less tolerant (Hadebe et al., 2017). Flooding linked to heavy rainfall or tropical cyclones already causes widespread damage to crops in Zambia, Zimbabwe, Mozambique, and Madagascar, contributing to reduced cereal production and food insecurity (FSIN and GNAFC, 2021). In 2020, Zimbabwe's cereal production was nearly 13% below the five-year average due to flooding and dry spells (FSIN and GNAFC, 2021). A 30% decline in maize harvests in Malawi in 2014-2015 was attributed in part to late-onset rains during the growing season followed by heavy rain and flooding (Stevens and Madani, 2016).

Crop damage and damage to agricultural infrastructure and supply chains will result from projected increases in the intensity of tropical cyclone winds in Mozambique, Malawi, Botswana, Zimbabwe, Madagascar, Comoros, Seychelles and Mauritius. These hazards already impact cultivation in these regions. In 2019, Tropical Cyclone Idai led to the flooding of at least 715,000 hectares of cultivated land in Mozambique, affecting over 430,000 farming households, and destroyed crops, seed stores, and agriculture and irrigation infrastructure (Government of Mozambique, 2019).

Insect and plant disease driven agricultural losses may increase as rainfall patterns change and temperatures increase. More frequent fall armyworm infestations in Eswatini, Malawi, Zambia, Zimbabwe, and Madagascar and locust outbreaks in Zambia and Zimbabwe already contribute to food security crises, with delayed rainfall and high temperatures enabling pests to flourish (FSIN and GNAFC, 2021). Suitable conditions for the corn leafhopper, a maize pest, may increase in parts of South Africa due to rising temperatures – although given its upper thermal threshold of 30°C, other parts of the region may become less suitable (Santana et al., 2019). In Mozambique, the fall armyworm, which can cause significant losses to maize crops, increases in population density and infestation in the dry season (Caniço et al., 2020). Warmer temperatures may increase larval development among some pests. For example, in Botswana larval development periods in fruit flies accelerated at 35°C (Motswagole et al., 2019). Across sub-Saharan Africa, pests and diseases already contribute between 10-35% of yield losses for key staples (Savary et al, 2019).

The tolerance thresholds for some agricultural pests may be exceeded by rising temperatures. For example, temperature increases may reduce the range of the tomato red spider mite in Southern Africa (Meynard et al., 2013). Projected increases in intense rainfall

[6] Bhave et al (2022) conclude that deep uncertainty around future rainfall projections in the Lake Malawi-Shire River system generates a wide range of outcomes, including no lake outflow and a higher frequency of major downstream floods. However, irrigation expansion in Lake Malawi catchments would likely increase the risk of very low lake levels and downstream risks to hydropower and irrigation. Improved regulation of lake outflows through the upgraded barrage offers some risk mitigation but trade-offs still emerge.

© Crown Copyright 2022, Met Office

events may also reduce pest populations by washing away eggs and larvae (Caniço et al., 2020).

Agricultural livelihoods, productivity, and vulnerabilities in Southern Africa are affected not only by climate change but also by wider sectoral conditions. These include inadequate infrastructure (e.g., irrigation, transport), limited extension services and technological innovation, and low farming incomes (Hachigonta et al., 2013; Mapfumo et al., 2014; USAID, 2016a, 2016c; Davis-Reddy and Vincent, 2017; World Bank, 2021a). In Mozambique, violent conflict has also affected agricultural production through loss of access to agricultural land and crops due to displacement and restrictions on movement (FSIN and GNAFC, 2021). Future risks to agricultural livelihoods will be shaped by the interaction of climatic changes and broader political and economic factors.

3.1.3 Pastoral and agro-pastoral livelihoods

Pastoralism and livestock are important for rural economies and food security in Southern Africa (see Figure 7 above). Livestock numbers are highest in South Africa, Malawi, Zimbabwe, and Madagascar. In Botswana and Namibia, livestock accounts for 70-90% of all agricultural production value, and roughly 80% of rural populations in Botswana depend on livestock production as their main livelihood source (Syed and Gomes, 2022). Livestock also serve an important 'insurance' function for farmers reliant on rainfed cultivation via sales of livestock in cases of crop failures (Hachigonta et al., 2013; Hänke and Barkmann, 2017).

Climate change will negatively affect regional livestock sectors through impacts on fodder availability and quality, livestock food supply chains, access to drinking water, direct heat-induced physical stress, prevalence of livestock diseases, and livestock mobility (Assan, 2014; Mapfumo et al., 2014; de Leeuw et al., 2020; Magiri et al., 2021; Trisos et al., 2022).

Livestock health and mortality, impaired livestock reproduction and milk production, and increases in drinking water needs will result from heat stress caused by rising temperatures (Thornton and Cramer, 2012; Sejian et al., 2021). The strongest warming is projected for eastern Namibia, Botswana, and Mozambique where pastoral and agropastoral livelihoods are prominent. In Namibia, climatic changes could lead to a 15-35% decline in livestock carrying capacity in north-central areas and cattle numbers could drop by over 50% by 2080 (World Bank, 2021d). European breeds of cattle are favoured in Namibia due to their higher market value but are not as resistant to high temperatures (World Bank, 2021d). Changes in breed types may be required to adapt, with implications for market share. Although goats are better able to cope with heat stress, animal health and reproduction are likely to be reduced as temperatures increase (Thornton and Cramer, 2012; Mapfumo et al., 2014; Sejian et al., 2021).

Livestock feed crops and availability of pasture and drinking water will be negatively affected through rising temperatures, combined with increases in year-to-year rainfall variability – and increasing risks of drought in Namibia, Botswana and South Africa. Negative impacts on fodder availability arising from reductions in rangeland net primary productivity (NPP)[7] are projected in most modelling studies. Under 2.4˚C global warming (RCP8.5), NPP is projected to decline by 37% in Southern Africa by 2050 compared to a 2000 baseline (Boone et al, 2018).

---

[7] NPP is a measure of biomass production per unit area over time.

© Crown Copyright 2022, Met Office

The risk of livestock disease outbreaks may also increase with rainfall and temperature changes. Increased temperature and rainfall changes already contribute to the expanding range of tick species that carry livestock diseases in Southern Africa (Trisos et al., 2022). Livestock diseases present significant economic risks. In Zambia and Malawi, the annual cost of East Coast fever, a disease affecting cattle, has been estimated at USD 48.8 and USD 2.6 million, respectively (Bouley and Plante, 2014). At the same time, temperature and rainfall changes may result in declining habitats for some disease vectors, such as brown ear ticks (which cause East Coast fever) in areas such as south-eastern Zimbabwe and southern Mozambique (Mapfumo et al., 2014).

Losses of feed crops and stores, and displacement and death of livestock will result from increases in the intensity of heavy rainfall events and flooding. In 2019, Tropical Cyclone Idai led to the death of tens of thousands of poultry and livestock and destroyed pasture and feed as well as livestock infrastructure (Government of Mozambique, 2019). Extreme rainfall affects forage yield, perhaps more than any other changes to average annual precipitation (de Leeuw et al., 2020), and may also negatively affect the quality of water sources (e.g., through runoff).

Pastoralists already face political and economic obstacles that restrict their mobility and access to water and pasture, and limit possibilities for adaptations to climatic changes. These include changes in land tenure, enclosure and fragmentation of formerly open land (including for agricultural and conservation purposes), and limited access to veterinary services (Chakoma, 2012; Mapfumo et al., 2014; Cumming et al., 2015). These also limit possibilities for adaptations to climatic changes, including through access to new pasture or water sources. Policies and development interventions have also tended to favour crop-based agriculture and sedentary livestock production at the expense of pastoral livelihoods and mobility rights (Boffa et al., 2020; de Leeuw et al., 2020). However, rising temperatures and effects on pasture and water resources may also put sedentary livestock raising at risk.

3.1.4 Freshwater fisheries

Inland fisheries provide an important food and livelihood source in Southern Africa. In 2020, inland fisheries and aquaculture production reached over 17,000 tonnes in Madagascar, over 34,000 tonnes in Zimbabwe, over 100,000 tonnes in Mozambique, over 152,000 tonnes in Zambia, and over 180,000 tonnes in Malawi (FAO, 2021). In Malawi, small-scale inland fisheries account for more than 90% of national fish supplies and 60-70% of animal protein consumption (Midgley et al., 2012a; Simmance et al., 2021). Freshwater catches are underreported and may be up to 65% higher than official figures (Fluet-Chouinard et al., 2018). Inland fisheries include floodplain-based systems and lake-based systems (Hamerlynck et al., 2020). Lake-based fisheries include Lake Mweru in Zambia, Lake Malawi and Lake Chilwa in Malawi, and Lake Kariba between Zambia and Zimbabwe. Floodplain fisheries include the Okavango River and Okavango Delta, and the Zambezi River and its tributaries.

Fish populations will be negatively impacted by an increase in the temperature of freshwater bodies. This may adversely impact Southern African fish stocks through direct negative impacts on growth, metabolism, reproduction, health, and mortality, as well as changes in migration patterns (Muringai et al., 2022a,b). Higher water temperatures also reduce oxygen content and vertical mixing of the water column, negatively affecting aquatic biodiversity, habitats, and water quality and in turn fish health and stocks (Mapfumo et al., 2014; Muringai et al., 2022b). Effects of thermal stratification are more pronounced in deep

© Crown Copyright 2022, Met Office

lakes such as Lake Malawi (Ogutu-Ohwayo et al., 2016; Muringai et al., 2022b). In Lake Kariba, increasing temperatures and evaporation, decreased rainfall, and changing water levels have already contributed to declining fish catches (Ndebele-Murisa et al., 2011). Higher water temperatures may also lead to a decline in plankton, an important fish food source (Mapfumo et al., 2014; Muringai et al., 2022b). In Lake Malawi and Lake Kariba, rising temperatures have already been linked to declining phytoplankton productivity (Magadza, 2011; Ndebele-Murisa et al., 2012), although warming temperatures may also contribute to *increased* phytoplankton productivity (Marshall, 2017).

Loss of suitable habitats and disruption of fisheries will occur through reduced inundation of seasonally flooded wetlands from higher temperatures and evapotranspiration. Drying conditions and more frequent/intense droughts may contribute to declining lake levels and reduced river flows and runoff across Southern Africa (including in major river systems such as the Zambezi), and in turn to reduced biodiversity and fish productivity (Simmance et al., 2021; Mapfumo et al., 2014; Muringai et al., 2022b). Rising surface temperatures and evapotranspiration and changing surface inflows have already reduced fish catches in Zimbabwe's Lake Chivero (Utete et al., 2018). Changing flood patterns in wetlands such as the Okavango Delta may affect fisheries through impacts on fish food sources (i.e., microcrustaceans) (Siziba et al., 2011, 2013). Changes in seasonal flood patterns and intensity could contribute to declines in wetland productivity.

River and lake systems will face increased risks of flooding, erosion, sediment input and pollution due to increased heavy rainfall events. Erosion of riverbanks and shorelines from heavy rainfall, and resultant sediment deposits can contribute to shallower waters, in turn affecting water temperatures. Floods also cause damage to fishing equipment and infrastructure, loss of fishing days, and danger to life (Muringai et al., 2022b).

Risks to inland fisheries associated with climatic change will interact with and be intensified by the impacts of other human activities. Changes in lake and river systems in Southern Africa are being driven by deforestation and land clearance for agricultural expansion and settlement, resulting in soil erosion and siltation, and agricultural and urban pollution (Palamuleni et al., 2011; Utete et al., 2018; Chemura et al., 2020; Pullanikkatil et al., 2020; Makwinja et al., 2021a, 2021b, 2021c; Nkwanda et al., 2021; Sibanda and Ahmed, 2021; Simmance et al., 2021). Fish stocks are also impacted by fisheries intensification and overexploitation (Weyl et al., 2010; Bell et al., 2012; Marshall, 2012; Tweddle et al., 2015). For example, changes to fishing livelihoods in the Okavango Delta are determined by a combination of flooding variability, fishing regulations, and social relations tied to gender and ethnicity, rather than climate change alone (Shinn and Hall-Reinhard, 2019).

3.1.5 Food security

Links between climate change and broader food security are more difficult to predict because pathways are complex. Food security[8] is shaped by access to and uptake of food, not just production and availability. Nonetheless, most studies to date have focused on output and output variability only (Trisos et al, 2022). Food security may be threatened by a

[8] Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). For further information on the four dimensions of food security flagged here (availability, access, utilisation and stability), see: https://www.worldbank.org/en/topic/agriculture/brief/food-security-update/what-is-food-security

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

combination of (1) declining output and availability; (2) lower access due to declining household incomes and price variability; (3) changing uptake/utilisation of food within the body affected by (for example) disease; and (4) lower stability as a result of more variable output, prices, and incomes. Untangling the climate signal across each of these four areas is difficult, but a growing body of evidence indicates that yield losses are likely to translate into higher agricultural prices and much greater output and price volatility. These impacts will, in turn, affect the purchasing power and real income of households (Hallegatte et al, 2016).

In 2019, more than half of the populations of Botswana, Namibia, Zambia, Zimbabwe, Malawi, Mozambique, Eswatini, and Lesotho (ranging from 50% in Lesotho to 82% in Malawi) faced moderate or severe levels of food insecurity driven by a combination of weather extremes, pests and disease, economic-income shocks and conflict and insecurity (FAOSTAT, 2022). In Eswatini, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Zambia, and Zimbabwe, 30 to 50% of assessed populations experienced crisis-level food insecurity or worse in 2020 (FSIN and GNAFC, 2021). Across Southern Africa, food security crises are driven by a combination of weather extremes (e.g., drought, heavy rains, floods), agricultural pests and diseases, and economic-income shocks (linked to COVID-19 restrictions, border closures, and rising food prices), as well as conflict and insecurity in Mozambique (FSIN and GNAFC, 2021).

The impacts of production and price volatility on poverty will depend on how vulnerable households make a living. Net sellers of food and those dependent on agricultural wages *may* benefit, though much depends on the interplay between prices, output and incomes. Net consumers of food will be harmed, while those who depend on agricultural wages and profits are likely to experience mixed impacts. Poorer consumers – the growing numbers of households living in informal urban settlements and subsistence-orientated[9] farmers who struggle to feed themselves from own production – will be worst affected (Hallegatte, 2016). Poorer urban households typically spend 40% or more of their incomes on food (Wiggins, 2022).

Changes in food production, consumption and security will be shaped by climate change, increasing urbanisation and import reliance. These include shifts away from agricultural livelihoods and increased consumption of processed and imported foods – trends already observable in Southern Africa (Tschirley et al., 2014; Boffa et al., 2020; WFP, 2021). Some countries in the region are highly reliant on food imports. In 2016-2018, cereal import dependency ratios (ratio of imported vs domestically produced food supplies) reached nearly 70% in Eswatini and Namibia, 75% in Lesotho, 81% in Comoros, 84% in Botswana, 95% in Mauritius and 100% in Seychelles (FAOSTAT, 2022 – see Section E of the Technical Reference Document). In the short term, rising global food prices may undermine economic performance and affect those on low incomes, though major regional producers (notably South Africa) may step up production to meet demand.[10]

[9] Smallholders who depend on a single rainy season for most of their staple food needs and practise low input, low output agriculture. Their farming is subsistence-orientated, but they are not 'subsistence' farmers because they rely on diversified sources of income and because they struggle to achieve self-sufficiency in most years (Devereux, 2009; Ellis, 2013).
[10] Rising commodity prices generally, including imported wheat, maize and fertilisers, will tend to raise domestic prices in the countries that import them, potentially affecting poorer consumers. For some

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

Links between climate-induced ecosystem change, food security and poverty have not been systematically assessed but are likely to be important. Poorer rural households are more likely to depend on foraging and wild foods to meet food and income needs, smoothing consumption between season and years. For example, harvesting of edible non-timber forest products (e.g., fruits) is a coping mechanism among poorer farmers in response to climatic shocks in Zimbabwe (Woittiez et al., 2013). Incomes from resource stocks that grow *continuously* over years (e.g. timber and fish) also play a key 'buffering' role as they are less sensitive to weather fluctuations than those that depend on annual cycles, like crops (Naidoo et al, 2013; Hallegatte, 2016). Although the safety net function of ecosystems is well-known, few studies have looked at links between climate-induced ecosystem change and poverty.

farmers, higher prices may present an opportunity if local consumers switch from increasingly expensive imported wheat to locally grown staples. Higher fertiliser prices could see farmers use less, affecting production, though many poorer farmers in sub-Saharan Africa use little or no mineral fertiliser (Wiggins, 2020).

© Crown Copyright 2022, Met Office

3.2 Water resources and water-dependent services

Summary of risks relevant to water and water-dependent services

- Rising temperatures, declining rainfall in the south-west and greater rainfall variability will increase periodic water scarcity and flooding, with areas experiencing wet and dry extremes at different times. This makes water management more difficult.
- Reliance on groundwater as a source of climate-resilient drinking water may increase as river flows become more variable. Large numbers of people still do not have access to safe water and sanitation, increasing their exposure to climate hazards.
- Rising temperatures and more frequent and intense rainfall events will have negative impacts on water quality, increasing pollution and sediment loads, and increasing threats to health in rural and urban areas.
- Greater rainfall variability and drought will further disrupt hydropower generation, with periods of low rainfall and river flow potentially affecting multiple countries with concurrent reductions in electricity production.

3.2.1 Context

Southern Africa's freshwater resources are distributed very unevenly between areas and over time. High intra-annual and multi-annual rainfall variability results in many areas experiencing large variations year-on-year, much greater than in the more temperate climate of Central Africa (Conway et al, 2009; Foster and Garmendia, 2010; Conway et al, 2017). Variability and uncertainty in rainfall make water management adaptation more difficult (Damania et al, 2017; Caretta et al, 2022). Together with relatively low runoff, it also explains why there are few perennial rivers, and the importance of groundwater in meeting dispersed rural demand (Taylor et al, 2013; MacDonald et al, 2021).

With the exception of South Africa, all countries in Southern Africa fall within the low or no 'water stress' categories used for monitoring SDG 6.4.2[11], highlighting low (overall) water use on average relative to availability. South Africa falls within the 'medium stress' category, withdrawing roughly 64% of its renewable water/year (see Section E of the Technical Reference Document for data and definitions). These are averages, however, and do not account for peaks and troughs over time linked to seasonality, increasingly frequent droughts and floods, and the presence of basin 'hot spots' where rivers have been intensively developed for urban, industrial and agricultural users. Hydropower is another major user, though its *consumptive* water use is limited.[12]

[11] Water stress: water withdrawals as a percentage of available (renewable) water. FAO (2018) data.
[12] Good water accounting makes a distinction between water withdrawals, consumption and return flows. Although evaporation from hydropower lakes/reservoirs can be significant, most stored water is returned to the basin downstream of dams and turbines. The biggest consumptive use of water, in terms of water 'lost' to evapotranspiration, is typically agriculture (Perry, 2011).

© Crown Copyright 2022, Met Office

Low per capita water withdrawals reflect limited investment in water development, surface storage and distribution for key economic and social sectors (ADB, 2016). This is mainly because the big water-withdrawing sectors, particularly irrigation, remain under-developed (ADB, 2016; Calow et al, 2018). For example, although water control is vital for agriculture, providing insurance against rainfall variability, only around 5% of the region's cultivated land is irrigated, mostly in Madagascar and South Africa (FAO, 2018).

In the sections below, we look at risks across three areas: water resources and water quality; rural water supply and sanitation; and electricity generation from hydropower. Urban water supply and sanitation, and risks to other types of power, are addressed under Infrastructure and Settlements (3.4).

3.2.2 Water resources – availability and quality

Water resources in Southern Africa will be negatively affected by changes to the hydrological cycle in the form of amplified rainfall variability, greater fluctuations in lake levels and river flows, and more severe droughts and floods. Across the region risks are expected to increase with every degree of global warming (Caretta et al, 2022). In river basins that are already water-stressed, such as the Limpopo, Zambezi, Orange and Okavango, greater flow variability will increase allocation tensions between different uses and users. The Limpopo Basin, in particular, is already notable for having both high economic productivity and strong ENSO associations. The basin, shared between South Africa, Botswana, Mozambique and Zimbabwe, includes major urban centres, irrigation schemes, industry and mining operations competing for shared flows (Conway et al, 2015).[13]

***Overall* surface water availability in river basins may be reduced by rising temperatures and higher rates of evapotranspiration**. Annual rainfall totals will continue to decline in south-west of South Africa and western Namibia through to the 2050s (see Section 2), further reducing water availability in this region. However, much will also depend on catchment conditions, particularly land use and vegetation cover.

Water management will be more difficult as a result of greater variability in rainfall (including more frequent and severe floods and droughts) and through contamination of water supplies during flood events. Greater variability and scarcity in surface water systems will increase dependence on groundwater for urban and rural supply (Calow et al, 2018; Cuthbert et al, 2019; Foster et al, 2020). Making better use of water storage, from surface impoundments and especially groundwater aquifers, will become more critical for supply security. Groundwater stored in aquifers (see below) offers sustainable, decentralised and cost-effective solutions for climate change adaptation, at the scale of specific cities, their hinterland catchments and across rural areas (Foster et al, 2020).[14] At the same time, 'hidden' transfers of water that occur through regional and international food trade will likely grow in

[13] Including the cities of Pretoria, Johannesburg, Gaborone, Francistown Bulawayo. Irrigation still accounts for over 50% of basin withdrawals (Conway et al, 2015).
[14] The smaller island states of Seychelles, Comoros and Mauritius also depend on groundwater to varying degrees. The Seychelles relies mainly on surface water, supplemented by groundwater and desalination to meet dry season shortfalls. The islands of the Comoros rely on a mix of rainwater harvesting, surface water and groundwater. Groundwater is the main source of water in Mauritius.

© Crown Copyright 2022, Met Office

importance – balancing out annual and interannual fluctuations in food *and* water availability (Conway et al, 2015).[15]

Groundwater resources are more resilient than surface water resources, and periodic recharge from heavy rainfall events may compensate for reductions in average rainfall (Caretta et al, 2022; Trisos et al, 2022; Scanlon et al, 2022). Although the region's groundwater resources remain poorly characterised, a growing body of studies[16] highlight their significance in terms of spatial extent (compared with isolated rivers and lakes) and storage, with groundwater providing climate-resilient water supply at relatively low cost for millions of dispersed rural residents (Calow et al, 2018; Cobbing, 2020; MacDonald et al, 2021). In particular, the storage groundwater aquifers provide makes groundwater less sensitive to annual and multiannual rainfall variability. Moreover, even under the drying conditions projected for the south-west of Southern Africa, intense rainfall events can still produce substantial (episodic) groundwater recharge, challenging the model-driven consensus that drying climates will decrease water resources in most dry subtropical regions (Taylor et al, 2013; Cuthbert et al, 2019; MacDonald et al, 2021; Scanlon et al, 2022). That said, more research is still needed to understand exactly how much water can be sustainably withdrawn from storage as the climate changes.

Freshwater ecosystems and water quality will be negatively impacted by a combination of changes in streamflow (varying from future increases and future decreases) and rising temperatures (Cisneros et al, 2014; Caretta et al, 2022; Nijhawan and Howard, 2022). Higher water temperatures encourage algal blooms and increase risks from cyanotoxins and natural organic matter in water sources that pose health risks. Intense rainfall and flood events can also increase the load of fertilisers, human/animal wastes and particulates in water bodies, including in (better protected) groundwater systems. Periods of low streamflows, meanwhile, reduce the capacity of rivers to dilute, attenuate and remove pollution and sediment. Reductions in raw water quality pose serious risks to drinking water quality, even for conventional treatment in urban utilities (Howard et al, 2016; Calow et al, 2018). Although regional data are not available, we know that utilities across sub-Saharan Africa are struggling to meet demand, with access to (treated) piped water on premises declining from roughly 40% in 2000 to 33% in 2015 (van den Berg and Danilenko, 2017). Very few utilities provide wastewater services (van den Berg and Danilenko, 2017).

3.2.3 Rural water supply and sanitation

Secure water, sanitation and hygiene (WASH) provides a crucial buffer against climate variability. This is because access to safe water and sanitation reduces people's dependence on more climate-vulnerable, unprotected systems and practices, frees up time (particularly for woman and girls) for more productive activities, and plays a key role in improving long-term health and nutrition (Cumming and Cairncross, 2016; Howard et al, 2016; Calow et al, 2018).

Countries and areas with limited sanitation and safe water are most exposed to climate risks. An initial assessment of climate risk therefore needs to consider how countries and

---

[15] Trade of agricultural products corresponds to significant transfers of embedded water resources, or 'virtual' water trade (Allan, 1993). Water resources embedded in the regional food exports of South Africa and Zambia account for most (current) intraregional flows, mostly to Zimbabwe. However, the region as a whole is a net *importer* of virtual water (Conway et al, 2015).

[16] Including those using Gravity Recovery and Climate Experiment (GRACE) satellite data to assess spatiotemporal variability in water storage, and those drawing on (limited) ground-based monitoring. See Scanlon et al (2022) for the most recent review of the evidence.

© Crown Copyright 2022, Met Office

regions perform in terms of *extending* and *sustaining* services. There are significant differences across Southern Africa regarding access to at least *basic* services including drinking water, sanitation, and access to power (Table 2). Wealthier countries have the greatest access, with upper-middle- and high-income Botswana, Namibia, South Africa, Seychelles and Mauritius all achieving high coverage, albeit with big sanitation gaps in Namibia and Comoros. Exclude those wealthier countries and the figures drop significantly. Low-income Madagascar and Mozambique fare worst - populous countries (almost 60 million combined, over 60% rural) where the majority of rural people have no access to basic sanitation. Populations lacking these services are most exposed water contamination, the spread of disease and malnutrition, particularly after heavy rainfall and flood events.

Table 2: Population, WASH, electricity and hydropower data across the focus countries. Sources: Country classifications: L (low income), LM (low-middle income), UM (upper middle income) World Bank income classification 2023 fiscal year update. Population (2020 data): World Bank, World Development Indicators. Access to drinking water (DW) & sanitation (San) (2020 data): UNICEF/WHO 2021. Hydropower as a % of installed capacity (hydro instal cap): various sources. See Section E of the Technical Reference Document for further data and notes.

	Population		**DW Access**		**San Access**		**Elec Access**		**Hydro**
Country	Total (M)	Rural (%)	Total (%)	Rural (%)	Total (%)	Rural (%)	Total (%)	Rural (%)	Instal cap (%)
Zambia (L)	18.4	55	65	48	32	25	45	14	65
Malawi (L)	19.1	83	70	67	27	25	15	7	70
Mozambique (L)	31.2	63	63	49	37	23	31	5	80
Zimbabwe (LM)	14.8	68	63	48	35	32	53	37	65
Botswana (UM)	2.4	29	92	79	80	52	72	26	0
Namibia (UM	2.5	48	84	71	35	20	56	36	51
Eswatini (LM)	1.2	76	71	63	64	68	80	76	60
Lesotho (L)	2.1	71	72	64	50	52	47	35	95
South Africa (UM)	59.3	33	94	83	78	81	85	75	6
Madagascar (L)	27.7	61	53	36	12	8	34	11	18
Seychelles (UM)	0.1	43	97	97	100	100	100	100	0
Mauritius ((UM)	1.3	59	99	99	96	95	100	100	4
Comoros (LM)	0.8	71	80	77	36	32	87	81	4

The evidence linking WASH service outcomes with climate change is limited. This is because WASH programmes typically measure progress in terms of systems built rather than outcomes over time[17] (see ICAI, 2016; Calow et al, 2017). However, a growing body of evidence in sub-Saharan Africa points to sustainability issues, with somewhere between 10-65% of systems 'non-functional' at a given time.

Surveys conducted in Malawi and Mozambique indicate that **most water supply and water quality problems are attributable to poor design, siting, construction and maintenance rather than climate-driven changes in water availability** (Calow et al, 2018; Lapworth et al, 2020). A detailed audit conducted in Malawi, for example, found that only 41% of boreholes equipped with handpumps (the most common technology in rural areas) had adequate yield and reliability and also passed WHO guidelines for water quality. Roughly 20% of boreholes were contaminated with E. coli – a key but solvable problem during and after heavy rainfall events and floods (Mwuathunga et al, 2019; Lapworth et al, 2020). In Mozambique, the World

[17] In terms of access, service levels, behaviour change and sustainability.

© Crown Copyright 2022, Met Office

Bank estimate that roughly 35% of small village systems and boreholes with hand pumps are 'non-operational' at any one time (World Bank, 2017).

Groundwater resources *can* provide resilient supplies even during severe drought, confirmed by an audit of over 5000 water points in Ethiopia in the immediate aftermath of the 2015-16 El Niño drought (MacAllister et al, 2020). Well built and maintained boreholes, in particular, are able to tap water stored from historical rainfall events, not just the last wet season (Taylor et al, 2013; MacDonald et al, 2019; MacDonald et al, 2020). Protected springs and shallow wells are typically more vulnerable to both contamination and rainfall variability because they exploit shallower, less well protected aquifers (Calow et al, 2018; MacDonald et al, 2019; Lapworth et al, 2020). A key conclusion is that *most* existing technologies are resilient to climate change, provided systems are built and maintained to higher standards (Calow et al, 2017; MacAllister et al, 2020).

3.2.4 Hydropower

Access to electricity, often unreliable, averages 53% across Southern Africa, with coverage skewed heavily to urban areas Excluding upper-middle-income Botswana, Namibia, South Africa, Seychelles and Mauritius coverage falls to 35% overall and only 14% in rural areas, dropping to less than 10% in Malawi and Mozambique (World Bank 2020 data - see Table 2 and further data in Technical Reference).

Hydropower makes up a significant share of Southern Africa's electricity production and that share is growing. Across sub-Saharan Africa as a whole, hydropower accounts for over 70% of the renewable electricity budget and 15-20% of installed electricity capacity (Conway et al, 2017).[18] In some Southern African countries – Malawi, Mozambique, Namibia, Zambia, Lesotho – the proportion of renewable electricity from hydropower rises to 80% or more, and investment is increasing with funding from a mix of domestic and international sources (Conway et al, 2017; Brautigam and Huang, 2017). In Zambia for example, the 750 MW Kafue Gorge Lower hydropower project has recently been commissioned, and the 2,400 MW Batoka Gorge hydropower project, jointly owned by Zambia and Zimbabwe, is under construction. A key pillar of Mozambique's National Energy Masterplan (2018-2043), designed also to supply the Southern Africa Power Pool (SAPP), is the USD 4.5 billion, 1500 MW Mphanda Nkuwa hydropower project due to be operational by 2031 (ADB, 2022).

Periodic disruption to hydropower generation is widespread, and drought-related power outages will likely increase. Rainfall variability is already responsible for significant fluctuations in lake/reservoir levels and river flows on both short and long timescales, creating major challenges for water management and significant risks to hydropower generation. The economic costs of power outages generally have been estimated at 5-7% of GDP for Malawi and South Africa (Conway et al, 2017). Low rainfall and streamflow conditions during the 2015-16 El Niño led to concurrent power disruptions across Malawi, Tanzania, Zambia and Zimbabwe (Conway et al, 2017). In Zambia, inflows into Lake Kariba dropped to as low as 12% of capacity in January 2016, just above the minimum operating level for electricity production, leading to daily power outages (load shedding) and blackouts in Lusaka Province and the Copper Belt mining region of Zambia where most electricity is consumed (Gannon et

[18] Installed capacity is the maximum amount of electricity a power plant can produce under given conditions specified by the manufacturer. This amount is usually higher than a plant actually generates because of (for example) low river flows, repair and maintenance, or curtailment of electricity generation at times of limited demand.

© Crown Copyright 2022, Met Office

al, 2018; Conway et al, 2018). Flooding is also an issue because of threats to dam safety and over-topping (Conway et al, 2015).

Climate-related hydropower insecurity will become a critical source of economic and social risk across Southern Africa. Risks are amplified because over 70% of hydropower generation is concentrated in the Zambezi basin, a figure expected to reach almost 90% by 2030 – see Figure 8 (Conway et al, 2015, 2017; Hamududu and Killingtveit, 2016). This is an area of broadly similar rainfall variability where most studies point to drying conditions, more severe drought and greater inter-annual rainfall variability over the coming decades (see Section 2). However, there are few suitable hydropower sites in other regional basins which have not already been intensively developed, and all are likely to experience lower rainfall and/or more frequent droughts over the coming decades (e.g. Limpopo Basin in South Africa, Orange Basin in Namibia and Okavango Basin in Botswana).

Most big infrastructure projects with a long design life have been planned for historical and poorly characterised climate conditions. For both existing and new hydropower schemes, risks are linked to greater river flow variability, the ability to balance power generation with other priorities (including the maintenance of environmental flows for rivers) and flood management (Conway et al, 2017; Gannon et al, 2018; Siderius et al, 2021). Guidelines for factoring-in climate change into hydropower have only recently been published (IHA, 2019), and whether safeguards apply will likely depend on funding modalities: the way the financing package is structured, who is involved, and financing periods. Future Chinese investment, limited at present in Southern Africa, raises some concerns as environmental and social safeguarding norms have been applied inconsistently to date in sub-Saharan Africa (Buckley et al, 2022).

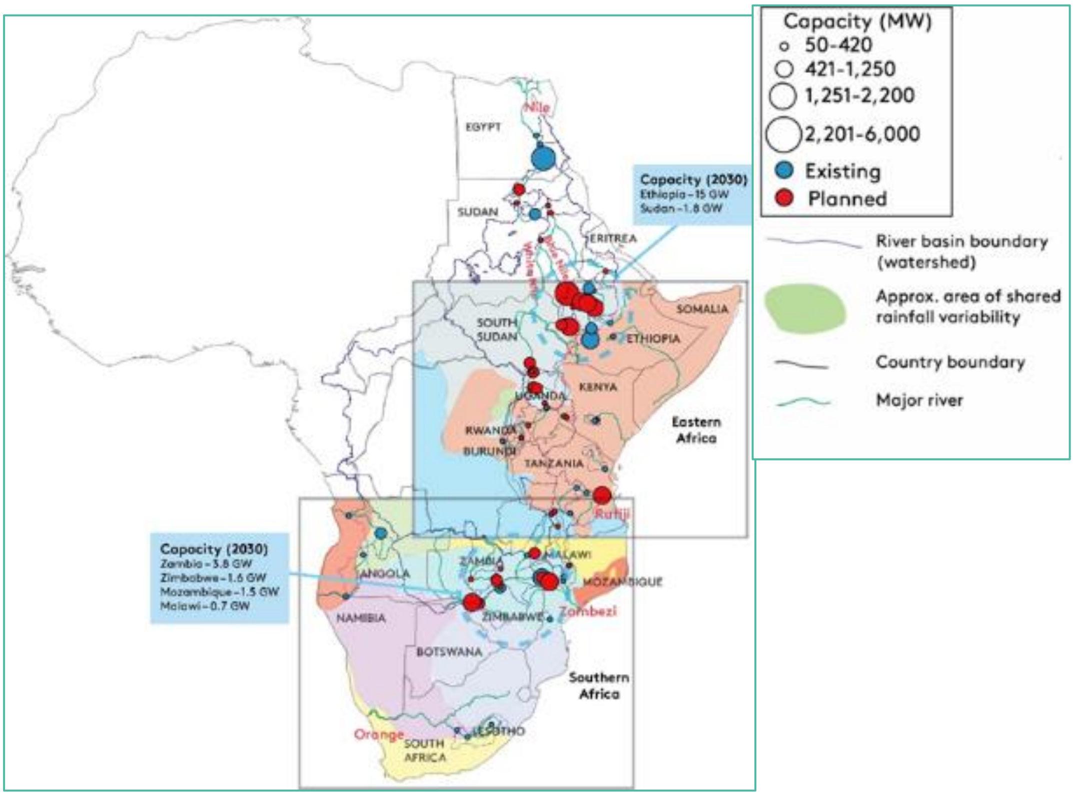


Figure 8: Hydropower development, Eastern and Southern Africa. Source: Conway et al (2017). Note: Existing hydropower dams in blue circles, planned (2013) in red. Only dams over 50 MW included in analysis. Circles are sized according to installed generating capacity (MW).

© Crown Copyright 2022, Met Office

Risk management strategies rely on transboundary cooperation around information sharing, dam releases and broader basin management, plus the development of different energy sources. Transboundary management is already a key issue because the bigger rivers, such as the Zambezi, are shared. Cooperation works reasonably well, at least for flood mitigation. For example, collaborative management of the Kariba Dam on the Zambezi between Zambia and Zimbabwe has proved critical to the prediction and reduction of flooding in Mozambique along the lower Zambezi. The sharing of hydrological data from the Shire (a tributary of the Zambezi) has also been important (ADB, 2016). Power sharing is potentially more difficult, however, when both upstream and downstream riparians in a shared basin all face concurrent power disruption arising from shared rainfall deficits and low streamflows. The ability to mitigate risks will therefore depend also on developing more diversified energy portfolios. Resilient systems will rely increasingly on multiple options spread across multiple grids – smart, mini, hybrid and cross-border power pool (Conway et al, 2017; Siderius et al, 2021).

Wider cross-regional power sharing between different power pools holds potential for risk mitigation. For Southern Africa, the obvious candidate is the Central African Power Pool (CAPP), since the Congo Basin has enormous hydropower potential and experiences different climatic conditions and river flows (Karam et al, 2022). However, CAPP is not yet functional within Central Africa (ADF, 2021), and power sharing between regions would depend on major investment in transmission and enabling political and economic conditions in the Democratic Republic of Congo and other power pool countries. South Africa, a country with rapidly accelerating energy needs still heavily dependent on coal, has nonetheless signed an agreement (in 2014) with DRC to buy electricity from the long-proposed Inga 3 development on the lower Congo, though the status of that project is unclear (World Bank, 2016).[19] However, with decades to go before electricity can be imported from DRC (if at all), South Africa has embarked on a green energy transition through a mix of (mainly) solar, wind and nuclear outlined in an Integrated Resource Plan (RoSA, 2019). The shift to renewables is being supported by France, Germany, UK, US and EU through the *Just Energy Transition Partnership* (UK Government Press Release, 2021)[20].

---

[19] There have been multiple rounds of consortium identification with Chinese involvement, culminating in selection, withdrawal, recomposition of consortia and now unilateral reallocation by DRC to a private Australian company. The World Bank, after initially funding feasibility studies, withdrew its support in 2016 citing 'differences of opinion' over the project's strategic direction (World Bank 2016).

[20] See UK Government Press Release November 2021 here: https://www.gov.uk/government/news/joint-statement-international-just-energy-transition-partnership

© Crown Copyright 2022, Met Office

3.3 Environment – Terrestrial forests, ecosystems and biodiversity

Summary of risks relevant to environment

- Rising temperatures, greater aridity and the increasing risk of fire weather will affect the geographical range and composition of forests and the services forests provide, though most forest loss will continue to be driven other pressures.
- Rising levels of CO_2 and higher temperatures are linked with the spread of woody vegetation in savannas and grasslands, and decreases in bird, reptile and mammal species that require grassy habitats.
- Rising temperatures and changing rainfall patterns will affect the coverage, composition, and functionality of wetland ecosystems. Where wetlands dry out, permanently or more frequently, they turn from carbon sinks to emission sources.
- Ecosystem loss and degradation threatens food security, flood control and carbon storage among other key services.

3.3.1 Context

Southern Africa contains a wide range of terrestrial biomes (or ecosystems) including tropical and sub-tropical forests, grasslands and savanna woodlands, desert ecosystems and wetlands. Savanna woodlands and grasslands cover approximately 54% of the region (Cornier-Salem et al., 2018), providing habitat that supports agricultural and livestock production, diverse flora and fauna, and national parks important to regional ecotourism and the generation of foreign currency (Reddy-Davis and Vincent, 2017). Wetlands form part of Southern Africa's diverse water bodies and include both inland and coastal systems and saltmarshes (Adeeyo et al., 2022). Protected areas have expanded in number and extent over the last three decades, and all 15 Southern African Development Community (SADC) member states now have National Biodiversity Strategies and Action Plans, with legal responsibilities to conserve land according to commitments under the UN Convention on Biological Diversity (Reddy-Davis and Vincent, 2017).

Forested areas include the tropical and subtropical humid forests on the norther fringes of the region, extending into Angola and DRC, and the tropical rainforests of eastern Madagascar (see Figure 9). More widespread are the dry deciduous forests - the Miombo and Mopane woodlands - that cover large areas of Malawi, Mozambique, Zambia, Zimbabwe, northern Namibia and Botswana (Naidoo et al, 2013). Zambia and Mozambique have the largest (natural) forest cover in the region (Naidoo et al, 2013). Commercial plantations are also important, with South Africa accounting for roughly 50% of plantation forests - mainly pine and eucalyptus - in the SADC region. The majority are privately owned and used for industrial purposes (Naidoo et al, 2013; Reddy-Davis and Vincent, 2017). Mangrove forests are also found in the tropical coastal areas of Mauritius, Seychelles, Comoros, Madagascar, Mozambique and South Africa Naidoo et al, 2013; Reddy-Davis and Vincent, 2017; see Section 3.6).

© Crown Copyright 2022, Met Office

The region's different biomes (Figure 9) provide a range of services, often characterised as regulating (e.g., carbon storage, erosion control, flood protection), provisioning (e.g., fuel wood, wild foods), supporting (e.g., nutrient cycling, space for wildlife) and cultural (e.g., through their recreation and religious importance). However, Southern African ecosystems and services are threatened by climate change and other pressures, including land degradation, the spread of invasive species, urbanisation, mining and agricultural expansion (Naidoo et al, 2013; Reddy-Davis and Vincent, 2017). Untangling the climate signal from these other drivers of change is difficult, although the evidence base is improving (Parmesan et al, 2022; Trisos et al, 2022).

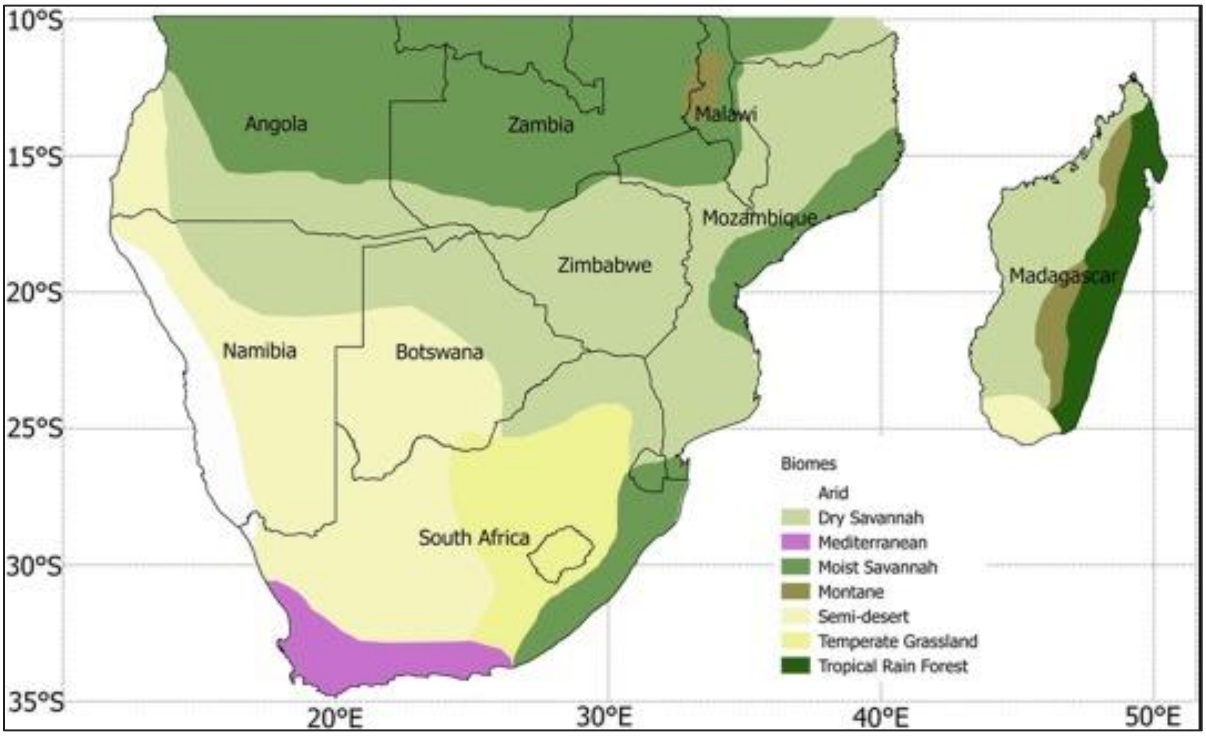


Figure 9: Major biomes in Southern Africa. Note: a biome is an area classified according to the species that live in that area. Source: Lawal et al (2019)

3.3.2 Forests

Southern Africa's forested areas will be negatively impacted by rising temperature, greater aridity and the increasing risk of fire weather conditions (Reddy-Davis and Vincent, 2017). These factors will contribute to changes in the boundary limits in which species are able to grow and survive, leading to their decline in some forested areas and their expansion in others (Reddy-Davis and Vincent, 2017; Parmesan et al, 2022). They may also affect the phenology for certain species (life cycle changes, e.g. flowering, leaf fall), and the incidence and distribution of pests and pathogens (Naidoo et al, 2013).

Forest composition and range will be affected by higher temperatures and rising levels of CO_2, though impacts remain uncertain. The expansion of woody plant cover into grasslands and savannas across sub-Saharan Africa is now confidently attributed to rising levels of CO_2 and higher temperatures (Parmesan et al, 2022 – see Section 3.3.3 below). However, the impacts of climate change on different forest types in the region appear less clear cut. Looking at Zimbabwe specifically, the World Bank (2021f) cite Zimbabwe

© Crown Copyright 2022, Met Office

government research indicating that two of the three main forest ecosystems - the Baikiaea[21] (western regions) and Miombo[22] (northern and eastern regions) - are projected to decline in cover by 18% and 10% respectively by 2050 due to hotter and drier or more variable yearly rainfall conditions. Conversely, Mopane forests[23] that thrive in hotter, drier environments are projected to expand (Parmesan et al, 2022).

The Afro-temperate forests[24] of South Africa, as well as widespread Miombo and Baikiaea woodlands, may be vulnerable because of their drought and heat sensitive vegetation (Reddy-Davis and Vincent, 2017). Afro-temperate contain rich fauna and flora, including endemic species that are not found anywhere else in the world (Reddy-Davis and Vincent, 2017). Miombo woodlands, the most common in Southern Africa, *currently* extend across large areas of Malawi, Mozambique, Zambia and Zimbabwe. Baikiaea woodlands are found in western Zimbabwe, northern Botswana, north-eastern Namibia and Zambia. Both have high species richness and provide a wide variety of fruit, fodder, honey and fuelwood for local people (Naidoo et al, 2013).

The region's tropical rainforests are limited to small areas of Mozambique (e.g. Mount Lico) and the east coast of Madagascar, threatened mainly by agricultural expansion and logging. New forest protection initiatives link conservation with emission reduction payments. The largest areas of remaining rainforest are located on the east coast of Madagascar, supporting rich biodiversity and an exceptional proportion of endemic plant and animal species (CBD, 2015). An agreement signed in February 2021 between the World Bank's Forest Carbon Partnership Fund (FCPF) and Madagascar's Ministry of Environment and Sustainable Development aims to protect much of the remaining rainforest by linking emissions reduction payments with conservation.[25] The FCPF is a World Bank trust fund for reducing emissions from deforestation and forest degradation—commonly known as REDD+. Under the FCPF, payments are received for independently verified emission reduction from forest conservation and community forest management, building on forest-friendly agroforestry value chains such as vanilla (World Bank, 2021g).

The frequency of fire weather has increased across Southern Africa, a trend that is expected to continue this century. Forest fires are a major contributor to greenhouse gas emissions (Ramo et al, 2021; Parmesan et al, 2022). Zambia, Zimbabwe, Botswana and western Mozambique are projected to see a major increase in fire weather affecting areas already experiencing a high density of forest fires (World Bank, 2021a,f,h,i). The fragmentation of forests following agricultural expansion may negate the impact of increasing fire weather, ultimately leading to a reduction in the extent of burned areas (Parmesan et al, 2022; Trisos et al, 2022). Impacts on greenhouse gasses and aerosols are significant, however. Recent research using high resolution satellite imagery suggests that fire burn across Africa is under-represented in conventional (lower resolution) mapping, with emissions 31-101% higher than

[21] Deciduous trees from the legume family, including teak and redwood.
[22] A type of woodland-savanna ecosystem dominated by deciduous trees.
[23] Mopane trees are adapted to grow in hot, dry, generally low-lying areas.
[24] Tall, shady and multi-layered forest type indigenous to South Africa, including many medicinal plants.
[25] The FCPF will unlock up to USD 50M for efforts to reduce carbon emissions from deforestation and forest degradation between 2020 and 2024. With this Emission Reductions Payment Agreement (ERPA) in place, Madagascar is expected to reduce 10M tons of $C0_2$ emissions from the country's rainforest-rich eastern coast (See FCPF, 2022).

© Crown Copyright 2022, Met Office

previous estimates, representing some 14% of global CO_2 emissions from fossil fuel burning (Ramo et al, 2021).[26]

Forest loss across Southern Africa will continue to be driven primarily by the expansion of agricultural land, over-harvesting of fuel wood, encroachment of human and industrial settlements and lack of effective forest management (Cornier-Salem et al., 2018). Over the period 1990-2010, Zimbabwe lost roughly 327,000 ha or 1.5% of forest cover per year, totalling over 6.5 million ha (World Bank, 2021f). Malawi's natural forest cover declined by over 50% in the period 1972-1992, and although the rate of loss has since declined, cover is still falling (World Bank, 2019). In Mozambique, forests cover roughly 43% of the country but 270,000 ha/year are lost (0.8%/year). In 2021, Mozambique became the first country to receive payments from the FCPF (see above) under a REDD+ agreement to protect ecosystems and simultaneously reduce greenhouse gas emissions (FCPF, 2022). Activities focus on sustainable agriculture practices, monitoring forest use and restoring degraded land (FCPF, 2022).

Deforestation, particularly in Southern Africa's poorer and more densely populated countries is closely linked with demand for fuelwood and charcoal. Some of this is driven by climate extremes. In Malawi, for example, demand for urban charcoal increased during the 2015-16 El Niño drought when a decline in hydropower generation led to widespread power outages (Reddy-Davis and Vincent, 2017). In Madagascar, drought has been linked to tree felling as farmers seek to maintain agricultural output by cultivating new land (Hallegatte et al, 2016).

3.3.3 Savanna woodlands and grasslands

Cattle grazing is being negatively impacted by encroachment of woody plants into savanna and grassland areas as a result of changes in temperature, water availability, levels of atmospheric CO_2 and the increased risk of fire weather (Reddy-Davis and Vincent, 2017). A clear and ongoing observed trend is the increase in woody plant cover (more shrubs and trees), including invasives, linked to rising CO_2 concentrations (Reddy-Davis and Vincent; 2017; Trisos et al, 2022). Over the last 60 years or so, woody cover has increased by 10% on subsistence grazing lands and 20% on commercially important grazing lands in South Africa (Stevens et al, 2016). This trend has also been linked with decreases in bird, reptile and mammal species that require grassy habitats (Trisos et al, 2022). Poaching also contributes to the decline in species found within these areas, including 'charismatic' species such as rhinos and lions (Cornier-Salem et al., 2018).

Grass cover may be increased in drier mixed savanna systems due to rising temperatures. In Namibia for example, desert and arid-land shrubs or grasslands are likely to take over parts of the grassy and mixed savanna areas in the country. Arid vegetation is projected to increase by almost 20% by 2050 (World Bank, 2021d). The country's central highlands and northeast plains are expected to be most affected (World Bank, 2021d).

3.3.4 Wetlands

Important Southern African wetlands include the Kafue flats in southern Zambia, the Okavanga Delta in north-western Botswana, the ephemeral wetland system of northern Namibia (including the Etosha Pan, Lake Oponono and the Cuvelai inland delta), and the

[26] Mainly from shrublands, forests, grasslands and croplands. In the southern hemisphere Malawi, South Africa, Tanzania and Madagascar were the biggest contributors (Ramo et al, 2021).

© Crown Copyright 2022, Met Office

seasonally and permanently flooded grasslands, savannas and swamp forests of the Zambezi delta. The region also includes a series of dambo wetlands – seasonal wetlands located on elevated plateaus – that are found in countries such as Zimbabwe and Malawi. Such wetlands provide a range of important services including water storage, flood control and water quality regulation, as well as providing fish and wildlife habitats (Xu et al, 2020).

Impacts remain uncertain, but **changes in wetland coverage, composition and functionality will occur due to rising temperatures, higher rates of evapotranspiration and increases in the frequency and intensity of extremes.** Where annual rainfall declines (projected for the south-west of Southern Africa), wetlands may shrink or, in the case of more seasonal wetlands, dry out completely. More frequent and extended droughts across the region are likely to negatively impact wetland habitats and their ability to store water and carbon. When wetlands dry out, they turn from carbon sinks to emission sources (Opperman et al, 2021). Higher temperatures are also linked with shifts in biochemical processes affecting water quality, impacting fish, invertebrates and algae (Trisos et al, 2022).

Loss of water storage and filtration from wetlands can have significant economic impacts on downstream users and uses. The Lukanga Swamp wetlands in Zambia, roughly 100km north of the capital Lusaka, cover an area of 3300 km^2, but the inundated area more than doubles during the wet season. The wetland serves as a natural reservoir that stabilises water and energy supplies and is also crucial for local communities who use it for hunting, fishing and charcoal production. Although climate attribution studies have not been carried out, wetland storage is declining, with downstream costs on users estimated at nearly USD 42M/year borne mainly by the electric utility (Opperman et al, 2021).

As with other ecosystems, **the decline in the extent and functionality of wetlands is driven by multiple pressures, particularly mining, dam construction, pollution and agricultural expansion** (Cornier-Salem et al., 2018). Small wetlands are often the victim of drainage and river 'canalisation' to facilitate the planting of crops (Darwall et al., 2009). Wetlands are also drained to control vector breeding sites linked to malaria and other diseases (Darwall et al., 2009).

3.3.5 Ecosystem services

There may be a decline in Southern Africa's natural carbon capture and storage as a result of deforestation and degradation of savannas, grasslands and wetlands (Reddy-Davis and Vincent, 2017). The decline in the region's wetlands could also see the loss of a habitat that helps to regulate levels of carbon dioxide, methane and nitrogen in the atmosphere (Salimi et al., 2021).

Southern Africa's biomes provide critical services which are threatened by climate change and other pressures. Healthy ecosystems play a key role in maintaining agricultural yields, for example, sustaining soil quality and reducing erosion through mixed ground cover (Sintayehu, 2018). Livestock production has already been impacted by reductions in rangeland carrying capacity – see Section 3.1 (Trisos et al, 2022), and woody encroachment into grasslands could see an overall reduction in livestock used within beef and dairy farming (Davis-Reddy and Vincent, 2017).

Food security is threatened by ecosystem degradation as many poor people are dependent on ecosystems for food and income. Declines in the extent and productivity of ecosystems such as wetlands may also impact food security. Whilst fish stocks in areas such as the wetlands in northern Namibia may not be *commercially* important, they provide an

© Crown Copyright 2022, Met Office

important source of food and material for surrounding communities. Wild harvested foods, including fish, also provide important nutrition (Hallegatte et al, 2016; Trisos et al, 2022 - see Section 3.1). The importance of coral reefs as nurseries and breeding grounds for fish, important to artisanal fishers, is discussed in Section 3.6.

Ecotourism industries are potentially threatened by a reduction in biodiversity and increases in extreme temperature. A reduction in Southern Africa's biodiversity could have a knock-on effect on ecotourism – a commercially important sector and significant source of income and jobs in countries such as South Africa, Namibia and Botswana (Reddy-Davis and Vincent, 2017). Higher daytime temperatures restrict the movements of wildlife, reducing their visibility to tourists, threatening this sector (Trisos et al, 2022).

Commercial plantations will continue to be negatively impacted by pests, diseases and wildfires, and productivity levels may reduce as tree types become unsuitable for climatic conditions. Forested areas in countries such as South Africa include commercial plantations. These sites are already impacted by pests and diseases, and wildfires (Naidoo et al, 2013). The impact of climate change could undermine the commercial value of these sites. Tree types within plantations are chosen based on their productivity levels and there is a risk that these may become unsuitable as a result of changing climatic conditions (Reddy-Davis and Vincent, 2017).

© Crown Copyright 2022, Met Office

3.4 Infrastructure and settlements

Summary of risks relevant to infrastructure and settlements

- Climate risk and poverty will increasingly coincide in urban areas, particularly in the region's rapidly growing informal settlements where poorer households are pushed into more exposed areas.
- Floods are the leading cause of damage to housing and transport, while floods, rising temperatures and high winds threaten power and communication networks. Risks can cascade across sectors and areas where networks are fragile and backup options limited.
- Growing water demand and supply constraints will increase competition for water in and around urban hot spots, while urban flooding will increasingly threaten infrastructure and health.
- More intense tropical cyclones and storm surges, plus rising sea levels, threaten the region's coasts where people and economic assets are increasingly concentrated.

3.4.1 Context

Southern Africa is home to 181 million people, with roughly 54% living in rural settlements (see Table 2, Section 3.2.3). The rural-urban split varies considerably depending on levels of economic development and transformation. Higher income countries Botswana, Namibia, South Africa, and Seychelles are predominantly urban. Mauritius is a higher income country but has a rural population of 59%. The other eight countries falling into the lower/lower-middle income brackets remain overwhelmingly rural (66%), with Malawi reaching 83% (World Development Indicators, 2022 – see Section E of the Technical Reference Document). Population growth across Southern Africa remains high, compared with the global average of 1.1%, at 1.7% overall and for lower/lower-middle countries 2.1%, with annual growth rates nearing 3% in Zambia, Malawi, Mozambique and Madagascar. Most of this growth will be absorbed by urban areas (OECD/SWAC, 2020).

Southern Africa's large rural population and growing urban diversity has implications for the way climate risks are considered. In particular, descriptions of urban and rural in most reporting refer to administrative boundaries that do not reflect patterns and flows of economic activity. This means that climate risks can cascade over large areas, such as when drought in an arable area leads to food price spikes and insecurity in cities, or where flood damage to urban transport infrastructure leads to prolonged isolation of small towns, rural settlements and small islands (Dodman et al, 2022).

Climate risks can also cascade across economic sectors. A key reason is because a lot of infrastructure – power, communications, transport, water supply and sanitation – is in the form of networks, and Southern Africa is no exception (Hallegatte et al, 2017; Rozenberg and Fey, 2019). While the severity of natural disasters is often measured in terms of asset loss and damage, it is the secondary impacts on economic activities and output that often explain a larger share of impacts (Hallegatte et al, 2017). Hence studies of the resilience (or

© Crown Copyright 2022, Met Office

vulnerability) of road networks and other networked systems increasingly focus on at-risk services rather than just assets. An example from Mozambique is described in Focus Box 2.

3.4.2 Housing and transport

Climate-related risks to housing will be felt most keenly in Southern Africa's rapidly growing informal settlements. Excluding upper-middle income countries, roughly 61% of the region's urban population live in households lacking one or more basic living conditions/services[27] (World Bank, 2020). In Mozambique, that figure rises to 77%. Mozambique's urban population increased from roughly one million at the country's independence in 1975 to over 11 million by 2020. The rapid influx, exacerbated by conflict in the north, has overwhelmed the capacity of towns and cities to provide urban infrastructure and services, ensure land tenure rights, and provide adequate housing.

Urbanisation is linked to population growth, economic transformation and, in some instances, conflict. A common characteristic is the growth of informal settlements and 'secondary' towns and cities where infrastructure provision lags behind urban expansion. Many are 'spontaneous' extensions and neighbourhoods emerging beyond or across administrative boundaries that are not officially recognised as urban[28] (OECD/SCAC, 2020). While larger cities have the *potential* to draw on significant human and financial resources to address vulnerabilities and invest in new infrastructure, this is often not the case in fast-growing towns and villages. Informality is a key pathway through which urbanisation generates *differentiated* climate risks, since poorer, more vulnerable households are pushed into more exposed areas lacking basic services (Hallegatte, 2017; Dodman et al, 2022). Moreover, social protection programmes that provide safety nets for struggling households are often thin or absent in urban areas – an issue highlighted by the growth of a 'newly impoverished urban poor' in sub-Saharan Africa during the COVID-19 pandemic (World Bank, 2020).

Land and housing markets typically push poorer households into more exposed, often low-lying areas where land is cheaper and more accessible to those living in poverty (Hallegatte et al, 2017; UN-Habitat, 2022). Informal settlements typically lack basic services (e.g. drainage, safe water and sanitation, electricity) and are constructed from materials that offer little protection from heat (see 3.5.3 in Health section), or against floods and high winds. Moreover, the compact construction of informal settlements also means that vehicular access is difficult, so on-site sanitation systems and septic tanks cannot be easily emptied, and emergency services are effectively out of reach (Davis-Reddy and Vincent, 2017) – see 3.4.4 below. Given high rates or population growth and urbanisation in the region, a key conclusion is that climate risk and poverty will increasingly coincide in urban areas, particularly in the region's rapidly growing informal settlements.

Risks to Southern African housing and wider infrastructure have been highlighted by a number of recent flooding events such as the devastating floods of April 2022 in South Africa. South-eastern Africa, and particularly Mozambique, is most exposed to the projected increase in the intensity of tropical cyclones (Section 2; see also Figure 10 in Section 3.4.5).

---

[27] Specifically, households lacking one or more of the following conditions: access to improved water, access to improved sanitation, sufficient living area, housing durability, housing affordability and security of tenure (indicators for SDG 11.1.1).

[28] Roughly 97% of Africa's urban areas have fewer than 300,000 people. Many of these are not officially recognised as urban (OECD/SWAC, 2020).

© Crown Copyright 2022, Met Office

In March 2019, Topical Cyclone Idai swept across Southern Africa causing widespread damage and a humanitarian crisis in Mozambique, Zimbabwe and Malawi. Over 1000 people were killed, and 2.6 million people left needing emergency assistance. In Mozambique alone, over 200,000 houses were destroyed or damaged; in the coastal city of Beira over 70% of houses were damaged or destroyed, mainly in the poorest neighbourhoods, and 90% of the city's power grid was affected (Dodman et al, 2022). In April 2019, Tropical Cyclone Kenneth hit Mozambique while recovery efforts from Tropical Cyclone Idai were still underway, exacerbating the existing crisis. The rapid spread of cholera after this event triggered a major vaccination programme in an attempt to control the epidemic (Lequechane et al, 2020).

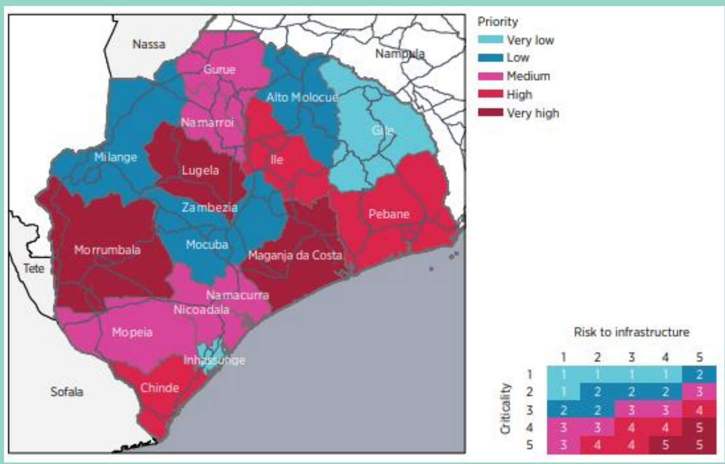
In response to Tropical Cyclone Idai, the Government of Malawi declared a State of Disaster in the 13 districts and two cities in Southern Region, and in two districts of Central Region. A post-disaster needs assessment (GoM, 2019) identified the 'social sector' (housing, health, nutrition) and infrastructure (including transport and energy) as worst hit, with the biggest economic losses to housing (USD 83M) and transport (USD 36M). The majority of houses affected (over 280,000) did not conform to the Malawi Government's Safer Housing Construction Guidelines which prioritise low-cost safeguards: good site-selection, decent drainage and robust (traditional) designs/materials (GoM, 2019). Failure to comply with existing guidelines was also highlighted for transport, with floods damaging or destroying over 1800km of roads across Malawi and destroying 129 bridges, hampering relief efforts.

Floods are also the largest contributor to transport damage and disruption, with many of the poorest countries in Southern Africa facing the highest expected annual damages to road and rail assets relative to GDP (Koks et al, 2019). Risks to livelihoods, businesses and economies are exacerbated where transport networks are fragile and have little redundancy (Hallegatte et al, 2019; Lumbrusco, 2020). In Mozambique, modelling work ('criticality analysis') by the World Bank has demonstrated how even small numbers of disrupted links can lead to very high functionality losses, with the resilience of the transport network measured as the ratio of the loss of functionality to the loss of assets (Espinet et al, 2018). This type of analysis is useful because it shows how the cost of building resilience depends critically on the ability to target investment at the most vulnerable areas, and then at key 'choke' points in the network within those areas (see Focus Box 2).

© Crown Copyright 2022, Met Office

Focus Box 2: Identifying critical links in Mozambique's road network

Mozambique is one of the most climate exposed and vulnerable countries in Southern Africa. Successive tropical cyclones and floods have had major impacts on the economy and exposed dependence on a fragile road network. Mozambique's agricultural sector employs roughly 70% of the workforce and unreliable rural connectivity can lock people into low return subsistence farming. Increasing the resilience of Mozambique's road network could boost the resilience of the agricultural sector to successive climate hazards by enabling people to maintain their income streams.



In their background study for a roads project, the World Bank compared risks to Mozambique's road network in terms of hazard-linked annual damage with road criticality based on services provided. Road criticality incorporated information about end users and uses, including poverty and agricultural data in provinces served by different roads. In provinces with a high risk of floods, low redundancy and poverty, it was found that repairing and rehabilitation culverts and bridges would generate the highest socio-economic returns. Those returns were based on a cost-benefit analysis of five different options (including upgrades of dirt roads to gravel roads), with comparisons against a baseline of routine 'business as usual' maintenance on the road network.

Source: Espinet et al, 2018.

3.4.3 Communications and power

Information Communication Technologies (ICT) comprises the integrated networks, systems and components enabling the transmission, receipt, capture, storage and manipulation of information by users on and across electronic devices (Fu, Horrocks and Winne, 2016). **ICT provides critical functions for business, industry, education, healthcare and transportation**, and can be affected by extreme weather events. For example, storms bringing **high winds, floods and debris (in wind and water) pose risks to above ground infrastructure such as phone masts, cables, pylons and data centres**. Damage can lead to the loss of voice communications, inability to process financial transactions and interruption to control and clock synchronisation signals (Dodman et al, 2022). Threats were highlighted during Tropical Cyclone Idai in 2019 when high winds and floods knocked-out radio and mobile phone communications to 2.5 million people in Mozambique, removing vital sources of information during relief efforts (ILO, 2019). The proportion of intense tropical cyclones, such

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

as Idai and Kenneth, are projected to increase in Southern Africa, although the yearly number is expected to remain about the same as present.

Power generation and transmission are also vulnerable to the effects of climate change through extreme events and rising temperatures. **Thermo-electric[29] power systems are vulnerable to direct effects of increasing temperatures on efficiency, and indirectly because of their demand for water** in Southern Africa's increasingly variable rainfall climate. Thermo-electric power, typically from fossil fuels, remains an important source of energy in some countries: Botswana and South Africa generate the bulk of their electricity from coal (over 80%); Comoros, Seychelles and Mauritius are overwhelmingly dependent on oil (via mixed systems); and a number of other countries retain coal, gas and/or oil within their energy mix (Namibia, Mozambique, Malawi, Madagascar, Zimbabwe). Risks to hydropower systems from rainfall-river flow variability and extremes are discussed in Section 3.2.

Coal-fired power plants with wet cooling systems are vulnerable to changing climate because of their cooling demands (Davis-Reddy and Vincent, 2017). They consume (via evaporation) much more water than most other energy technologies. In South Africa for example, where over 80% of energy production is coal-based, the main energy utility (Eskom) uses about 2% of the country's freshwater resources, mainly for cooling plant equipment (Conway et al, 2015). A 1°C increase in the temperature of water used as coolant yields a decrease of 0.1-0.7% in power output (Mima and Criqui, 2015), meaning that most thermal generation plants relying on water for cooling need to be curtailed or closed when intake water exceeds permitted temperatures – typically around 24°C.

In the current global context of rising of rising energy prices, particularly for gas, questions remain over the pace and scale of Southern Africa's green(er) energy transition. For example, more than 50% of Botswana's energy is imported from (mainly) South Africa and Zambia, and while the country has significant solar potential, it also has vast reserves of coal and gas. Southern Africa's only nuclear plant is the Koeberg power station in South Africa. However, Namibia has some of the largest uranium deposits in the world, supplying over 8% of global production, and has stated its interest in developing nuclear energy. South Africa has now embarked on a green transition through a mix of (mainly) solar, wind and nuclear outlined in an Integrated Resource Plan (RoSA, 2019). The shift to renewables is being supported through the Just Energy Transition Partnership (see Section 3.2) but is unlikely to exclude coal altogether given its importance in the current energy mix and the country's rising demand for power. However, coal-fired plants are likely to get cleaner, and are already switching to dry cooling systems that enable a 15-fold reduction in water use (Conway et al, 2015).

Southern Africa's solar potential is significant, and a number of countries already have large-scale solar photovoltaic (PV) programmes completed or underway (e.g. Namibia, Malawi, South Africa, Eswatini, Madagascar, Mauritius). Solar outputs change with climate because PV output is sensitive to shortwave irradiance from the sun, which is in turn affected by aerosols and clouds (Feron et al, 2021). Output is also affected by air temperature, with hotter conditions generally reducing the efficiency of PV panels and lowering output (Feron et

[29] Those that convert heat energy into electrical energy, often by creating high pressure steam that drives a turbine linked to an electrical generator. Natural gas or oil can be burned directly in a gas turbine linked to an electrical generator.

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

al, 2021). Moderate impacts on PV solar potential (±3%) are projected for Southern Africa by mid-century, with uncertainties linked mainly to changes in cloud cover.[30]

Increases to extreme weather events, including heavy rainfall and more intense storms, have clearer impacts on electricity transmission: transmission pylons are susceptible to wind damage, whilst distribution pylons are more likely to be affected by treefall and debris (Karagiannis et al, 2019). After Tropical Cyclone Idai, in Mozambique alone, over 1000 km of transmission lines, 10,000 km of distribution lines, two generating plants, 30 sub-stations and 4000 transformers were damaged or destroyed, with direct asset losses of over USD 48M in the energy sector *before* accounting for secondary impacts on services and end users (Dodman et al, 2022).

Rising temperatures can also lead to the de-rating (lower performance) of power lines as their electrical resistance increases with temperature. Studies in the US, for example, indicate that by mid-century increases in ambient air temperature may reduce average summertime transmission capacity by 1.9%–5.8% relative to a 1990–2010 baseline (Bartos et al, 2016).[31]

Higher temperatures will increase demand for cooling (household, industrial, food storage etc), straining electricity supplies in countries already struggling with unreliable and/or patchy services (UN-Habitat, 2022). Southern Africa has already experienced the cascading effects of power outages on different economic sectors (see also 3.2). During the 2015-16 El Niño drought, declining hydropower output from the Zambezi and its tributaries contributed to power disruptions and rationing in Zambia, Malawi and Zimbabwe, exacerbated by a heat wave. In Zambia, load-shedding and enforced demand reduction caused widespread shutdowns and job losses in industrial sectors, particularly in Lusaka Province and the Copper Belt mining region of northern Zambia, and major business employers in Lusaka reported electricity supply as their leading business challenge (Gannon et al, 2018).

3.4.4 Urban water supply and sanitation

The combination of urban growth and climate change is likely to increase pressure on the water resources needed to meet urban demand. Urban growth projections highlight this concern, even in areas that have relatively low urban populations. For example, urban growth in the Zambezi River Basin out to 2050 could reach 50% with most occurring in Malawi, Zambia and Zimbabwe (UN-Habitat, 2022). This will significantly increase urban water demand in a catchment with multiple, competing needs – especially for energy and agriculture (UN-Habitat, 2022). The experience of Cape Town during the 2015-17 drought illustrates the risks that even a well-resourced and organised city can face when rising water demand, drought and limited supply coincide (see Focus Box 3). Across Southern Africa, it could be expected that rapidly growing towns and cities will increasingly compete for water with neighbouring users and uses, often rural, and for supply costs to increase.

Urban flooding is also a key risk because of its links with water-borne disease. This is because of the link between flooding and damage to onsite sanitation, problems gaining vehicular access to flooded areas to empty on-site systems, and because the mixing of flood

---

[30] Under RCP4.5 – an intermediate emissions scenario under which global temperatures rise by 2-3°C by 2100 (Feron et al, 2021).

[31] Depending on the emission and therefore temperature scenario (upper and lower bounds).

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

water and sewage over wide areas can contaminate the environment and water supply. Faecal sludge management remains largely unregulated across Southern Africa, and even where safe transport of faecal matter does exist, safe *disposal* at treatment facilities is a rarity (Howard et al, 2016; Calow et al, 2017). A systematic review of the health evidence highlights strong links between flood events and outbreaks of water-related disease, including cholera, hepatitis A and E, and pathogenic E.coli (Alderman et al, 2012). Such outbreaks were seen in the aftermath of Tropical Cyclone Idai, for example, but can occur after much smaller and more localised flood events, particularly in informal settlements with poor drainage and WASH. Nonetheless, the implications of climate change for urban non-sewered and complex, fragmented, and decentralised systems remains under-researched (Hyde-Smith et al, 2022).

Focus Box 3: Cape Town's Day Zero: Climate change, drought and nature-based solutions

Over the period 2015-17, the South African city of Cape Town and its surrounding area experienced its worst drought since 1904. The city's water supply is dependent on streamflow from a relatively small area made up of several mountainous catchments, with water then stored in six downstream reservoirs. During the drought, dam levels dropped to <20% of their capacity, forcing the city authorities to plan for Day Zero – the day the taps would run dry.

Fortunately, good rains in 2018 restored water flows and Day Zero was avoided. Plans for increasing supply security have focused not just on hard infrastructure (e.g. desalination, bigger dams) but also nature-based solutions (NBS). Specifically, clearing invasive trees in the upper catchments and restoring native, scrub vegetation that consumes less water. In contrast to most nature-based interventions, detailed economic and scientific studies were conducted to estimate how much water could be saved, and at what cost. Initial clearing took place before the drought.

Scientific studies indicated that climate change increased the likelihood of the rainfall deficit by a factor of three. The initial clearing of invasive species could have increased streamflow by 3-16%. Preventing further invasive spread in the run up to the drought could have increased flows by 10–27%. Recognising the financial case for clearing invasives has led to the establishment of the Greater Cape Town Water Fund and a commitment from the city to make substantial investments in catchment restoration.

Results also offer a reminder that planting or encouraging forests to grow in native shrubland ecosystems will typically reduce water yields, not increase them. Promoting tree-planting in shrubland, savanna and grassland systems for carbon capture, or under the assumption that water outcomes will be neutral or positive, carries big risks.

Sources: Opperman et al, 2021; Holden et al, 2022.

3.4.5 Coastal settlements

Southern Africa's coastal areas are densely populated, have a high concentration of economic assets and are exposed to multiple risks from cyclones, storm surges, flooding and landslides (Davis-Reddy and Vincent, 2017). The southern and eastern coasts of the region have a higher concentration of population than the west coast and include major cities such as Cape Town (3.7 million), Durban (3.1 million) and Maputo (2.6 million)

© Crown Copyright 2022, Met Office

(Africapolis 2015 data). Coastal regions support multiple economic sectors such as fishing, aquaculture, tourism and mining and major port infrastructure is found in Walvis Bay (Namibia), Cape Town Durban and Coega (South Africa), Maputo and Beira (Mozambique). Southern Africa's ports have a regional importance in terms of development, serving the economies of landlocked countries such as Malawi, Zimbabwe and Botswana. The islands of

Madagascar, Seychelles, Mauritius and Comoros also have dense coastal populations and rely on key port cities for fishing and trade (see Section 3.6).

Climate risks are concentrated on the south-east coast of Southern Africa and the small islands of the West Indian Ocean. In Mozambique, roughly 60% of the population live in low-lying areas and are exposed to some combination of sea level rise, storm surges, flooding and cyclones (Cabral et al., 2017). By 2040, coastal land areas could shrink (by up to 40%), and damage to infrastructure - port facilities, housing, transport – could amount to USD 103 million/year (Mucova et al., 2021). Major urban areas such as Durban, South Africa are also threatened. The city is already vulnerable to sea level rise, coastal erosion and flooding, with informal settlements located on coastal flood plains at particular risk (Gajjar et al., 2021). Extreme waves, storm surges, high winds and heavy rainfall will result in increased risks to port infrastructure and cargo, with disruptions to operations and higher maintenance and repair costs (Lumbroso and Woolhouse, 2014).

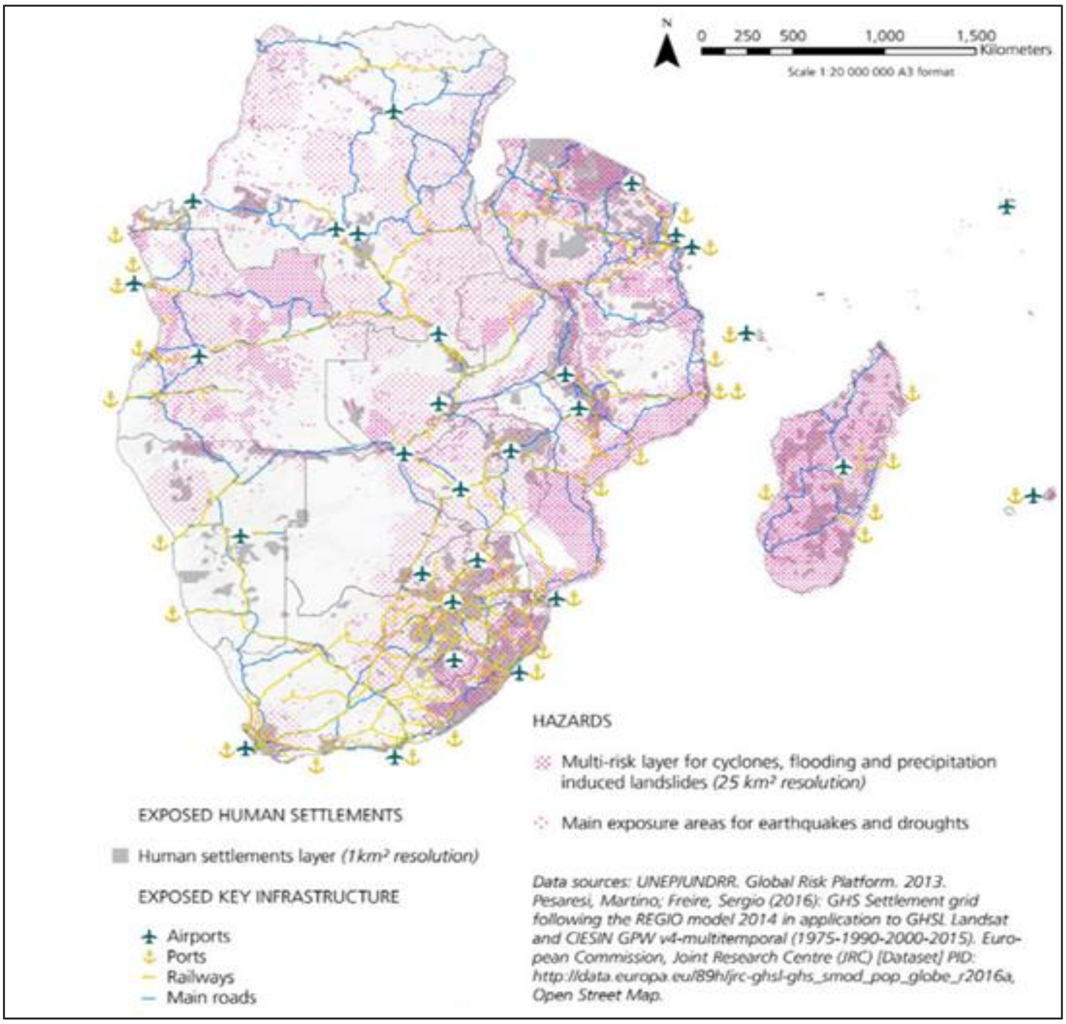


Figure 10:. Climate hazards and exposure in Southern Africa. Source: UN-HABITAT, 2022.

© Crown Copyright 2022, Met Office

3.5 Health

<u>Summary of risks relevant to health</u>

- Rising temperatures and changing rainfall patterns, as well as increased flooding, will increase the overall geographical range and incidence of vector borne diseases such as malaria.
- Flooding and higher temperatures will increase the risk of water-borne diseases such as cholera, typhoid and leptospirosis, already common in flood prone areas.
- Higher temperatures and temperature extremes increase the risk of heat stress, particularly for the elderly, pregnant women, children, people with existing health concerns and those working outdoors.
- Higher temperatures, heatwaves and dust storms will contribute to poorer air quality, increasing the risk of respiratory diseases.

3.5.1 Context

Human health outcomes in Southern Africa have improved over the past two decades, with all countries experiencing an increase in life expectancy at birth and a decline in infant, child and adult mortality rates (WHO, 2022). However, the region still faces a major disease burden due to limited access to healthcare facilities (particularly in rural areas), inadequate waste management and drainage, and low access to safe water and sanitation (USAID, 2016) Urbanisation and expanding informal settlements may exacerbate these challenges in combination with climatic changes, due to the impacts of poor water and sanitation services, poor air quality, and stressful conditions on health. Per capita health spending differs hugely across countries, ranging from about USD 20-30 per capita in Madagascar and Malawi to over USD 600 per capita in Mauritius and the Seychelles (WHO, 2022 reporting 2019 figures).

Leading causes of death across Southern Africa include communicable diseases such as diarrhoea, pneumonia, malaria, tuberculosis and HIV/AIDS (WHO, 2022). In 2016, the average mortality rate attributed to unsafe water, sanitation, and hygiene (WASH) conditions ranged from 25 to 51 per 100,000 people in Zimbabwe, Eswatini, Malawi, Mozambique, Madagascar, Zambia, Lesotho, and Comoros, vs a world average of 14 (WHO, 2022). In 2019, communicable diseases and maternal, prenatal, and nutrition conditions accounted for 40 to 50% of all deaths in Botswana, Comoros, Eswatini, Lesotho, Madagascar, Namibia, and Zimbabwe, and over 50% in Malawi, Mozambique, and Zambia, vs a world average of 33% (WHO, 2022). Eswatini, Lesotho and Namibia also face a high prevalence of HIV/AIDS among the population and a high prevalence of tuberculosis fuelled by HIV/AIDS in Namibia (World Bank, 2021b,c,d).

The region's existing health burdens are likely to amplified by climate change (see Figure 11). Climate variability and change already affect the health of tens of millions of people in Southern Africa via exposure to high temperatures, extreme weather, and increased transmission of infectious diseases (Trisos et al., 2022). Projected increases in temperature and changes in precipitation may increase the risks of communicable and non-communicable

© Crown Copyright 2022, Met Office

diseases, heat- and air quality-related risks, and risks associated with changes in nutrition (Watts et al, 2017). As with other risks, impacts of climate change will exacerbate existing inequalities in health outcomes and access to healthcare services, shaped by socioeconomic determinants of health linked to economic status (e.g., poverty), location (e.g., rural areas, informal settlements), and social position (gender, age, etc.) (Trisos et al., 2022).

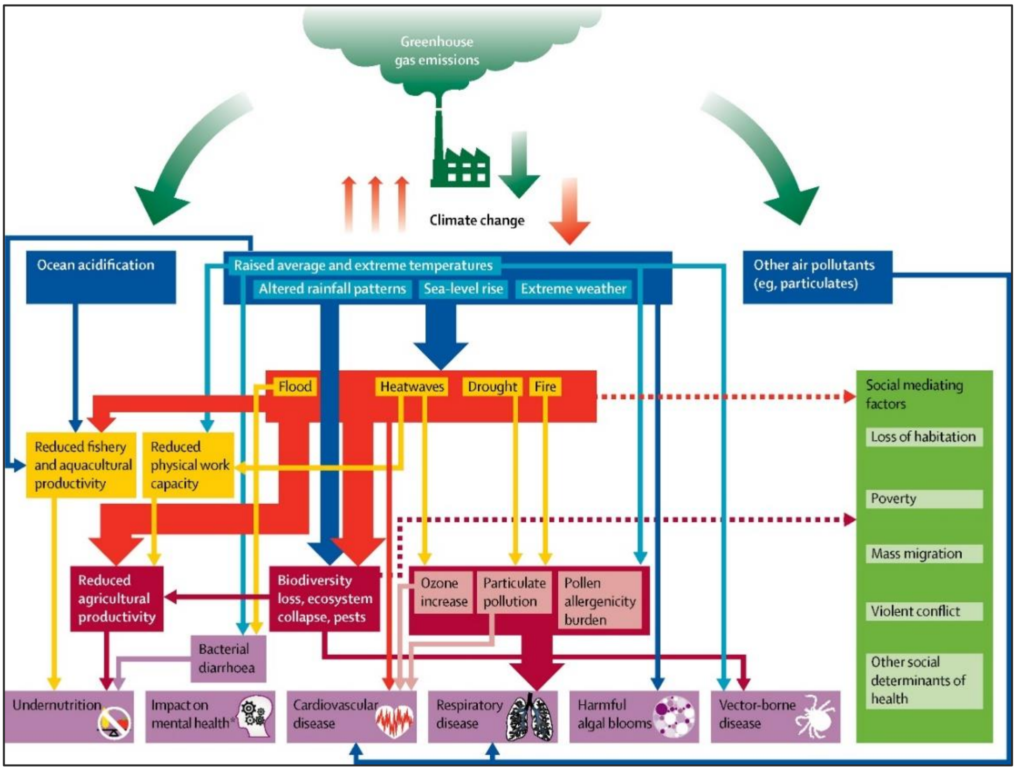


Figure 11: Pathways to impact: Health risks of a changing climate. Source: Watts et al, 2017.

3.5.2 Communicable and non-communicable diseases

Temperature and precipitation changes will contribute to changes in vector-borne diseases in Southern Africa, particularly those transmitted by mosquitoes such as malaria. This can lead to shifts in the geographic distribution of malaria as well as shifts from seasonal to endemic transmission in some locations. Temperature determines the life cycle and habitat for malaria carrying mosquitos and the malaria parasite (USAID, 2022), with the optimum transmission range being 25-28°C (Lunde et al., 2013). Increased temperature can increase the availability of suitable habitats for mosquito development and decrease virus incubation time, in turn increasing transmission rates – although very high temperature (especially approaching 40°C) may increase mosquito mortality and decrease transmission risk (Ngarakana-Gwasira et al., 2016).

Temperature increases and changes in rainfall patterns are likely to mean new areas become suitable for malaria transmission, while other areas may decline in suitability (USAID, 2022). For example, following heavy rainfall events in Botswana, high risk areas for malaria may shift from the north to areas in the west and south of the country (World Bank, 2021a). In Namibia, rainfall and temperature increases could contribute to shifts in malaria outbreaks to areas in the centre and south of the country (World Bank, 2021d). Countries currently outside malaria transmission zones (e.g., Lesotho) could witness new outbreaks of the disease in the future (World Bank, 2021c).

© Crown Copyright 2022, Met Office

Over the period 2030-2060, a further 2.9 million people could be living in areas classified as endemic for malaria, including new areas in northern Zambia, Mozambique and Malawi (USAID, 2022). New areas which are suitable for seasonal transmission could emerge in Zambia, Madagascar, Mozambique, South Africa, Eswatini, Botswana and Namibia (Figure 12). In these areas, people are unlikely to have existing immunity and healthcare facilities are unlikely to be experienced in dealing with outbreaks of malaria. The expansion could mean that an additional 23-29 million people are at risk of malaria. Other factors will also shape malaria risk, including deforestation, land use change, and urbanisation, affecting mosquito habitats as well as transmission opportunities (Reddy-Davis and Vincent, 2017).

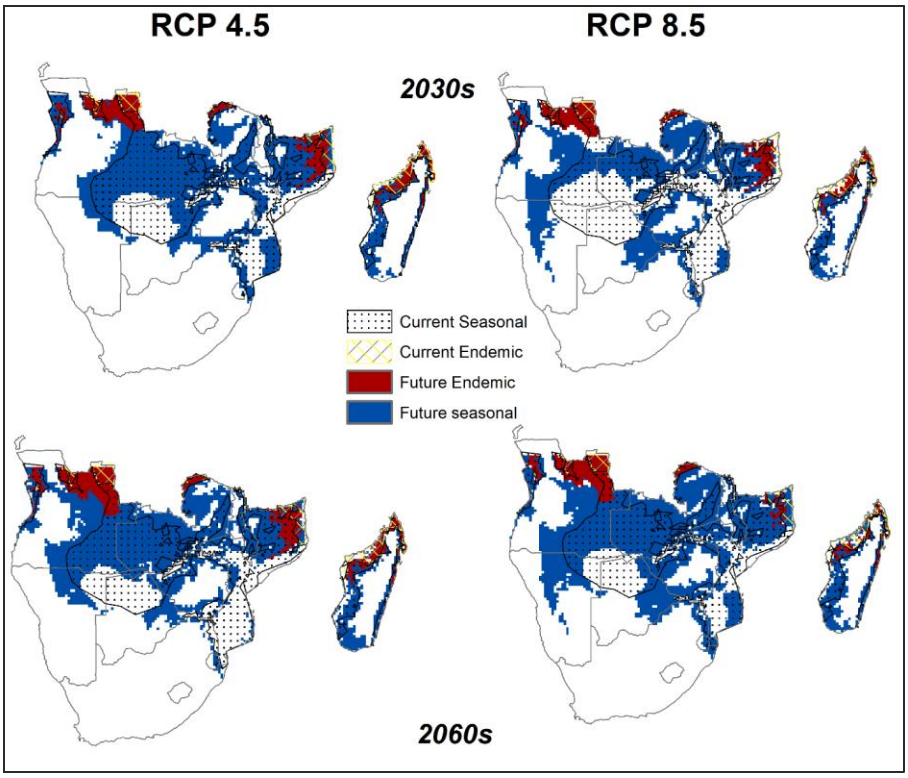


Figure 12: Extent of malaria areas classified as seasonal and endemic by the 2030s and 2060s under medium (RCP4.5) and high (RCP8.5) emission scenarios. Source: USAID, 2022.

Increases in heavy rainfall events and flooding will increase the risk of water-borne diseases such as cholera, typhoid and leptospirosis, which are already common in flood prone areas (Howard et al, 2016). The contamination of drinking water through flooding is a particular risk, notably in urban centres. The contamination of drinking water in cities such as Lusaka, Zambia already results in outbreaks of cholera, dysentery, and diarrhoea (World Bank, 2021h). Higher temperatures will also facilitate the proliferation of diarrhoea bacterial pathogens and allow them to survive for longer periods (Carlton et al., 2016). In informal settlements across Southern Africa, recurring outbreaks and deaths from cholera are already common (UN-Habitat, 2022). Risks are heightened in areas where there is inadequate access to safe drinking water, sanitation and adequate drainage (see also Sections 3.2 and 3.4).

An increase in average annual temperatures and in hot extremes, combined with other factors such as air pollution, will increase the non-communicable disease burden. High/extreme temperatures can exacerbate cardiovascular disease, respiratory disease, stroke, renal diseases, neurodegenerative diseases, and type-2 diabetes (Ncongwane et al.,

© Crown Copyright 2022, Met Office

2021). The risk posed by these health issues will likely be intensified as extreme weather events increase in frequency and intensity and air pollution in urban areas increases.

3.5.3 Heat stress

Projected increases in the intensity and frequency of hot extremes are likely to have significant impacts on human health, including dehydration, heat-stroke, reduced productivity, exacerbation of respiratory conditions, and indirect impacts via deteriorating water quality (Ncongwane et al, 2021). Heat stress occurs when the body is unable to regulate its temperature between the range of 35-37°C. Combinations of heat and humidity, typically measured in terms of wet bulb temperatures, present a particular risk to human health and survival. Wet bulb temperatures above 34-35°C pose severe risks to human health and productivity, with wet bulb temperatures of 35°C identified in some studies as a limit for human survivability (Ncongwane et al, 2021; Speizer et al., 2022). Risks are exacerbated when overnight temperatures do not drop below 20°C and allow sufficient cooling – sometimes referred to as 'tropical nights'.

Heat stress presents particular risks to vulnerable populations including elderly people, infants, pregnant women, people living in cramped conditions in informal settlements, and those engaged in manual labour without cooling and in direct sunlight (Ncongwane et al., 2021). Due to the 'urban heat island' effect, those living in densely populated urban areas are at higher risk than their rural and semi-rural counterparts (Ncongwane et al. 2021).

The impacts of heat extremes are likely to affect all of Southern Africa but may vary in severity across the region, with the strongest warming trends projected for the arid desert regions. Those include Namibia, Botswana, Zimbabwe and South Africa, as well as the tropical regions of Mozambique and Malawi. Risks associated with heat stress will be shaped by the ways in which urban spaces are planned and constructed, including provisions for adequate access to reliable sources of energy and electricity to provide cooling as well as availability of green spaces, which have the potential to lower the risk of heat stress (Reddy-Davis and Vincent, 2017).

3.5.4 Air quality

Climate change is likely to have a detrimental impact on air quality in Southern Africa, though the severity of impacts will be determined by local emissions and land use. Changes to temperature, rainfall, and wind speed and direction all determine the spread and concentration of air pollutants (Marcantonio et al, 2021). Higher temperatures and heatwaves can aid the formation of surface ozone, through the oxidation of nitrogen and carbon monoxide, which exacerbates respiratory diseases (Marcantonio et al, 2021). This risk is increased where countries lack emission controls. In Southern Africa, inadequate air quality control and emissions monitoring is already contributing to poor air quality in the region (Davis-Reddy and Vincent, 2017).

Rising temperatures in arid and semi-arid areas will lead to greater drying and evaporation, potentially increasing the risk of dust storms. Whilst arid and semi-arid areas may be at higher direct risk, dust storm particles can be transported thousands of kilometres and affect other areas (Schweitzer et al., 2018). Dust storm particles can be damaging to human respiratory systems and can contribute to respiratory diseases (Schweitzer et al., 2018). Soil contaminants (agricultural, sewage, and industrial) may be disturbed during dust storms, presenting further health risks (Schweitzer et al., 2018).

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

Poor air quality resulting from industrial activity, waste burning, transport emissions, forest and savanna fires and fuelwood/charcoal burning contributes to respiratory diseases (Marcantonio et al, 2021; Health Effects Institute, 2022). Across Southern Africa, air pollution has been associated with higher mortality than unsafe WASH and, in Africa as a whole, as the second leading risk factor for premature death after malnutrition. A growing body of evidence links long-term exposure to air pollution, including domestic use of biomass, with chronic diseases such as tuberculosis, pneumonia, pulmonary disease, lung cancer and type 2 diabetes, as well as impaired cognitive development in children (Marcantonio et al, 2021; Health Effects Institute, 2022).

3.5.5 Nutrition

Those most at risk of nutrition-related health risks include elderly people, children, pregnant people and nursing mothers, and people with pre-existing health concerns (WFP, 2016). Higher temperatures can reduce agricultural yields and increase long-term food insecurity (see Section 3.1) Higher temperatures can also impact a child's ability to retain nutrients through 'thermal stress-induced' appetite loss and increased dehydration and diarrhoea (Baker and Anttila-Hughes, 2020). Childhood malnutrition can increase vulnerability to other health risks such as malaria, respiratory diseases, and intestinal infections, as well as increasing mortality risks (Baker and Anttila-Hughes, 2020).

There are clear links between malnutrition and inadequate WASH, likely to be exacerbated by rising temperatures, floods and the contamination of water (Howard et al, 2016; Calow et al, 2018 – see also Sections 3.2.3, 3.4.4). Frequent bouts of diarrhoea (and intestinal parasitosis - infection with parasites) contribute to malnutrition, rendering children, in particular, more susceptible to other diseases, with lasting impacts on growth and development. It has been suggested that 40-60% of childhood undernutrition is caused by repeated diarrhoea or intestinal parasitosis as a result of unsafe WASH (Pruss-Usten et al, 2008). Malnutrition also increases both the susceptibility to diarrhoea and the severity of episodes, and WASH-related pathogens (especially those causing diarrhoea) lead to reduced food intake and the malabsorption of nutrients (Khalil et al, 2018; Iddrisu et al, 2021).

© Crown Copyright 2022, Met Office

3.6 Coastal fisheries and the marine environment

Summary of risks relevant to coastal fisheries and the marine environment

- The impacts of climate change on coastal-marine ecosystems are likely to be significant, with coral, seagrass, mangrove and saltmarsh ecosystems adversely affected,
- Climate-related disruption to coastal-marine ecosystems presents risks to key services and support functions, including food security, employment, flood protection and tourism.
- Fisheries are threatened by rising sea surface temperatures, marine heatwaves, coastal eutrophication, ocean acidification, and habitat disruption, amplifying other pressures from overfishing and habitat destruction. Artisanal fishers may be especially vulnerable.
- Risks to the blue economy include impacts on important tourism industries in Mauritius, Seychelles and Comoros, as well as wider impacts on maritime transportation and offshore mineral/fossil fuel exploitation.

3.6.1 Context

The waters surrounding Southern Africa are home to globally significant, diverse, and productive marine ecosystems. The Northern Mozambique Channel, bordering Mozambique, western Madagascar, and Comoros, is home to one of the world's richest marine biodiversity areas (Ghermandi et al., 2019). The Benguela upwelling system off the coast of Namibia, where regular pulses of nutrient-rich cold water rise from the ocean depths, is among earth's most productive fisheries (Heymans and Baird, 2000).

South Africa is home to a diverse range of marine ecosystems on an extensive coastal shelf where the Atlantic and Indian Oceans meet. The Sardine Run (March to July) starting off the Agulhas Bank is among the world's largest biomass migrations (Teske et al, 2021). The marine ecosystems of Seychelles, Mauritius, and eastern Madagascar are nationally important sources of revenue, employment, and food security.

3.6.2 Biodiversity and ecology

The negative impacts of climate change on marine ecosystems will be significant, compounding other pressures from over-fishing, pollution, dredging, and habitat destruction (Donney et al, 2012; Gissi et al, 2021; Cooley et al, 2022). In Southern Africa, marine warming will push species southwards and intensifying marine heatwaves will cause more frequent eutrophic conditions and more coral bleaching events in coastal areas of South Africa, Mozambique and the Indian Ocean Islands (Donney et al, 2012; Gissi et al, 2021). Sea level rise and increasing storm intensity will jeopardise shallow marine habitats, while ocean acidification poses a long-term risk to marine life generally (Donney et al, 2012; Gissi et al, 2021).

© Crown Copyright 2022, Met Office

Coral reefs

Marine heatwaves threaten coral reefs and the important ecosystem services they provide, including nurseries and habitats for fish, particularly for benthic and demersal fish critical to artisanal fisheries, services to tourism and recreation (see below), coastal protection, and sources of material for bioprospecting. Coral reef ecosystems are found across the Western Indian Ocean. The Northern Mozambique Channel (Zone 5, western side of Zone 8, and Comoros) is a global coral reef biodiversity hotspot, although biodiversity and reef development rapidly attenuate into southern Mozambique and South Africa (Veron, 2000; Spalding, Ravilious & Green, 2001). A recent IUCN study concluded that **coral reefs across the region are existentially threatened by climate change and other anthropogenic stresses**, with the reefs of Comoros, Mauritius, East and South Madagascar rated as Critically Endangered, the reefs of Outer Seychelles, West and North Madagascar as Endangered, and the reefs of Mozambique, north Seychelles, and eastern South Africa as Vulnerable (Obura et al., 2021).

Warming seas and marine heatwaves are the principal threat from climate change to coral reefs, with **heatwaves of just 1°C to 2°C above average conditions causing coral bleaching** (Obura et al., 2021). Large-scale coral bleaching killed approximately 20% of Western Indian Ocean corals during in 2016; in the Seychelles 90% of sites were affected and 50% of coral cover died (Gudka et al, 2018; Gudka et al., 2020). Although it may be regularly exposed to marine heatwaves by mid-century (van Hooidonk et al. 2016) some research suggests the Northern Mozambique Channel may be relatively resilient and adaptable to marine heatwaves due to its diversity of coral reef micro-habitats and refuges (McClanahan & Muthiga, 2017). Consequently, the area has been tentatively identified as a globally important refuge for corals and proposed as a centre for global conservation efforts (Beyer et al., 2018).

The loss or degradation of coral reefs increases coastal exposure to waves, storms and floods. Meta-analyses reveal that coral reefs provide substantial protection against natural hazards by reducing wave energy by an average of 97%. Reef crests alone dissipate most of this energy – some 86% (Ferrario et al, 2014).

Until 2050, coral reefs in some areas may benefit from vertical growth allowed by sea level rise (Mucova et al, 2021), although this is not guaranteed. Ocean acidification will increasingly slow reef growth (Allemand & Osborn, 2019), and sea level rise will alter favourable conditions for reef growth in some areas; by 2100 the negative impacts of sea level rise on coral reefs are expected to be more significant (Mucova et al, 2021).

Mangroves

Rising sea levels and more intense tropical cyclones threaten mangrove habitats in most areas of Southern Africa. Mangroves in Madagascar, Mozambique, eastern South Africa, and the Seychelles, Mauritius, and Comoros provide important ecosystem services including sea defences, fish nurseries, livestock grazing, timber, and carbon sequestration. They are, however, under anthropogenic pressure from land conversion to agriculture, shrimp farming, and urbanisation (Friess et al., 2019); for example, mangrove cover in Madagascar declined 21% between 1990 and 2010 (Jones et al., 2016). Intense tropical cyclones and increasing storm intensity will devastate mangrove areas (Rakotondravony et al. 2018).

Some aspects of climate change may enable mangrove habitats to colonise new areas. Increasing temperatures may see mangrove stands up to 70km further south along South Africa's coast, while sea level rise may permit inland expansion of habitats in central

© Crown Copyright 2022, Met Office

Mozambique and western Madagascar, although this depends on coastal development not blocking settlement (Naidoo, 2016; Friess at el., 2019). Localised and limited studies suggest mangroves in the Indo-Pacific are not growing rapidly enough to keep pace with current rates of sea level rise (Lovelock et al, 2015), but there is limited confidence in projections of future growth rates (Friess et al, 2019).

Seagrasses and saltmarshes

Seagrasses provide important ecosystem services including fish nurseries, carbon sequestration, and the mitigation of coastal erosion, and may be threatened by rising sea, salinity and ultra-violet light levels (Lugendo, 2015; Obura et al, 2019, Sunny, 2017). Seagrasses are common and diverse across Southern Africa's tropical waters, especially in the Northern Mozambique Channel (Lugendo, 2015). Seagrasses in the region are impacted by floods, storms, fisheries, pollution and coastal development (Lugendo, 2015; Obura et al, 2019). Climate impacts on seagrasses are not well studied, but increasing temperatures and salinity - particularly in shallow waters - are expected to change patterns of distribution, while sea level rise may make some existing deep areas unviable (Sunny, 2017).

Saltmarshes provide important ecosystem services but are threatened by rising sea levels as well as droughts and floods. South Africa has over 150km^2 of saltmarshes, as assessed in 2020, which support diverse ecosystems and are challenged by encroaching agriculture and coastal development; 34% of South Africa's saltmarshes were lost between 1930 and 2018 (Adams, 2020). Rising sea levels are likely to squeeze saltmarshes between deepening waters and coastal development, while increasing occurrence of storm surges, floods, and droughts pose further threats (Adams, 2020). Consequently, **ecosystem services from saltmarshes, such as the mitigation of coastal erosion** (Samoilys et al., 2019) **and carbon sequestration** (Ghermandi et al., 2019), **are likely to deteriorate** (Obura et al, 2019).

Charismatic species

Charismatic species are those with a symbolic value, or widespread popular appeal, used by environmental campaigners to gain popular support for environmental goals, and which can also have high value to tourism. Marine turtles are a case in point, and are common in Mozambique, South Africa, Madagascar, and Mauritius; large green turtle nesting sites are found in Comoros and Seychelles (Obura et al, 2019). **Turtles are particularly vulnerable to the impacts of rising temperatures and sea levels** on their terrestrial reproductive phase, and loggerhead, leatherback and olive ridely populations are particularly vulnerable in Southern Africa compared to other global populations (Fuentes et al., 2013). While climate impacts on sharks are not widely understood, there is speculation that **reduced sightings of white sharks in South Africa may be related to warming waters** (Micarelli et al., 2021). Rising water temperatures may also disrupt migrations of juvenile whale sharks to feed in the cool waters of Southern Mozambique during the southern summer (Rohner et al, 2018).

Other significant but vulnerable charismatic species in the region include East Africa's only viable dugong[32] population in the Bazaruton Archipelago (Findlay, Cockcroft and Guissamulo, 2011), and humpback whales in the Northern Madagascar Channel (Obura et al,

[32] Commonly known as sea cows, dugongs are related to manatees and share a similar appearance, but have a dolphin fluke-like tail and are strictly a marine mammal. The species is listed as vulnerable.

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

2019). The impacts of climate change on these species remains unclear because they have not been well studied.

3.6.3 Impacts on fisheries

Climate change will affect the distribution, productivity and value of fisk stocks. Over-fishing, pollution, and physical degradation of habitats threaten most fish stocks in Southern Africa. Fisheries will also be increasingly threatened by rising sea surface temperatures, marine heatwaves, coastal eutrophication, ocean acidification, and habitat disruption (Cooley et al, 2022). Consequently, climate change will impact the distribution, productivity, and socio-economic value of fish stocks (Sumalia et al., 2012). One study suggests warming will profoundly affect the biomass of target species in south and western South Africa, with reductions of 10-20% in hake and 50% in anchovy by 2050 (Ortega-Cisneros et al., 2018).

Well-documented impacts from climate change observed in South Africa include an eastward shift in stocks of anchovy, sardine, and west coast rock lobster, and a southerly shift of several tropical and subtropical species on the eastern coast (Augustyn et al., 2018; van der Lingen and Hampton, 2018). Declining catches In Mozambique have been attributed to climate change alongside other pressures (McClanahan & Muthiga, 2017; van der Lingen and Hampton, 2018).

Coral reefs, mangroves, and seagrasses are important habitats and nurseries, and climate impacts on these ecosystems will negatively affect associated fisheries in coming decades. Of particular importance are coral reefs, which support many artisanal fisheries in the Western Indian Ocean and are vulnerable to bleaching (see above). Recovery of fish populations after coral bleaching can take several decades, as seen in the widespread mass bleaching of 1998 (Moustahfid et al., 2018). Projections of increasing frequency in bleaching events imply fish populations will not recover between future events (Obura et al., 2019).

Ocean acidification is also likely to become a long-term stressor on stocks of commercial fish and invertebrates, such as lobster, shrimps, and shellfish (Bhadury, 2015; Wang and Wang, 2020). Increases in carbon dioxide content of the oceans changes its chemical composition (causes decreases in carbonate ions) which makes building and maintaining shells difficult for calcifying organisms.

Impacts of climate change on the fisheries sector

Fisheries are socioeconomically significant across Southern Africa but untangling climate risks in a very diverse sector is difficult. There is considerable variation in how significant they are, to whom, why, and how the sector is organised. Socioeconomic vulnerabilities to climate impacts on the fisheries sector vary accordingly.

The upwelling Benguela Current System makes waters off **Namibia** among the most productive in the world and supports an industrialised fleet generating exports worth USD 787 million in 2013. The industrialised sector employs just 15,000 people, however, and artisanal fisheries are almost non-existent (FAO, 2022a). The IPCC 6th Assessment Report revisited earlier assessments of the impacts of climate change on the Benguela Current System (IPCC, 2019) and found no clear trends (Cooley et al, 2022). One study concluded the most climate vulnerable fisheries in Namibia are demersal-trawlers catching hake and monkfish, which are traded to other African countries as an important source of animal protein (van der Lingen and Hampton, 2018).

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

In **South Africa**, most industrial vessels are concentrated in the western shelf, with artisanal activities limited to rural areas such as Transkei and KwaZulu-Natal (FAO, 2022b). Artisanal sardines, anchovies, and other small pelagic fisheries are the most vulnerable subsector due to their socioeconomic importance, low adaptive capacity, and sensitivity to environmental forcing (van der Lingen and Hampton, 2018). The eastward shift of the sardine fishery has also negatively affected its profitability as most large-scale landing sites are in the west of the country (van der Lingen and Hampton, 2018).

Mozambique has a developing industrial fleet in the south, but most fishers are engaged in the artisanal sector, fishing from shore or using boats with either small or no motors (FAO, 2022c). As elsewhere, artisanal fishing is a precarious livelihood with catches declining in recent years. Fisheries production has also been affected by tropical cyclones, with strong winds, heavy rainfall and flood damage to fishing equipment, aquaculture, port and transport infrastructure, and mangrove and coral reef nursery areas (Muhala et al., 2021). Mozambique's fishing sector was recognised as the eighth most climate vulnerable in the world over a decade ago (Allison et al., 2009), yet little progress has been made with assessing climate vulnerability or strengthening resilience (van der Lingen and Hampton, 2018).

In **Madagascar** a small industrial fishing fleet produces an important source of exports (FAO, 2022d). However, artisanal fisheries provide critical sources of animal protein and are thought to provide over 100,000 jobs (FAO, 2022d). Fishing is often a livelihood of last resort due to limited economic diversification and employment opportunities (Failler et al., 2011). Because of this lack of economic diversification in rural areas, the actual number of people depending on fisheries from indirect employment in fish processing, trade, and spillover may be as many as one million (Moustahfid et al., 2018). There has been little progress with assessing the climate vulnerability of the artisanal fishing sector since it is informal and seasonal, though since it depends on shallow water coral reef, mangrove and seagrass habitats, it is thought to be very high (Cooley et al, 2022).

In the **Western Indian Ocean islands**, fishing has economic, cultural, and food security importance, with up to 90% of animal protein coming from fish. In Comoros artisanal fishing dominates and produces limited exports (FAO, 2022e). By contrast, both Mauritius and the Seychelles have extensive fishing industry operations. In the Seychelles the fishing sector contributed 4.1% to GDP in 2013 and generated exports of USD 525 million in 2017, mostly from an industrialised tuna fleet (FAO, 2022f). In Mauritius, by contrast, most fishing is artisanal, but the nation serves as a seafood hub to foreign fleets, including cold storage, processing, and logistics facilities, generating exports worth USD 458 million in 2017 (FAO, 2022g).

Artisanal fishers in the islands largely target demersal and semi-pelagic[33] fish and are highly vulnerable to climate impacts on the coral reefs which underpin the productivity of these systems. As regional hubs, the industrialised fishing operations of Mauritius and the Seychelles are also exposed to climate impacts from the wider Western Indian Ocean region, especially climate variability affecting tuna stocks. In both 1998 and 2007, marine heatwaves off the coast of the Seychelles decimated tuna harvests, with great loss of revenue to the country (Moustahfid et al., 2018). With warmer oceans likely to drive tuna populations towards

[33] Demersal fish live and feed on or near the bottom of water bodies. Pelagic fish occupy mid-water zones, neither close to the bottom nor near the shore.

© Crown Copyright 2022, Met Office

higher latitudes, affecting the distribution and profitability of fleet operations, this key sector of the Seychelles' and Mauritian economies may be vulnerable (Moustahfid et al., 2018).

3.6.4 The blue economy

Coastal and marine resources provide important and increasingly diverse benefits to coastal nations of Southern Africa aside from fisheries, and the sustainable growth of these are an important component of building resilience. Chief among these is **tourism**, but **maritime transportation, offshore fossil fuel** and **mineral resources**, and new technology such as bioprospecting (obtaining commercially valuable materials from plant and animal species) and blue carbon sectors are of growing interest and investment (Attri and Bohler-Mulleris, 2018; Bolaky, 2020; Hammar, Kaal & Holgerson, 2020). The Seychelles, Mauritius, Comoros, South Africa, and Namibia have developed national blue economy strategies and/or policies, while Mozambique and Madagascar are preparing their own.

Coastal and marine tourism

Risks to important tourist industries include degradation of sandy beaches due to sea level rise, declining amenity value to tourism from degraded coral reefs and declines in marine wildlife, plus shifting seasonality due to increasing thermal stress and visitor preferences. Coastal and marine tourism, while under-exploited, makes significant contributions to the economies of Mauritius, Comoros and especially the Seychelles (Karani & Failler, 2020 – see Table 3 below). Tourism is a particularly important sector for the relatively undiversified economies of the small island nations, where all tourism is effectively coastal- or marine-related, and focuses on beach holidays, marine sports, and marine eco-tourism (Brett, 2021). Wildlife watching, scuba diving and beach holidays are also significant tourism products in South Africa, Mozambique, and Madagascar (Karani & Failler, 2020). All are potentially threatened by climate-related degradation of the marine environment (Karani & Failler, 2020).

Table 3: Contributions of tourism to GDP and Employment in 2019 for Comoros, Mauritius, and the Seychelles. Source: World Travel and Tourism Council 2022 data: https://wttc.org/

	% of GDP	% of Employment
Comoros	9.6%	10.1%
Mauritius	19.5%	19.2%
Seychelles	39.2%	41.8%

Maritime transport and resource extraction

Offshore shipping, gas and oil and seabed mining are all growth sectors in the region. Globally important shipping routes between Asia and the Atlantic pass through the Indian Ocean, and Mauritius is a regional loading and transhipment hub for the maritime logistics industry, while the Seychelles generates income from port services to fishing vessels. South Africa, Namibia and Mozambique all have large port facilities serving regionally important trade routes, including for landlocked countries such as Malawi and Botswana. While offshore oil, gas, and mineral extraction are relatively under-developed, Southern Africa is a hotspot of exploration and investment (Llewellyn et al., 2016; Attri & Bohler-Mulleris, 2018). Oil and gas are exploited in South Africa and Mozambique and being intensively explored in Namibia and the Indian Ocean Island states, while seabed mining exploration is accelerating across the

Met Office Hadley Centre ODI UKaid from the British people
© Crown Copyright 2022, Met Office

region despite concerns about environmental impacts (Miller et al., 2018). Rising international gas prices may encourage exploration and production, despite climate concerns.

Threats from climate change include **sea level rise impacts on port facilities and the impacts of storms, storms surges, and cyclones on port facilities, surface support vessels, and shipping safety and routing**, as well as indirect impacts (Wright, 2013; Caier et al., 2018). For example, the maritime security sector has also noted that climate impacts on livelihoods may see fishing vessels turning to piracy and other maritime crime, as happened in Somalia between 2008-2012 (Moss & Pigeon, 2022). Climate change may also affect Mauritius' role as a shipping hub, with Indian Ocean shipping declining in preference to faster routes between Asia and Europe via an ice-free Arctic (Smith and Stephenson, 2013).

© Crown Copyright 2022, Met Office

Image location: Anakoa, Madagascar

© Crown Copyright 2022, Met Office

4 References

Introduction

Begum, A., R., R. Lempert, E. Ali, T.A. Benjaminsen, T. Bernauer, W. Cramer, X. Cui, K. Mach, G. Nagy, N.C. Stenseth, R. Sukumar, and P. Wester, (2022): Point of Departure and Key Concepts. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 121-196, doi:10.1017/9781009325844.003.

Hansen, J., Hellin, J., Rosenstock, T., Fisher, E., Cairns, J., Stirling, C., Lamanna, C., van Etten, J., Rose, A. and Campbell, B. (2019) Climate risk management and rural poverty reduction. *Agricultural Systems*, 172: 28-46

Sachs, J., McArthur, J.W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M. and McCord, G. (2004). *Ending Africa's poverty trap*. Brookings papers on economic activity 2004(1): 117-240 .

Schipper, L. and Pelling, M. (2006). Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters* 30(1): 19-38

Wisner, B., Blaikie, P., Cannon, T. and Davis, I. (2003) *At Risk: natural hazards, people's vulnerability and disasters* (2nd Ed.) New York, NY, Routledge, 464 pp.

© Crown Copyright 2022, Met Office

Section 2

Allison, L et al (2021) Projections of 21st century sea level rise for the coast of South Africa. *Environmental Research Communications* **4** 025001

Cucchi, M. et al., 2020: WFDE5: bias-adjusted ERA5 reanalysis data for impact studies. *Earth System Science Data*, 27 **12(3)**, 2097–2120, doi:10.5194/essd-12-2097-2020

Doherty et al. (2022) Climate risk report for the Central Africa region. Met Office, ODI, FCDO.

Devereux, S. (2009). *Seasonality and Social Protection in Africa*. Growth and Social Protection Working Paper 07, Future Agricultures Programme, IDS. January 2009.

Dunning, C. M., Black, E., & Allan, R. P. (2018). Later wet seasons with more intense rainfall over Africa under future climate change. *Journal of Climate*, *31*(23), 9719–9738. https://doi.org/10.1175/JCLI-D-18-0102.1

Ellis, F. (2013). *Topic Guide: Agriculture and Growth*. Evidence on Demand, DFID. https://www.gov.uk/research-for-development-outputs/topic-guide-agriculture-and-growth

Engelbrecht, F.A., J.L. McGregor, and C.J. Engelbrecht, 2009: Dynamics of the Conformal-Cubic Atmospheric Model projected climate-change signal over southern Africa. *International Journal of Climatology*, **29(7)**, 1013–1033, doi:10.1002/joc.1742.

FAOSTAT (2022) Food and agriculture data. https://www.fao.org/faostat/en/#home

Hallegatte, S. et al. (2016). *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Washington, DC: World Bank.

Hamududu and Killintveit (2016) *Assessing Climate Change Impacts on Global Hydropower* in: Climate Change and the Future of Sustainability. Apple Academic Press, New York, NY

Herschbach, H. et al (2020) The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society. 146(730), 1999-2049

IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

IPCC Interactive Atlas (2021). Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon. *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K.Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/

Luijendijk, A., Hagenaars, G., Ranasinghe, R. *et al.* The State of the World's Beaches. *Sci Rep* **8,** 6641 (2018). https://doi.org/10.1038/s41598-018-24630-6

© Crown Copyright 2022, Met Office

Mather A.A. and Stretch, D.D. (2012) A perspective on sea level rise and coastal storm surge from southern and eastern africa: a case study near Durban, South Africa Water 4 237–59

Pinto, I., C. Jack, and B. Hewitson, 2018: Process-based model evaluation and projections over southern Africa from Coordinated Regional Climate Downscaling Experiment and Coupled Model Intercomparison Project Phase 5 models. *International Journal of Climatology*, **38(11)**, 4251–4261, doi:10.1002/joc.5666.

Prevention Web (2022). *Climate Change – Exacerbated Rainfall Causing Devastating Flooding in Eastern South Africa*. Research Brief, 13 May 2022. https://www.preventionweb.net/news/climate-change-exacerbated-rainfall-causing-devastating-flooding-eastern-south-africa

Raga, S. and Pettinotti, L. (2022). *Economic vulnerability to the Russia–Ukraine war Which low- and middle-income countries are most vulnerable?* ODI Emerging Analysis, April 2022. ODI: London.

Relief Web (2022) Southern Africa: Drought - 2018-2022. https://reliefweb.int/disaster/dr-2018-000429-zwe

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen. (2022). *Africa*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.011

Wiggins, S. (2022). *Impacts of War on Food Prices and Food Security in Potentially Vulnerable Countries*. ODI Policy Brief, April 2022.

© Crown Copyright 2022, Met Office

Agriculture

Adhikari, U, Nejadhashemi, A. P., and Woznicki, S. A. (2015). Climate change and eastern Africa: a review of impact on major crops. *Food and Energy Security,* 4(2): 110–132.

Adjei-Nsiah, S. et al (2020). The root and tuber crop farming system: diversity, complexity and productivity potential. In J. Dixon et al. (eds.), *Farming Systems and Food Security in Africa: Priorities for Science and Policy under Global Change* (182-213). London and New York: Routledge.

Assan, H. (2014). Possible impact and adaptation to climate change in livestock production in Southern Africa. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 8(2), 104-112.

Asseng, S. et al., (2019). Climate change impact and adaptation for wheat protein. *Global Change Biology*, 25(1), 155–173, doi:10.1111/gcb.14481.

Bell R. J. et al. (2012) Changes in the biomass of chambo in the southeast arm of Lake Malawi: a stock assessment of *Oreochromis* spp. *Journal of Great Lakes Research,* 38, 720–729.

Bhave, A.G., Bulcock, L., Dessai, S., Conway, D., Jewitt, G., Dougill, A.J., Kolusuf, S.R. and Mkwambisig, D. (2020). Lake Malawi's threshold behaviour: A stakeholder-informed model to simulate sensitivity to climate change. *Journal of Hydrology* 584 (2020) 124671. https://doi.org/10.1016/j.hydrol.2020.124671

Bhave, A.G., Conway, D., Dessai, S., Dougill, A.J. and Mkwambisi, D. (2022). Stree-testing development pathways under a changing climate: water-energy-food security in the lake Malawi-Shire river system. *Phil.Trans. R. Soc*. A380:20210134. https://doi.org/10.1098/rsta.2021.0134

Boffa, J.-M. et al. (2020). The agropastoral farming system: achieving adaptation and harnessing opportunities under duress. In J. Dixon et al. (eds.), *Farming Systems and Food Security in Africa: Priorities for Science and Policy under Global Change* (105-147). London and New York: Routledge.

Boone, R. B. et al., (2018): Climate change impacts on selected global rangeland ecosystem services. *Global Change Biology*, 24(3), 1382–1393, doi:10.1111/ gcb.13995.

Bouley, T. and Plante, C. (2014). *Reducing Climate-Sensitive Disease Risk*. World Bank Report 84956-GLB. Washington, DC: World Bank.

Caniço, A., Mexia, A., and Santos, L. (2020). Seasonal dynamics of the alien invasive insect pest Spodoptera frugiperda smith (Lepidoptera: Noctuidae) in Manica province, central Mozambique. *Insects*, *11*(8), 512.

CDKN (2022) *The IPCC'S Sixth Assessment Report: impacts, adaptation options and investment areas for a climate-resilient southern Africa.* Climate and Development Knowledge Network (CDKN), African Climate and Development Initiative (ACDI), SouthSouthNorth (SSN) and ODI.

Chakoma, C. I. (2012). Sustainable forage production strategies for small scale livestock production in Zimbabwe. *International Journal of Agriculture Innovations and Research*, *1*(3), 85-90.

© Crown Copyright 2022, Met Office

Chapman, S. et al. (2020). Impact of climate change on crop suitability in sub-Saharan Africa in parameterized and convection-permitting regional climate models. *Environmental Research Letters*, 15(9), 094086.

Chemura, A. et al. (2020). The impact of land-use/land cover changes on water balance of the heterogeneous Buzi sub-catchment, Zimbabwe. *Remote Sensing Applications: Society and Environment*, 18, 100292.

Cumming, D. H. M. et al. (2015). Beyond fences: wildlife, livestock and land use in Southern Africa. In J. Zinsstag et al. (eds.), *One Health: The Theory and Practice of Integrated Health Approaches* (243-257). CABI International.

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

de Leeuw, J. et al. (2020). The pastoral farming system: balancing between tradition and transition. In J. Dixon et al. (eds.), *Farming Systems and Food Security in Africa: Priorities for Science and Policy under Global Change* (318-353). London and New York: Routledge.

Devereux, S. (2009). *Seasonality and Social Protection in Africa*. Growth and Social Protection Working Paper 07, Future Agricultures Programme, IDS. January 2009.

Dixon, J. et al. (2020a) Africa through the farming systems lens: context and approach. In J. Dixon et al. (eds.), *Farming Systems and Food Security in Africa: Priorities for Science and Policy under Global Change* (3-36). London and New York: Routledge.

Dixon, J. et al. (2020b) Ways forward: strategies for effective science, investments and policies for African farming and food systems. In J. Dixon et al. (eds.), *Farming Systems and Food Security in Africa: Priorities for Science and Policy under Global Change* (562-588). London and New York: Routledge.

Ellis, F. (2013). *Topic Guide: Agriculture and Growth*. Evidence on Demand, DFID. https://www.gov.uk/research-for-development-outputs/topic-guide-agriculture-and-growth

FAO (2021). 'Fishery statistical collections: global production', https://www.fao.org/fishery/statistics/global-production/en

FAOSTAT (2022). 'Crops and livestock products', https://www.fao.org/faostat/en/#data/QCL

Fluet-Chouinard, E., Funge-Smith, S., and McIntyre, P. B. (2018). Global hidden harvest of freshwater fish revealed by household surveys. *Proceedings of the National Academy of Sciences*, 115(29), 7623-7628.

FSIN and GNAFC (2021). *2021 Global Report on Food Crises.* Food Security Information Network (FSIN) and Global Network Against Food Crises (GNAFC). Rome: FSIN and GNAFC.

Government of Mozambique. (2019). *Mozambique Cyclone Idai: post disaster needs assessment*. Maputo: Government of Mozambique.

Hachigonta, S. et al. (eds.) (2013). *Southern African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

Hadebe, S. T., A. T. Modi, and T. Mabhaudhi (2017). Drought tolerance and water use of cereal crops: a focus on sorghum as a food security crop in Sub-Saharan Africa. *Journal of Agronomy and Crop Science*, 203, 177–191.

© Crown Copyright 2022, Met Office

Hallegatte, S. et al. (2016). *Shock Waves: Managing the Impacts of Climate Change on Poverty.* Washington, DC: World Bank.

Hamerlynck, O. et al. (2020). The fish-based farming system: maintaining ecosystem health and flexible livelihood portfolios. In J. Dixon et al. (eds.), *Farming Systems and Food Security in Africa: Priorities for Science and Policy under Global Change* (354-392). London and New York: Routledge.

Hänke, H., and Barkmann, J. (2017). Insurance function of livestock: farmers coping capacity with crop failure in southwestern Madagascar. *World Development*, 96, 264-275.

Hasegawa, T. et al., (2021). A global dataset for the projected impacts of climate change on four major crops. *bioRxiv*, 2021.2005.2027.444762, doi:10.1101/2021.05.27.444762.

Jarvis, A. et al. (2012). Is cassava the answer to African climate change adaptation? *Tropical Plant Biology*, 5, 9–29.

Magadza, C.H.D. (2011). Indications of the effects of climate change on the pelagic fishery of Lake Kariba, Zambia–Zimbabwe. *Lake and Reservoirs: Research and Management*, 16, 15-22.

Magiri, R. et al. (2021). Impact of climate change on animal health, emerging and re-emerging diseases in Africa. In W. L, Filho et al. (eds.), *African Handbook of Climate Change Adaptation* (1835-1851). Springer Cham.

Makwinja, R. et al. (2021a). Impact of land use/land cover dynamics on ecosystem service value: a case from Lake Malombe, Southern Malawi. *Environmental Monitoring and Assessment*, 193(8).

Makwinja, R. et al. (2021b). Lake Malombe fishing communities' livelihood, vulnerability, and adaptation strategies. *Current Research in Environmental Sustainability*, 3, 100055.

Makwinja, R. et al. (2021c). Land use/land cover dynamics, trade-offs and implications on tropical inland shallow lakes' ecosystems' management: case of Lake Malombe, Malawi. *Sustainable Environment,* 7(1).

Mapfumo, P., Jalloh, A., and Hachigonta, S. (2014). *Review of research and policies for climate change adaptation in the agriculture sector in Southern Africa*. AfricaInteract.

Marshall, B. E. (2012). Does climate change really explain changes in the fisheries productivity of Lake Kariba (Zambia-Zimbabwe)? *Transactions of the Royal Society of South Africa*, 67(1).

Marshall, B. E. (2017). An assessment of climate change and stratification in Lake Kariba (Zambia–Zimbabwe). *Lakes and Reservoirs: Research and Management*, 22, 229–240.

Meynard, C. N., Migeon, A., and Navajas, M. (2013). Uncertainties in predicting species distributions under climate change: a case study using Tetranychus evansi (Acari: Tetranychidae), a widespread agricultural pest. *PLoS One*, *8*(6), e66445.

Midgley, S. J. E. et al. (2012a). *Mapping climate risk and vulnerability in the Zambezi River Basin: country report for Malawi*. Cape Town: Climate and Development Knowledge Network (CDKN).

Midgley, S. J. E. et al. (2012b). *Mapping climate risk and vulnerability in the Zambezi River Basin: country report for Mozambique*. Cape Town: CDKN.

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Midgley, S. J. E. et al. (2012c). *Mapping climate risk and vulnerability in the Zambezi River*

Motswagole, R., Gotcha, N., and Nyamukondiwa, C. (2019). Thermal biology and seasonal population abundance of Bactrocera dorsalis Hendel (Diptera: Tephritidae): implications on pest management. *International Journal of Insect Science*, *11*, 1179543319863417.

Muringai, R. T., Mafongoya, P., and Lottering, R. T. (2022a). Climate change perceptions, impacts and adaptation strategies: insights of fishers in Zambezi River Basin, Zimbabwe. *Sustainability*, 14(6), 3456.

Muringai, R. T., Mafongoya, P., and Lottering, R. T. (2022b). Sub-Saharan Africa freshwater fisheries under climate change: a review of impacts, adaptation, and mitigation measures. *Fishes*, 7(3), 131.

Naidoo, S., Davis, C. and Archer van Garderen, E. (2013). *Forests, rangelands and climate change in southern Africa*. Forests and Climate Change Working Paper No.12. Rome, Food and Agriculture Organisation (FAO) of the United Nations.

Ndebele-Murisa, M. R., Mashonjowa, E., and Hill, T. (2011). The implications of a changing climate on the Kapenta fish stocks of Lake Kariba, Zimbabwe. *Transactions of the Royal Society of South Africa*, *66*(2), 105-119.

Ndebele-Murisa, M. R., Musil, C. F., and Raitt, L. M. (2012) Phytoplankton biomass and primary production dynamics in Lake Kariba. *Lakes and Reservoirs: Research and Management*, 17, 275-289.

Nkwanda, I. et al. (2021). Impact of land-use/land-cover dynamics on water quality in the upper Lilongwe river basin, Malawi. *International Journal of Energy and Water Resources*, 5(2), 193–204.

Ogutu-Ohwayo, R. et al. (2016). Implications of climate variability and change for African lake ecosystems, fisheries productivity, and livelihoods. *Journal of Great Lakes Research*, *42*(3), 498-510.

Ortiz-Bobea, A. et al.,(2021). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11(4), 306–312, doi:10.1038/s41558-021-01000-1.

Palamuleni, L., Ndomba, P., and Annegarn, H. (2011). Evaluating land cover change and its impact on hydrological regime in upper Shire river catchment, Malawi. *Regional Environmental Change*, 11(2011), 845–855.

Pullanikkatil, D. et al. (2020). Unsustainable trade-offs: provisioning ecosystem services in rapidly changing Likangala River catchment in southern Malawi. *Environment, Development and Sustainability,* 22(2), 1145–1164.

Ray, D. K. et al.(2019). Climate change has likely already affected global food production. *PLoS One*, 14(5), e0217148, doi:10.1371/journal.pone.0217148.

Santana, P. A. et al. (2019). Assessing the impact of climate change on the worldwide distribution of Dalbulus maidis (DeLong) using MaxEnt. *Pest Management Science*, *75*(10), 2706-2715.

© Crown Copyright 2022, Met Office

Savary, S. et al., (2019). The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution*, 3(3), 430–439, doi:10.1038/s41559-0180793-y.

Sejian, V. et al. (2021). Heat stress and goat welfare: adaptation and production considerations. *Animals*, 11(4), 1021.

Shinn, J. E. and Hall-Reinhard, A. (2019). Emphasizing livelihoods in the study of social-ecological systems: insights from fishing practices in the Okavango Delta, Botswana. *South African Geographical Journal*, 101(1), 121-139.

Sibanda, S. and Ahmed, F. (2021). Modeling historical and future land use/land cover changes and their impact on wetland area in Shashe sub-catchment, Zimbabwe. *Modeling Earth Systems and Environment*, 7(1), 57–70.

Siderius, C., Kolusu, S.R., Todd, M.C., Washington, R.T., Bhave, A., Dougill, A.J., Reason, C.J.C, Mkwambisi, D.D., Kashaigili, J.J., Pardoe, J. Harou, J.J., Vincent, K., Hart, N.C.G, James, R., Washington,R., Geressu, R.T. and Conway, D. (2021). Climate variability affects water-energy-food infrastructure performance in East Africa, *One Earth*, Volume 4, Issue 3, 2021, Pages 397-410, ISSN 2590-3322, https://doi.org/10.1016/j.oneear.2021.02.009.

Simmance, F. et al. (2021). *Sustaining and improving the contribution small-scale fisheries make to healthy and sustainable food systems in Malawi*. Penang: WorldFish.

Siziba, N. et al. (2011). Spatial and temporal variations of microinvertebrates across temporary floodplains of the lower Okavango Delta, Botswana. *Physics and Chemistry of the Earth, Parts A/B/C*, 36(14-15), 939-948.

Siziba, N. et al. (2013). Variation in assemblages of small fishes and microcrustaceans after inundation of rarely flooded wetlands of the lower Okavango Delta, Botswana. *Environmental Management*, *52*(6), 1386-1399

Stevens, T. and Madani, K. (2016). Future climate impacts on maize farming and food security in Malawi. *Scientific Reports,* 6, 36241*.*

Syed, T. and Gomes, A. C. C. (2022). 'Climate-resilient livestock in Botswana and Namibia', https://blogs.worldbank.org/nasikiliza/climate-resilient-livestock-botswana-and-namibia

Thornton, P. and L. Cramer (eds.) (2012). *Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate*. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen. (2022). *Africa*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.011.

Tschirley, D., Haggblade, S., and Reardon, T. (eds.). (2014). *Population growth, climate change and pressure on the land: Eastern and Southern Africa*. East Lansing: Global Center for Food Systems Innovation (GCFSI).

© Crown Copyright 2022, Met Office

Tweddle, D. et al. (2015). Challenges in fisheries management in the Zambezi, one of the great rivers of Africa. *Fisheries Management and Ecology*, 22, 99–111.

United States Agency for International Development (USAID). (2016a). *Climate change risk profile: Madagascar*. United States Agency for International Development.

USAID. (2016b). *Climate change risk profile: Mozambique*. United States Agency for International Development.

USAID. (2016c). *Climate change risk profile: Southern Africa*. United States Agency for International Development.

USAID. (2016d). *Climate change risk profile: Zambia*. United States Agency for International Development.

USAID. (2017). *Climate change risk profile: Malawi*. United States Agency for International Development.

Utete, B. et al. (2018). Fish catches, and the influence of climatic and non-climatic factors in Lakes Chivero and Manyame, Zimbabwe. *Cogent Food and Agriculture,* 4, 1435018.

Weyl, O. L. F., Ribbink, A. J., and Tweddle, D. (2010). Lake Malawi: fishes, fisheries, biodiversity, health and habitat. *Aquatic Ecosystem Health and Management,* 13, 241– 254.

Wiggins, S. and Lankford, B. (2019). *Farmer-led irrigation in sub-Saharan Africa: synthesis of current understandings*: DEGRP Synthesis Report.

Woittiez, L. S. et al. (2013) The use of woodland products to cope with climate variability in communal areas in Zimbabwe. *Ecology and Society*, 18(4), 24.

World Bank. (2021a). *Climate risk country profile: Botswana*. Washington, DC: World Bank.

World Bank. (2021b). *Climate risk country profile: Eswatini*. Washington, DC: World Bank.

World Bank. (2021c). *Climate risk country profile: Lesotho*. Washington, DC: World Bank.

World Bank. (2021d). *Climate risk country profile: Namibia*. Washington, DC: World Bank.

World Bank. (2021e). *Climate risk country profile: South Africa*. Washington, DC: World Bank.

World Bank. (2021f). *Climate risk country profile: Zimbabwe*. Washington, DC: World Bank.

World Bank (2022). 'World Development Indicators DataBank', https://databank.worldbank.org/source/world-development-indicators. Accessed May 2022.

World Food Programme (WFP). (2016). *El Niño: undermining resilience – Implications of El Niño in Southern Africa from a food and nutrition security perspective*. Johannesburg: WFP Regional Bureau for Southern Africa.

WFP. (2021). *Food systems in Southern Africa: drivers of change and opportunities for influence*. Johannesburg: WFP Regional Bureau for Southern Africa.

World Food Summit (1996). Rome Declaration on World Food Security.

Wiggins, S. (2022). *Impacts of War on Food Prices and Food Security in Potentially Vulnerable Countries*. ODI Policy Brief, April 2022.

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Wiggins, S. and Lankford, B. (2019) *Farmer-led irrigation in sub-Saharan Africa: synthesis of current understandings*: DEGRP Synthesis Report. https://www.gov.uk/research-for-development-outputs/farmer-led-irrigation-in-sub-saharan-africa-synthesis-of-current-understandings

© Crown Copyright 2022, Met Office

Water

ADF (2021). *Project Appraisal Report: Establishment of a Regional Project Accreditation Unit in Central Africa Power Pool* (CAPP). African Development Fund, September 2021.

ADB (2016). *Unlocking Africa's Transboundary Water Potential*. African Development Bank.

ADB (2022). *Mozambique: African Development Bank to serve as advisor for development of 1500 MW Mphanda Nkuwa hydropower project*. ADB News and Events, 25 May 2022.

Allan, J.A. (1993). *Fortunately There are Substitutes for Water, Otherwise our Hydro-Political Futures Would be Impossible*. In Priorities for Water Resources Allocation and Management, 13–26. London: Overseas Development Administration, 1993.

Brautigan, D. and Huang, J. (2017). Great walls over African rivers: Chinese engagement in African hydropower projects. *Development Policy Review* 37(3), 313-330. https://doi.org/10.1111/dpr.12350

Buckley, L., Wang, H., Zhou, X. and Norton, A. (2022). *What drives safeguarding for China's hydropower projects in LDCs?* IIED, London. https://pubs.iied.org/20721iied

Calow, R.C., Mason, N., Mosello, B. and Ludi, E. (2017). *Linking risk with response: options for climate resilient WASH*. Technical Brief for the GWP-UNICEF Strategic Framework for WASH Climate Resilience.

Calow, R.C., MacDonald, A.M. and Le Seve, M (2018). The Environmental Dimensions of Universal Access to Safe Water. Chapter 6 in: *Equality in Water and Sanitation Services*, edited by Tom Slaymaker and Oliver Cummings. Earthscan Water, Routledge.

Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, and S. Supratid (2022). *Water*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551–712, doi:10.1017/9781009325844.006.

Cisneros, J., Oki, T., Arnell, N., Benito, G., Cogley, J., Doll, P., et al. (2014). *Freshwater Resources. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group 11 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPPC. Cambridge: Cambridge University Press.

Cobbing, J. (2022). Groundwater and the discourse of shortage in Sub-Saharan Africa. *Hydrogeol J* 28, 1143–1154 (2020). https://doi.org/10.1007/s10040-020-02147-5

Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Mahe, G. and Dieulin, H. (2009). Rainfall and Water Resources Variability in Sub-Saharan Africa during the Twentieth Century. *Journal of Hydrometeorology*, Vol.10, February 2009.

Conway, D., van Garderen, E.A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Ringler, C., Thurlow, J., Zhu, T. and Dalin, C. (2015). Climate and southern Africa's water-energy-food nexus. *Nature Climate Change*, Vol 5, September 2015. DOI: 10.1038/NCLIMATE2735.

© Crown Copyright 2022, Met Office

Conway, D., Dalin, C., Landman, W.A. and Osborn, T.J. (2017). Hydropower plans in eastern and southern Africa increase risk of concurrent climate-related electricity supply disruption. *Nature Energy*, Vol. 2, December 2017, 946-953.

Conway, D., Curran, P. and Gannon, K.E. (2018). *Climate risks to hydropower supply in eastern and southern Africa*. Policy Brief: Grantham Research Institute on Climate Change and the Environment, and the Centre for Climate Change Economics and Policy. August 2018.

Cumming, O. and Cairncross, S. (2016). Can water, sanitation and hygiene help eliminate stunting? Current evidence and policy implications. *Maternal & Child Nutrition*. doi:10.1111 /mcn.12258.

Cuthbert, M.O., Taylor, R.G., Favreau, G. et al (2019). Observed controls on resilience of groundwater to climate variability in sub-Saharan Africa. *Nature* 572, 230-234 (2019). https://doi.org/10.1038/s41586-019-1441-7

Damania, R., Desbureaux, S., Hyland, M., Islam, A., Moore, S., Rodella, A.S., Russ, J. and Zaveri, E. (2017). *Unchartered Waters: The New Economics of Water Scarcity and Variability*. Washington, DC: World Bank. Doi10.11596/978-1-4648-1179-1.

Foster, V. and Briceno-Garmendia, C. (2010) *Africa's Infrastructure: A Time for Transformation*. AFD and World Bank co-publication. Washington DC: Agence Francaise de Development and World Bank.

Foster, S., Eichholz, M., Nlend, B. and Gathu, J. (2020). Securing the critical role of groundwater for the resilient water supply of urban Africa. *Water Policy* 22 (2020), 121-132.

Gannon, K.E., Conway, D., Pardoe, J., Ndiyoi, M., Batisani, N., Odada, E., Olago, D., Opere, A., Kgosietsile, S., Nyambe, M., Omukuti, J. and Siderius, C. (2018). Business experience of floods and drought-related water and electricity supply disruption in three cities in sub-Saharan Africa during the 2015/2016 El Niño. *Global Sustainability* 1, e14, 1-15. https://doi.org/10.1017/sus.2018.14

Hamududu, B.H. and Killingtveit, A (2016). Hydropower Production in Future Climate Scenarios; the Case for the Zambezi River. *Energies* 2016, *9*, 502. https://doi.org/10.3390/en9070502

Howard, G., Calow, R.C., MacDonald, A.M. and Bartram, J. (2016). Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annual Review of Environment and Resources*. 2016. 41:8.1-8.24.

ICAI (2016). *Assessing DFID's results in Water, Sanitation and Hygiene: An Impact Review*. Independent Commission for Aid Impact, May 2016

IHA (2019). *Hydropower Sector Climate Resilience Guide*. London: International Association of Hydropower.

Karam, S., Ousmane, S., Nagabhatia, N., Perera, D. and Tshimanga, R.M. (2022). Assessing the impacts of climate change on climatic extremes in the Congo River Basin. *Climate Change* (2022) 170:40 https://doi.org/10.1007/s10584-022-03326-x

Lapworth et al (2020). Drinking water quality from handpump boreholes in Africa. *Environ. Res. Lett*. 15 064020.

© Crown Copyright 2022, Met Office

MacAllister, D.J., MacDonald, A.M., Kebede, S., Godfrey, S. and Calow, R.C. (2020). Comparative performance of rural water supplies during drought. *Nature Communications* 11, Article No: 1099 (2020). https://doi.org/10.1038/s41467-020-14839-3

MacDonald, A.M., Bell, R.A., Kebede, S., Azagegn, T., Yehualaeshet, T., Pichon, F., Young, M., McKenzie, A.A., Lapworth, D.J., Black, E. and Calow, R.C. (2019). Groundwater and resilience to drought in the Ethiopian highlands. *Environmental Research Letters* 14 (2019) 095003. https://doi.org/10.1088/1748-9326/ab2821

MacDonald, A.M., Lark, R.M., Taylor, R.G., Abiye, T., Fallas, H.C., Favreau, G., Goni, I.B., Kebede, S., Scanlon, B., Sorenson, J.P.R., Tajani, M., Upton, K.A. and West, C. (2021). Mapping groundwater recharge in Africa from ground observations and implications for water security. *Environmental Research Letters*, 16, (2021), 034012. https://doi.org/10.1088/1748-9326/abd661

Mwuathunga, E., Fallas, H.C., MacAllister, D.J., Mkandawire, T., Makuluni, P., Shaba C., Jumbo, S., Moses, D., Whaley, L., Banks, E., Casey, V. and MacDonald, A.M. (2019). *UPGro Hidden Crisis Research Consortium, Technical Report – Malawi*. British Geological Survey (BGS) Open Report, OR/19/057, pp 25.

Nijhawan, A. and Howard, G. (2022). Associations between climate variables and water quality in low-and middle-income countries: A scoping review. *Water Research* 210 (2022) 117996.https://doi.org/10.1016/j.watres.2021.117996.

Perry, C. (2011). Accounting for water use: Terminology and implications for saving water and increasing production. *Agricultural Water Management* 98 (2011) 1840– 1846.

RoSA (2019). *Integrated Resource Plan, IRP 2019*. Department of Mineral Resources and Energy, Republic of South Africa. October 2019.

Scanlon, B.R., Rateb, A., Anyamba, A., Kebede, S., MacDonald, A.M., Shamsudduha, M., Small, J., Sun, A., Taylor, R.G. and Xie, H. (2022). Linkages between GRACE water storage, hydrologic extremes, and climate teleconnections in major African aquifers. *Environmental Research Letters*, Volume 17, Number 1.

Siderius, C., Kolusu, S.R., Todd, M.C., Washington, R.T., Bhave, A., Dougill, A.J., Reason, C.J.C, Mkwambisi, D.D., Kashaigili, J.J., Pardoe, J. Harou, J.J., Vincent, K., Hart, N.C.G, James, R., Washington,R., Geressu, R.T. and Conway, D. (2021). Climate variability affects water-energy-food infrastructure performance in East Africa, *One Earth*, Volume 4, Issue 3, 2021, Pages 397-410, ISSN 2590-3322, https://doi.org/10.1016/j.oneear.2021.02.009.

Taylor, R.G., Scanlon, B., Doll, P., Rodell, M., van Beek, R., Wada, Y. et al (2013). Ground water and climate change. *Nature Climate Change*, 3, 322-329.

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, 2022: Africa. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

© Crown Copyright 2022, Met Office

UNICEF/WHO (2021). *Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs*. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2021.

van den Berg, C. and Danilenko, A. (2017). *Performance of Water Utilities in Africa*. World Bank, Washington, DC.

World Bank (2016). *World Bank Group Suspends Financing to the Inga-3 Basse Chute Technical Assistance Project*. World Bank Press Release, 25 July 2016. https://www.worldbank.org/en/news/press-release/2016/07/25/world-bank-group-suspends-financing-to-the-inga-3-basse-chute-technical-assistance-project

World Bank (2017). *Findings of the Mozambique Water, Sanitation, Hygiene and Poverty Diagnostic*. WASH Poverty Diagnostic Series, World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/27320.

© Crown Copyright 2022, Met Office

Environment

Adeeyo, A., Ndlovu, S.S., NgwagweEnvi, L.M., Mudau, M., Alabi, M.A. and Edokpayi, J.M. (2022). Wetland resources in South Africa: threats and metadata study. *Resources* 11(6): 54

CBD (2015). *UN Convention on Biological Diversity: Madagascar Country Profile*. https://www.cbd.int/countries/profile/?country=mg

Cornier-Salem et al. (2018). Chapter 3: Status, trends and trends and future dynamics of biodiversity and ecosystems underpinning natures contributions to people. *In IPBES regional assessment report on biodiversity and ecosystem services for Africa*. Archer, E., Dziba, L., Mulongoy, K.J., Maoela, M.A. and Walters, M. (eds) Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Darwall, W., Smith, K., Allen, D., Holland, R., Harrison, I. and Brooks, E. (2009). *The diversity of life in African freshwater species throughout mainland Africa*. Cambridge: IUCN

FCPF (2022). *Forest Carbon Partnership Facility*. Annual Report 2022. https://www.forestcarbonpartnership.org/

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D. and Vogt-Schilb, A. (2016). *Shock Waves : Managing the Impacts of Climate Change on Poverty. Climate Change and Development*;. Washington, DC: World Bank. World Bank. https://openknowledge.worldbank.org/handle/10986/22787.

Lawal, S., Lennard, C. and Hewitson, B. (2019). Response of Southern African vegetation to climate change at 1.5 and 2.0 global warming above the pre-industrial level. *Climate Services* 16(2019): 100134

Naidoo, S., Davis, C. and Archer van Garderen, E. (2013). *Forests, rangelands and climate change in southern Africa*. Forests and Climate Change Working Paper No.12. Rome, Food and Agriculture Organisation (FAO) of the United Nations.

Opperman, J., Oyare, E., Baleta, H., Fahrbach, S. and Camargo, R. (2021). *Waterways to Resilience: Nature-based Solutions for Adaptation in Africa*. WWF-International, Gland, Switzerland.

Parmesan, C., M.D. Morecroft, Y. Trisurat, R. Adrian, G.Z. Anshari, A. Arneth, Q. Gao, P. Gonzalez, R. Harris, J. Price, N. Stevens, and G.H. Talukdarr (2022). *Terrestrial and Freshwater Ecosystems and Their Services*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 197–377, doi:10.1017/9781009325844.004.

Ramo, R., Roteta, E., Bistinas, I., van Wees, D. Bastarrika, A., Chuvieco, E. and van der Werf, G.R. (2021). African burned area and fire carbon emissions are strongly impacted by small fires undetected by coarse resolution satellite data. *PNAS* 2021 Vol. 118 No. 9 e2011160118. https://doi.org/10.1073/pnas.2011160118

Reddy-Davis, C. and Vincent, K. (2017). Climate risk and vulnerability: a handbook for Southern Africa. Second Edition. Pretoria: CSIR

© Crown Copyright 2022, Met Office

Salimi, S., Almuktar, S., Scholz, M. (2021). Impact of climate change on wetland ecosystems: a critical review of experimental wetlands. *Journal of Environmental Management* (2021): 112160

Sintayehu, D.W. (2018). Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. *Ecosystem health and sustainability* 4(9): 225-239

Stevens N, Erasmus BF, Archibald S, Bond WJ. (2016). Woody encroachment over 70 years in South African savannahs: overgrazing, global change or extinction aftershock? *Philos Trans R Soc Lond B Biol Sci*. 2016 Sep 19;371(1703):20150437. doi: 10.1098/rstb.2015.0437. PMID: 27502384; PMCID: PMC4978877.

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, (2022). *Africa*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.011.

World Bank (2019). *Malawi Country Environmental Analysis*. World Bank, January 2019. Washington DC.

World Bank. (2021a). *Climate risk country profile: Botswana*. Washington, DC: World Bank.

World Bank. (2021d). *Climate risk country profile: Namibia*. Washington, DC: World Bank.

World Bank. (2021f). Climate risk country profile: Zimbabwe. Washington, DC: World Bank.

World Bank (2021g). *Madagascar Signs Landmark Agreement with the World Bank to Reduce Poverty, Deforestation and Carbon Emissions*. World Bank Press Release, 5 February 2021. https://www.worldbank.org/en/news/press-release/2021/02/05/madagascar-signs-landmark-agreement-with-the-world-bank-to-reduce-poverty-deforestation-and-carbon-emissions#:~:text=Madagascar's%20Emission%20Reductions%20Program%20is,protecting%20vital%20forests%20and%20biodiversity.

World Bank. (2021h). *Climate risk country profile: Zambia.* Washington, DC: World Bank.

World Bank. (2021i). *Climate risk country profile: Mozambique.* Washington, DC: World Bank.

Xu, X., Chen, M., Yang, G., Jiang, B and Zhang, Ji. (2020). Wetland ecosystem services research: A critical review. *Global Ecology and Conservation*, Volume 22, 2020, e01027, ISSN 2351-9894, https://doi.org/10.1016/j.gecco.2020.e01027.

© Crown Copyright 2022, Met Office

Settlements and infrastructure

Africapolis (2015 data). *Visualise urbanisation in Africa*. Website. Available from: https://africapolis.org/en

Alderman, K., Turner, L.R. and Tong, S. (2012). Floods and human health: a systematic review. *Environ. Int*. 47:37-47.

Bartos, M., Chester, M., Johnson, N., Gorman, B., Eisenberg, D., Linkov, I. and Bates, M. (2016). Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States. *Environ. Res. Lett*. 11 114008. DOI 10.1088/1748-9326/11/11/114008

Cabral, P., Augusto, G., Akanda, A., Costa, A., Amade, N., Niquisse, S., Atumane, A., Cuna, A., Kazemi, K., Mlucasse, R. and Santha, R. (2017) 'Assessing Mozambique's exposure to coastal climate hazards and erosion' *International Journal of Disaster Risk Reduction* 23(2017): 45-52

Calow, R.C., Mason, N., Mosello, B. and Ludi, E. (2017). *Linking risk with response: options for climate resilient WASH*. Technical Brief for the GWP-UNICEF Strategic Framework for WASH Climate Resilience.

Conway, D., van Garderen, E.A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Ringler, C., Thurlow, J., Zhu, T. and Dalin, C. (2015). Climate and southern Africa's water-energy-food nexus. *Nature Climate Change*, Vol 5, September 2015. DOI: 10.1038/NCLIMATE2735.

Dodman, D., B. Hayward, M. Pelling, V. Castan Broto, W. Chow, E. Chu, R. Dawson, L. Khirfan, T. McPhearson, A. Prakash, Y. Zheng, and G. Ziervogel (2022). *Cities, Settlements and Key Infrastructure*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907–1040, doi:10.1017/9781009325844.008.

Espinet, X., Rozenberg, J., Rao, K.S. and Ogita, S. (2018). *Piloting the Use of Network Analysis and Decision-Making under Uncertainty in Transport Operations*. Preparation and Appraisal of a Rural Roads Project in Mozambique Under Changing Flood Risk and Other Deep Uncertainties. World Bank Policy Research Working Paper 8490. World Bank, Washington DC.

Feron, S., Cordero, R.R., Damiani, A. and Jackson, R.B. (2021). Climate change extremes and photovoltaic power output. *Nature Sustainability* 4, 270–276 (2021). https://doi.org/10.1038/s41893-020-00643-w

Fu G, Horrocks L, Winne S. Exploring impacts of Climate Change on UK's ICT Infrastructure. *Infrastructure Asset Management* 2016, 3(1), 42-52.

Gajjar, S.P., Wendo, H., Polgar, A. and Hofemeier (2021) *Ecosystem-based flood management: a comparative study report of the cities of Cape Town and Durban (South Africa), Nairobi and Mombasa (Kenya).* London: CDKN.

© Crown Copyright 2022, Met Office

GoM (2019). Malawi 2019 Floods Post Disaster Needs Assessment Report.Malawi Government, GFDRR and World Bank.

Gannon, E., Conway, D., Pardoe, J., Ndiyoi, M., Batisani, N., Odada, E., Olago, D., Opere, A., Kgosietsile, S., Nyambe, M., Omukuti, J. and Siderius, C. (2018) 'Business experience of floods and drought related water and electricity supply disruption in three cities in sub-Saharan Africa during 2015/2016 El Nino' *Global Sustainability* 1(e14): 1-15.

Hallegatte, S. et al. (2017). *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. Climate Change and Development. Washington, DC: World Bank.

Hallegatte, S., Rentschler, J. and Rozenberg, J. (2019). *Lifelines: The Resilient Infrastructure Opportunity*. Sustainable Infrastructure Series. Washington DC: World Bank. Doi: 10.1596/978-1430-3.

Holden, P.B., Rebelo, A.J., Wolski, P. et al. (2022). Nature-based solutions in mountain catchments reduce impact of anthropogenic climate change on drought streamflow. *Commun Earth Environ* 3, 51 (2022). https://doi.org/10.1038/s43247-022-00379-9

Howard, G., Calow, R.C., MacDonald, A.M. and Bartram, J. (2016). Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annual Review of Environment and Resources*. 2016. 41:8.1-8.24.

Hyde-Smith, L., Zhan, Z., Roelich, K., Mdee, A. and Evans, B. (2022). Climate Change Impacts on Urban Sanitation: A Systematic Review and Failure Mode Analysis. *Environmental Science and Technology*, April 2022. https://doi.org/10.1021/acs.est.1c074424.

ILO (2019). Mozambique Cyclone Idai: Post Disaster Needs Assessment. International Labour Organisation, 23 May 2019.

Koks, E.E., Rozenberg, J., Zorn, C. et al. A global multi-hazard risk analysis of road and railway infrastructure assets. *Nat Commun* 10, 2677 (2019). https://doi.org/10.1038/s41467-019-10442-3

Lequechane, J.D., Mahumane, A., Chale, F. et al. Mozambique's response to cyclone Idai: how collaboration and surveillance with water, sanitation and hygiene (WASH) interventions were used to control a cholera epidemic. *Infect Dis Poverty* 9, 68 (2020). https://doi.org/10.1186/s40249-020-00692-5

Lumbroso, D. (2020) 'Flood risk management in Africa' *Journal of Flood Risk Management* 2020 13: e12612.

Lumbroso, D. and Woolhouse, G. (2014). *Future climate change for Africa: the use of climate services for decision making in the port sector*. Wallingford, Oxfordshire: HR Wallingford.

Mima, S. and P. Criqui, 2015: The costs of climate change for the European energy system, an assessment with the POLES model. *Environ. Model. Assess.*, 20(4), 303–319.

Mucova, S.A.R.; Azeiteiro, U.M.; Filho, W.L.; Lopes, C.L.; Dias, J.M.; Pereira, M.J. (2021). 'Approaching sea-level rise (SLR) change: strengthening local responses to sea-level rise and coping with climate change in northern Mozambique'. *Journal of Marine Science and Engineering* 2021 9, 205

© Crown Copyright 2022, Met Office

OECD/SWAC (2020). *Africa's Urbanisation Dynamics 2020: Africapolis, Mapping a New Urban Geography*. West African Studies, OECD Publishing, Paris. https://doi.org/10.1787/b6bccb81-en.

Opperman, J., Oyare, E., Baleta, H., Fahrbach, S. and Camargo, R. (2021). *Waterways to Resilience: Nature-based Solutions for Adaptation in Africa*. WWF-International, Gland, Switzerland.

Reddy-Davis, C. and Vincent, K. (2017). Climate risk and vulnerability: a handbook for Southern Africa. Pretoria: CSIR

RoSA (2019). *Integrated Resource Plan, IRP 2019*. Department of Mineral Resources and Energy, Republic of South Africa. October 2019.

Rozenberg, J. and Fay, M. eds (2019). Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet. Sustainable Infrastructure Series. Washington, DC: World Bank. Doi:10.1596/978-1-4648-1363-4.

UN-Habitat (2022). World Cities Report 2022: Envisaging the World of Cities. United Nations Human Settlements Programme (UN-Habitat), Nairobi, Kenya. www.unhabitat.org

World Bank (2020). *Poverty and Shared Prosperity 2020: Reversals of Fortune*. Washington, D.C: World Bank.

World Bank (2022). 'World Development Indicators DataBank', https://databank.worldbank.org/source/world-development-indicators. Accessed May 2022.

© Crown Copyright 2022, Met Office

Health

Abera, A., Friberg, J., Isaxon, C., Jerrett, M., Malmqvist, E., Sjostrom, C., Taj, T. and Vargas, A.M. (2020) 'Air quality in Africa: public health implications' Annual Review of Public Health 2021 42: 193-210

Baker, R.E. and Anttila-Hughes, J. (2020) Characterising the contribution of high temperatures to child undernourishment in Sub-Saharan Africa. *Sci Rep 10*: 18796

Calow, R.C., MacDonald, A.M. and Le Seve, M (2018). The Environmental Dimensions of Universal Access to Safe Water. Chapter 6 in: *Equality in Water and Sanitation Services*, edited by Tom Slaymaker and Oliver Cummings. Earthscan Water, Routledge.

Carlton, E.J., Woster, A.P., DeWitt, P., Goldstein, R.S., Levy, K. (2016) 'A systematic review and meta-analysis of ambient temperature and diarrhoeal diseases' *Int J Epidemiol* 45(1): 117-30

Health Effects Institute (2022). *The State of Air Quality and Health Impacts in Africa. A Report from the State of Global Air Initiative*. Boston, MA:Health Effects Institute.

Howard, G., Calow, R.C., MacDonald, A.M. and Bartram, J. (2016). Climate Change and Water and Sanitation: Likely Impacts and Emerging Trends for Action. *Annual Review of Environment and Resources*. 2016. 41:8.1-8.24.

Khalil,I.A., Troeger, C., Rao, P.C., Blacker, B.F., Brown, A., Brewer, T.G., Colombara, D.V., De Hostos, E.L., Engmann, C., Guerrant, R.L., Haque, R., Houpt, E.R., Kang, G., Korpe, P.S., Kotloff, K.L., Lima, A.A.M., Petri, W.A., Platts-Mills, J.A., Shoultz, D.A., Forouzanfar, M.H., Hay, S.I., Reiner, R.C. and Mokdad, A.H. (2018). Morbidity, mortality, and long-term consequences associated with diarrhoea from Cryptosporidium infection in children younger than 5 years: a meta-analyses study. The Lancet Global Health, Volume 6, Issue 7, 2018, e758-e768, ISSN 2214-109X, https://doi.org/10.1016/S2214-109X(18)30283-3.

Iddrisu, I.; Monteagudo-Mera, A.; Poveda, C.; Pyle, S.; Shahzad, M.; Andrews, S.; Walton, G.E. (2021). Malnutrition and Gut Microbiota in Children. Nutrients 2021, 13, 2727. https://doi.org/10.3390/nu13082727.

Lunde, T.M., Balkew, M., Korecha, D. Loha, E., Sorebegr, A. and Lindtjorn, B. (2013) 'A dynamic model of some malaria-transmitting anopheline mosquitos of Afrotropical region. Model description and sensitivity analysis' *Malaria Journal* 12(28) 2013

Marcantonio, R., Javeline, D., Field, S. and Fuentes, A. (2021). Global distribution and coincidence of pollution, climate impacts, and health risk in the Anthropocene. PLoS ONE 16(7): e0254060. https://doi.org/10.1371/journal. pone.0254060

Ncongwane, K.P., Botai, J.O., Sivakumar, V., Botai, C.M. and Adeoola, A.M. (2021) 'Characteristics and long-term trends of heat stress for South Africa' *Sustainability* 19(23) 13249 Environ Res. Lett. 13(2018) 064004

Ngarakana-Gwasira ET, Bhunu CP, Masocha M, Mashonjowa E. (2016). Assessing the Role of Climate Change in Malaria Transmission in Africa. Malar Res Treat. 2016;2016:7104291. doi: 10.1155/2016/7104291. Epub 2016 Mar 15. PMID: 27066290; PMCID: PMC4811621.

Pruss-Usten, A., Bos, R., Gore, F., & Bartram, J. (2008). *Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health*. Geneva: WHO.

© Crown Copyright 2022, Met Office

Reddy-Davis, C. and Vincent, K. (2017) Climate risk and vulnerability: a handbook for Southern Africa. Pretoria: CSIR

Schweitzer, M.D., Calzadilla, A.S., Slamo, O., Sharifi, A., Kumar, N., Holt, G., Campos, M. and Mirsaedi, M. (2018) 'Lung health in era of climate change and dust storms' Environmental Research 163(2018): 36-42.

Speizer, S., Raymond, C., Ivanovich, C., and Horton, R. M. (2022) Concentrated and intensifying humid heat extremes in the IPCC AR6 Regions. *Geophysical Research Letters*, 49(5), e2021GL097261.

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, (2022). *Africa*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.011.

UN-Habitat (2022) Regional assessment on urban vulnerability and resilience in Southern African development community member states. Nairobi: UN-Habitat

USAID (2016) Climate change risk profile: Southern Africa. Washington D.C.: USAID

USAID (2022) Shifting risks of Malaria in Southern Africa: a regional analysis. Washington D.C.: USAID

Watts, N., Adger, W.N., Ayeb-Karlsson, S., Bai, Y., Byass, P., Campbell-Lendrum, D. et al (2017). The Lancet countdown: tracking progress on health and climate change. The Lancet, Vol 389, March 18, 2017.

WFP (2016) El Nino: undermining resilience. Implications of El Nino in Southern Africa from a food and nutrition perspective. Rome: WFP

World Bank. (2021b). *Climate risk country profile: Eswatini*. Washington, DC: World Bank.

World Bank. (2021c). *Climate risk country profile: Lesotho*. Washington, DC: World Bank.

World Bank. (2021d). *Climate risk country profile: Namibia*. Washington, DC: World Bank.

World Bank. (2021h). *Climate risk country profile: Zambia.* Washington, DC: World Bank.

WHO (2022) Tracking Universal Health Coverage in the WHO African Region, 2022. Brazzaville: WHO Regional Office for Africa; 2022.

© Crown Copyright 2022, Met Office

Coastal

Adams, J.B., (2020). Salt marsh at the tip of Africa: patterns, processes and changes in response to climate change. *Estuarine, Coastal and Shelf Science*, 237, p.106650.

Allemand, D. and Osborn, D., (2019). Ocean acidification impacts on coral reefs: From sciences to solutions. *Regional Studies in Marine Science*, 28, p.100558.

Allison, Edward H., Allison L. Perry, Marie-Caroline Badjeck, W. Neil Adger, Katrina Brown, Declan Conway, Ashley S. Halls et al. (2009) "Vulnerability of national economies to the impacts of climate change on fisheries." *Fish and fisheries* 10, no. 2 (2009): 173-196.

Attri, V.N. and Bohler-Mulleris, N. eds., (2018). *The blue economy handbook of the Indian Ocean region*. Africa Institute of South Africa, Pretoria.

Augustyn, J., A. Cockroft, S. Kerwath, S. Lamberth, J. Githaiga-Mwicigi, G. Pitcher, M. Roberts, C. van der Lingen, L. Auerswald, (2018) pp 479–522 in Climate Change Impacts on Fisheries and Aquaculture: A Global Analysis, B. Phillips, M. Pérez-Ramírez, Ed. (John Wiley & Sons).

Becker, A., Ng, A.K., McEvoy, D. and Mullett, J., (2018). Implications of climate change for shipping: Ports and supply chains. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(2), p.e508.

Beyer, H. L., Kennedy, E. V., Beger, M., Chen, C. A., Cinner, J. E., Darling, E. S., ... & Hoegh-Guldberg, O. (2018). Risk-sensitive planning for conserving coral reefs under rapid climate change. *Conservation Letters*, 11(6), e12587.

Bhadury, P. (2015). Effects of ocean acidification on marine invertebrates - a review. Indian *Journal of Geo-Marine Science* 44(4): 454-464.

Bolaky, B., (2020). Operationalising blue economy in Africa: the case of South-West Indian Ocean. *ORF Issue Brief*, *398*.

Brett, M.R., (2021). How important is coastal tourism for island nations? An assessment of African and Indian Ocean islands. *Journal of Coastal Research,* 37(3), 568–575. Coconut Creek (Florida), ISSN 0749-0208.

Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, D.Y. Ghebrehiwet, S.-I. Ito, W. Kiessling, P. Martinetto, E. Ojea, M.-F. Racault, B. Rost, and M. Skern-Mauritzen, (2022). *Oceans and Coastal Ecosystems and Their Services*. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 379–550, doi:10.1017/9781009325844.005.

Doney, S.C., Ruckelshaus, M., Emmett Duffy, J., Barry, J.P., Chan, F., English, C.A., Galindo, H.M., Grebmeier, J.M., Hollowed, A.B., Knowlton, N. and Polovina, J., (2012). Climate change impacts on marine ecosystems. *Annual review of marine science*, 4, pp.11-37.

Failler, P., Kroese, M., and Valette, H.R. (2011*). Socio-economic impact assessment of local FAD fisheries in the South West Indian Ocean*. Study carried out as part of the French

© Crown Copyright 2022, Met Office

contribution to the South West Indian Ocean Fisheries Project (SWIOFP). COFREPECHE, Paris.

FAO (2022a). Fishery and Aquaculture Country Profiles: Namibia. https://www.fao.org/fishery/en/facp/search

FAO (2022b). Fishery and Aquaculture Country Profiles: South Africa. https://www.fao.org/fishery/en/facp/search

FAO (2022c). Fishery and Aquaculture Country Profiles: Mozambique. https://www.fao.org/fishery/en/facp/search

FAO (2022d). Fishery and Aquaculture Country Profiles: Madagascar. https://www.fao.org/fishery/en/facp/search

FAO (2022e). Fishery and Aquaculture Country Profiles: Comoros. https://www.fao.org/fishery/en/facp/search

FAO (2022f). Fishery and Aquaculture Country Profiles: Seychelles. https://www.fao.org/fishery/en/facp/search

FAO (2022g). Fishery and Aquaculture Country Profiles: Mauritius. https://www.fao.org/fishery/en/facp/search

Ferrario, F., Beck, M., Storlazzi, C. et al. (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nat Commun* 5, 3794 (2014). https://doi.org/10.1038/ncomms4794

Findlay, K.P., Cockcroft, V.G. and Guissamulo, A.T., (2011). Dugong abundance and distribution in the Bazaruto Archipelago, Mozambique. *African Journal of Marine Science*, 33(3), pp.441-452.

Friess, D.A., Rogers, K., Lovelock, C.E., Krauss, K.W., Hamilton, S.E., Lee, S.Y., Lucas, R., Primavera, J., Rajkaran, A. and Shi, S., (2019). The state of the world's mangrove forests: past, present, and future. *Annual Review of Environment and Resources*, 44(1), pp.89-115.

Fuentes, M.M., Pike, D.A., Dimatteo, A. and Wallace, B.P., (2013). Resilience of marine turtle regional management units to climate change. *Global Change Biology*, 19(5), pp.1399-1406.

Ghermandi, A.; Obura, D.; Knudsen, C.; Nunes, P.A.L.D. (2019) Marine ecosystem services in the Northern Mozambique Channel: A geospatial and socio-economic analysis for policy support. *Ecosyst. Serv*. 2019, 35, 1–12

Gissi, E., Manea, E., Mazaris, A.D., Fraschetti, S., Almpanidou, V., Bevilacqua, S., Coll, M., Guarnieri, G., Lloret-Lloret, E., Pascual, M. and Petza, D., (2021). A review of the combined effects of climate change and other local human stressors on the marine environment. *Science of the Total Environment*, 755, p.142564.

Gudka, M., Obura, D., Mwaura, J., Porter, S., Yahya, S. and Mabwa, R., (2018*). Impact of the 3rd global coral bleaching event on the Western Indian Ocean in 2016*. Global Coral Reef Monitoring Network (GCRMN)/Indian Ocean Commission, p.67.

Gudka, M., Obura, D., Mbugua, J., Ahamada, S., Kloiber, U. and Holter, T., (2020). Participatory reporting of the 2016 bleaching event in the Western Indian Ocean. *Coral Reefs*, 39(1), pp.1-11.

Met Office Hadley Centre ODI UKaid from the British people

© Crown Copyright 2022, Met Office

Hammar, M., Kaal, M., and Holgersson, P. (2020). *Future Exploitation in the Western Indian Ocean: Possibilities for the region's coastal states and island nations*. Report 2020:10. Anthesis, Stockholm.

Heymans, J.J. and Baird, D. (2009). A carbon flow model and network analysis of the northern Benguela upwelling system, Namibia. *Ecological Modelling*, Volume 126, Issue 1, 2000, pp9-32. https://doi.org/10.1016/S0304-3800(99)00192-1.

Jones, T.G., Glass, L., Gandhi, S., Ravaoarinorotsihoarana, L., Carro, A., Benson, L., Ratsimba, H.R., Giri, C., Randriamanatena, D. and Cripps, G., 2016. Madagascar's mangroves: Quantifying nation-wide and ecosystem specific dynamics, and detailed contemporary mapping of distinct ecosystems. Remote Sensing, 8(2), p.106.

Karani, P. and Failler, P., (2020). Comparative coastal and marine tourism, climate change, and the blue economy in African Large Marine Ecosystems. *Environmental Development*, *36*, p.100572. https://doi.org/10.1016/j.envdev.2020.100572

Lovelock, CE, Cahoon DR,Friess DA,Guntenspergen GR, Krauss KW, et al. (2015).The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature* 526:559–63

Llewellyn, L.E., English, S. and Barnwell, S., (2016). A roadmap to a sustainable Indian Ocean blue economy. *Journal of the Indian Ocean Region*, 12(1), pp.52-66.

Lugendo, B., (2015). *Mangroves, salt marshes and seagrass beds*. Chapter 5 in The Regional State of the Coast Report: Western Indian Ocean. UNEP and WIOMSA, Nairobi, Kenya, 546 pp.

McClanahan, T.R.; Muthiga, N.A. (2017) Environmental Variability Indicates a Climate-Adaptive Center under Threat in Northern Mozambique Coral Reefs. *Ecosphere* 2017, 8, e01812

Micarelli, P., Bonsignori, D., Compagno, L.J.V., Pacifico, A., Romano, C. and Reinero, F.R., (2021). Analysis of sightings of white sharks in Gansbaai (South Africa). *The European Zoological Journal*, 88(1), pp.363-374.

Miller KA, Thompson KF, Johnston P and Santillo D (2018) An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts, and Knowledge Gaps. *Front. Mar. Sci*. 4:418. doi: 10.3389/fmars.2017.00418

Moss, K., & Pigeon, M. (2022). *Stable Seas: Western Indian Ocean*. One Earth Future, Broomfield, USA. 128 pp. Available online: https://www.stableseas.org

Moustahfid, H., Marsac, F. and Gangopadhyay, A., (2019). *Climate change impacts, vulnerabilities and adaptations: Western Indian Ocean marine fisheries*. Chapter 12 in Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. and Poulain, F (eds) Impacts of climate change on fisheries and aquaculture. Synthesis of current knowledge, adaptation and mitigation options, (Rome: FAO).

Mucova, S.A.R., Azeiteiro, U.M., Filho, W.L., Lopes, C.L., Dias, J.M. and Pereira, M.J. (2021). Approaching Sea-Level Rise (SLR) change: strengthening local responses to sea-level rise and coping with climate change in Northern Mozambique. *Journal of Marine Science and Engineering*, 9(2), p.205.

© Crown Copyright 2022, Met Office

Muhala, V., Chicombo, T.F., Macate, I.E., Guimarães-Costa, A., Gundana, H., Malichocho, C., Hasimuna, O.J., Remedio, A., Maulu, S., Cuamba10, L. and Bessa-Silva11, A.R., (2021). Climate Change in Fisheries and Aquaculture: Analysis of the Impact Caused by Idai and Kenneth Cyclones in Mozambique. *Frontiers in Sustainable Food Systems*, 5:714187. doi: 10.3389/fsufs.2021.714187

Naidoo, G., (2016). The mangroves of South Africa: An ecophysiological review. *South African Journal of Botany*, 107, pp.101-113.

Obura, D.O., Bandeira, S.O., Bodin, N., Burgener, V., Braulik, G., Chassot, E., Gullström, M., Kochzius, M., Nicoll, M., Osuka, K. and Ralison, H.O., (2019). The Northern Mozambique Channel. In World seas: an environmental evaluation (pp. 75-99). Academic Press. https://www.researchgate.net/profile/Emmanuel-Chassot/publication/327989279_The_Northern_Mozambique_Channel/links/5bb8a0644585159e8d878de5/The-Northern-Mozambique-Channel.pdf

Obura, D., Gudka, M., Samoilys, M., Osuka, K., Mbugua, J., Keith, D.A., Porter, S., Roche, R., van Hooidonk, R., Ahamada, S. and Araman, A., (2022). Vulnerability to collapse of coral reef ecosystems in the Western Indian Ocean. *Nature Sustainability*, 5(2), pp.104-113.

Ortega-Cisneros, K., Cochrane, K.L., Fulton, E.A., Gorton, R. & Popova, E. (2018). Evaluating the effects of climate change in the southern Benguela using the Atlantis modelling framework. *Fisheries Oceanography*, 28. (also available at https://doi. org/10.1111/fog.12268).

Rakotondravony, H. A., I. Abdallah, H. Andrianaivo, L. N. Andrianarison, K. Hetz, P. T. Mahatante, H. N. Masezamana, N. A. H. Rakotoarivony, R. P. Rakotonaivo, S. Ramanantsialonina, J.-F. Randrianjatovo, A. A. Rasamison, and M. S. (adelphi/GOPA). (2018). *État des lieux des études de la vulnérabilité à Madagascar: revue bibliographique*. Antananarivo, Madagascar. GIZ, Bonn, Germany.

Rohner, C.A., Richardson, A.J., Jaine, F.R., Bennett, M.B., Weeks, S.J., Cliff, G., Robinson, D.P., Reeve-Arnold, K.E. and Pierce, S.J. (2018). Satellite tagging highlights the importance of productive Mozambican coastal waters to the ecology and conservation of whale sharks. *PeerJ*, 6, p.e4161.

Samoilys, A.M.; Osuka, K.; Mussa, J.; Rosendo, S.; Riddell, M.; Diade, M.; Mbugua, J.; Kawaka, J. (2019). An integrated assessment of coastal fisheries in Mozambique for conservation planning. *Ocean Coast. Manag*. 2019, 104924

Smith, L.C. and Stephenson, S.R. (2013). New Trans-Arctic shipping routes navigable by mid-century. *Proceedings of the National Academy of Sciences*, 110(13): E1191-E1195.

Spalding, M. D., Ravilious, C., & Green, E. P. (2001). *World atlas of coral reefs*. University of California Press, Berkley. 424 pp.

Sumaila, U.R., Cheung, W.W., Lam, V.W., Pauly, D. and Herrick, S. (2011). Climate change impacts on the biophysics and economics of world fisheries. *Nature climate change*, 1(9), pp.449-456.

Sunny, A.R. (2017). A review on effect of global climate change on seaweed and seagrass. Communities. *International Journal of Fisheries and Aquatic Studies*, 28(29), p.8.

Teske, P.R., Emami-Khoyi, A., Golla, T.R., Sandoval-Castillo, J., Lamont, T., Chiazzari, B., McQuaid, C.D., Beheregaray, L.B. and van der Lingen, C.D. (2021). The sardine run in

© Crown Copyright 2022, Met Office

southeastern Africa is a mass migration into an ecological trap. *Science advances*, 7(38), p.eabf4514.

van der Lingen, C., and Hampton, I. (2018). "*Climate change impacts, vulnerabilities and adaptations: Southeast Atlantic and Southwest Indian Ocean marine fisheries*," Chapter 11 in Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. and Poulain, F (eds) Impacts of climate change on fisheries and aquaculture. Synthesis of current knowledge, adaptation and mitigation options, (Rome: FAO).

van Hooidonk, R., Maynard, J., Tamelander, J., Gove, J., Ahmadia, G., Raymundo, L., Williams, G., Heron, S.F. and Planes, S. (2016). Local-scale projections of coral reef futures and implications of the Paris Agreement. *Scientific reports*, 6(1), pp.1-8.

Veron, JEN. (2000). *Corals of the World. Volume 3*. Australian Institute of Marine Science, Townsville, Australia. 490pp.

Wang, T. and Wang, Y. (2020). Behavioural responses to ocean acidification in marine invertebrates: new insights and future directions. *Journal of Oceanology and Limnology*, 38(3), pp.759-772.

Wright, P. (2013). Impacts of climate change on ports and shipping. *Marine Climate Change Impacts Partnership: Science Review*, pp.263-270

© Crown Copyright 2022, Met Office

The Met Office and Met Office Logo are registered trademarks

Image location: South Luangwa National Park, Zambia

www.metoffice.gov.uk

© Crown Copyright 2022, Met Office