Musina-Makhado SEZ

Climate Risk Profile Report

29 September 2023

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List of Acronyms and Abbreviations

°C	Degree Celsius
AFF	Agriculture, Forestry, and Fisheries
AR5	Fifth Assessment Report
BOTSOC	Botanical Society of South Africa
CABLE	CSIRO Atmosphere Biosphere Land Exchange model
CCAM	Conformal-cubic atmospheric model
CDRF	Climate and Disaster Resilience Fund
CMIP5	Coupled Model Intercomparison Project 5
CRVA	Climate Risk and Vulnerability Assessment
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DHS	Department of Human Settlements
DRR	Disaster risk reduction
DTI	Department of Trade and Industry
DWS	Department of Water and Sanitation
EcVI	Economic Vulnerability Index
EnVI	Environmental Vulnerability Index
GCM	General circulation model
GDP	Gross Domestic Product
GRiMMS	Groundwater Drought Risk Mapping and Management System
GVA	Gross Value Added
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
km	Kilometre
l/p/d	Litres Per Person Per Day
LRT	Let's Respond Toolkit
mm	Millimetre
NDMC	National Disaster Management Centre
PHSHDA	Priority Human Settlement and Housing Development Area
PVI	Physical Vulnerability Index
RCP	Representative Concentration Pathways (mitigation scenarios)

SCIMAP	Sensitive Catchment Integrated Modelling and Prediction
SEVI	Socio-Economic Vulnerability Index
SEZ	Special Economic Zone
SPI	Standardised Precipitation Index
SPLUMA	Spatial Planning and Land Use Management Act, 2013 (Act No.16 of 2013)
THI	Temperature Humidity Index
WMAs	Water Management Areas
WMO	World Meteorological Organisation
WRYM	Water Resources Yield Model
WUI	Wildland-Urban Interface

Glossary of Terms

Adaptation actions	A range of planning and design actions that can be taken by local government to adapt to the impacts of climate change, reduce exposure to hazards, and exploit opportunities for sustainable development (CSIR, 2023).
Adaptation planning	The process of using the basis of spatial planning to shape built-up and natural areas to be resilient to the impacts of climate change, to realise co-benefits for long-term sustainable development, and to address the root causes of vulnerability and exposure to risk. Adaptation planning assumes climate change as an important factor while addressing developmental concerns, such as the complexity of rapidly growing urban areas, and considers the uncertainty associated with the impacts of climate change in such areas – thereby contributing to the transformational adaptation of urban spaces. Adaptation planning also provides opportunities to climate proof urban infrastructure, reduce vulnerability and exploit opportunities for sustainable development (National Treasury, 2018; Pieterse, 2020).
Adaptive capacity	"The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2022, p. 2899).
Climate change adaptation	"In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2022, p. 2898).
Climate change mitigation	"A human intervention to reduce emissions, or enhance the sinks, of greenhouse gases (GHGs)" (IPCC, 2022, p. 2915). The goal of climate change mitigation is to achieve a reduction of emissions that will limit global warming to between 1.5°C and 2°C above preindustrial levels (Behsudi, A, 2021).

Climate hazards	Climate hazards are a sub-set of natural hazards and a grouping of hydrological, climatological, and meteorological hazards. This includes the spatial extent and frequency of, among others, floods, fires, and extreme weather events such as extreme rainfall and extreme heat. Sometimes referred to as hydrometeorological hazards. The potential occurrence of a climate hazard may cause loss of life, injury, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (IPCC, 2022). Climate hazards can increase in intensity and frequency with climate change (Pieterse et al., 2023).
Climate risk	Risk implies the potential for adverse consequences resulting from the interaction of vulnerability, exposure, and a hazard. Relevant adverse consequences include those on "lives and livelihoods, health and well-being, economic and sociocultural assets, infrastructure and ecosystems" (IPCC, 2022, p. 144). In the IPCC's 6th Assessment Report, it is confirmed that risks may result from "dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system" (IPCC, 2022, p. 132).
Coping capacity	"The ability of people, institutions, organizations and systems, using available skills, values, beliefs, resources and opportunities, to address, manage, and overcome adverse conditions in the short to medium term" (IPCC, 2022, p. 2904).
Disaster risk reduction	"Denotes both a policy goal or objective, as well as the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard or vulnerability; and improving resilience" (IPCC, 2022, p. 2906).
Exposure	Exposure implies the physical exposure of elements to a climate hazard. It is defined as the "presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected [by climate hazards]" (IPCC, 2022, p. 2908).
Mainstreaming	The process of integrating climate change adaptation strategies and measures into existing planning instruments and processes as opposed to developing dedicated adaptation policies and plans (Pieterse et al., 2021).

Resilience	"The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation" (IPCC, 2022, pp. 2920–2921).
Sensitivity	"The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (IPCC, 2022, p. 2922).
Vulnerability	Vulnerability is defined as the "propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including, sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2022, p. 2927). Vulnerability refers to the characteristics or attributes of exposed elements, i.e., elements that are exposed to potential climate-related hazards. Vulnerability is a function of sensitivity and (coping or adaptive) capacity (Pieterse et al., 2023).

1. Introduction

This Climate Risk Profile report, as well as the accompanying Adaptation Actions Plan, were developed specifically for the Musina-Makhado Special Economic Zone (SEZ) and Priority Human Settlements and Housing Development Area (PHSHDA), to support its strategic climate change response agenda. Both documents are primarily informed by the GreenBook, which is an open-access online planning support system that provides quantitative scientific evidence in support of local government's pursuit in the planning and design of climate-resilient, hazard-resistant settlements. The GreenBook is an information-dense resource and planning support system offered to South African local governments to better understand their risks and vulnerabilities in relation to population growth, climate change, exposure to hazards, and vulnerability of critical resources. In addition to this, the GreenBook also provides appropriate adaptation measures that can be implemented in cities and towns, so that South African settlements are able to minimise the impact of climate hazards on communities and infrastructure, while also contributing to developmental goals (See GreenBook l Adapting settlements for the future).

The purpose and strategic objectives of the Climate Risk Profile and the Adaptation Actions Plan are to:

- Build and further the climate change response agenda,
- Inform strategy and planning in the SEZ / PHSHDA, as well as the Local Municipality in which it is situated,
- Identify and prioritise risks and vulnerabilities,
- Identify and prioritise interventions and responses, as well as
- Guide and enable the mainstreaming of climate change response, particularly adaptation.

The report first outlines the approach used to determine the risk information outlined in this report, as well as the existing policy framework for climate change response in South Africa. Thereafter, both Musina and Makhado Local Municipalities', as well as Musina-Makhado SEZ's (PHSHDA) context is discussed in terms of locality, geography, demographics, and economy, as well as the environment. This is followed by an overview of current and future risk in the two Local Municipalities and the SEZ, where components of vulnerability and population change projections are unpacked at local municipal and settlement level; current and future climate is discussed in terms of temperature and rainfall; and current and future exposure to drought, heat, wildfire, and flooding is set out. The impact of climate change on the Local Municipalities' water supply and key sectors, including agriculture, are also discussed. To conclude the report, adaptation goals are recommended in response to the risks and vulnerabilities facing both Local Municipalities and the SEZ, in particular. The greatest risks faced across the Musina-Makhado SEZ are increasing temperatures, heat extremes and drought.

1.1. Approach followed

The approach used in the GreenBook, and the Climate Risk Profile report is centred around understanding climate-related risk. Climate-related risk implies the potential for adverse consequences resulting from the interaction of vulnerability, exposure, and the occurrence of a climate hazard (see Figure 1). "Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets, [as well as] investments, infrastructure, and services (including ecosystem services, ecosystems and species)" (Chen, et al., 2021, p. 64). The components of risk are dynamic. Climate hazards are driven by natural climate variability and anthropogenic climate change. Human activity contributes to Greenhouse Gas emissions that increase temperatures, which in turn affects changes in the occurrence of climate hazards such as drought, flooding, coastal flooding, and heat extremes. Planned as well as unplanned development and growth of our settlements drive the exposure of people, as well as the built- and natural environment to climate hazards. Vulnerability includes the inherent characteristics that make systems sensitive to the effects and impacts of climate hazards. Municipal risk is driven by vulnerability and exposure to certain climate-related hazards.

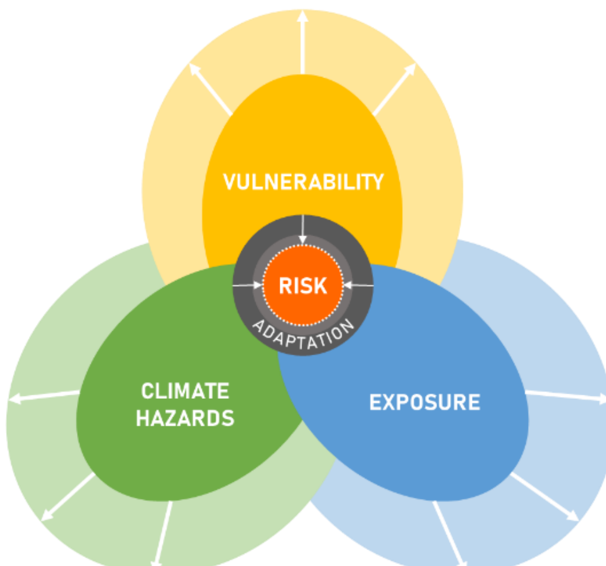

Figure 1: The interaction between the various components of risk, indicating the opportunity to reduce risk through adaptation (based on IPCC, 2014 and IPCC, 2021)

To understand climate risk, the exposure of a settlement to certain climate hazards, and its vulnerability to climate change are unpacked. In this Climate Risk Profile report, multiple vulnerability indices are provided, as well as variables for the current and future projected climate. Climate-related hazards such as drought, heat extremes, wildfire, and flooding, as well as the impact of climate on key resources are also set out for the Local Municipalities in which the SEZ / PHSHDA falls.

All information contained in this report is based on the GreenBook, unless otherwise specified. The information in the GreenBook is provided at local municipal level and settlement level. In this case, where the PHSHDA (SEZ) falls within two Local Municipalities, both local municipal risk profiles are utilised. Information and data were derived using GIS analysis and modelling techniques using secondary data and is not based on local surveys.

1.2. Policy framework

There are various regulatory and legislative requirements for climate change response [planning] in South Africa, at local government level. For instance, the Disaster Management Amendment Act of 2015, which aims to provide measures to reduce disaster risks through climate change adaptation and the development of early warning systems, requires each organ of state, provincial government, and municipality to identify measures for, as well as indicate plans to invest in disaster risk reduction (DRR) and climate change adaptation. The Spatial Planning and Land Use Management Act, No. 16 of 2013 (SPLUMA) outlines five principles intended to guide spatial planning, land development and land use management at all levels of planning, including local government level. Amongst them are the principles of (1) spatial resilience, which encourages "flexibility in spatial plans, policies and land use management systems, to ensure sustainable livelihoods in communities most likely to suffer the impacts of economic and environmental shocks" (Republic of South Africa, 2013, p. 20) – some of which may be induced by the impacts of climate change, and (2) spatial sustainability, which sets out requirements for municipal planning functions such as spatial planning and land use management to be carried out in ways that consider protecting vital ecosystem features such as agricultural land, i.e., from both anthropogenic and natural threats, including the impacts of climate change, as well as in ways that consider current and future costs of providing infrastructure and social services in certain areas (e.g., uninformed municipal investments may lead to an increase in the exposure of people and valuable assets to extreme climate hazards).

Furthermore, the National Climate Change Response White Paper – which outlines the country's comprehensive plan to transition to a climate resilient, globally competitive, equitable and low-carbon economy and society through climate change adaptation and mitigation, while simultaneously addressing the country's key priorities, including job creation, poverty reduction, social equality and sustainable development, amongst others – identifies local governments as critical role players that can contribute towards effective climate change adaptation through their various functions, including "[the] planning [of] human settlements and urban development; the provision of municipal infrastructure and services; water and energy demand management; and local disaster response, amongst others." (Republic of South Africa, 2011, p. 38). The Climate Change Bill takes it further by setting out reporting requirements on climate change response needs and interventions for every municipality in the country.

The National Climate Change Adaptation Strategy outlines several actions that are applicable at municipal level, including the development and implementation of adaptation strategies and vulnerability reduction programmes targeting communities and individuals that are most at risk to the impacts of climate change; the development of municipal early warning systems; as well as the integration of climate change adaptation into municipal development plans and relevant sector plans, i.e., mainstreaming. The National Climate Risk and Vulnerability Assessment

Framework – which is aimed at all actors, including local governments – guides the development and review of climate risk and vulnerability assessments (CRVAs) to enable alignment, aggregation and comparison across all CRVAs, in an effort to inform an integrated and effective climate change adaptation response across all scales and sectors.

In response to the national call to advance spatial transformation and consolidation in human settlement development, the National Department of Human Settlements (DHS) has identified a total of 136 Priority Human Settlements and Housing Development Areas (PHSHDAs). The PHSHDAs were declared to ensure that housing delivery is used to restructure and revitalise towns and cities, strengthen the livelihood prospects of households, and overcome apartheid spatial patterns by fostering integrated urban forms (DHS, 2020). PHSHDAs were designated using national criteria which includes an area or settlement's potential to support sustainable environmental management (which plays a critical role in mitigating the negative impacts of climate change), as well as its potential to accommodate the integration of land uses and amenities, i.e., in addition to other criteria.

The DHS has identified two key objectives for PHSHDAs, including (1) targeting and prioritising areas for integrated housing and human settlements development to ensure the delivery of housing for a diverse range of income groups within an integrated mixed-use development, as well as (2) transforming spatial patterns which have historically exacerbated social inequality and economic inefficiency (DHS, 2020). As part of the second objective, this initiative aims to develop post-apartheid cities and city patterns that ensure urban access, as well as achieve a balance between spatial equity, economic competitiveness and environment sustainability (DHS, 2020). As the impacts of climate change become more severe, the latter outcome (i.e., ensuring and maintaining environmental sustainability) will become increasingly important.

Furthermore, as part of the implementation approach for housing and human settlement development in PHSHDAs, the DHS has identified the provision and maintenance of ecological infrastructure to support development in priority areas as a key avenue for integrating climate considerations and mainstreaming climate responses (DHS, 2022).

1.3. Local Municipal context

The Musina-Makhado Priority Human Priority Human Settlement and Housing Development Area (PHSHDA) has been declared a Special Economic Zone (SEZ) by the South African National Government through the Department of Trade and Industry (DTI). The SEZ / PHSHDA is a located across two Local Municipalities, namely Musina and Makhado Local Municipalities (Figure 2). Both Local Municipalities form part of the Vhembe District – along with Thulamela and Collins Chabane Local Municipalities – which is located in the Province of Limpopo.

Musina Local Municipality is the northernmost Municipality of South Africa, and is home to the Beitbridge border post, thus making the Local Municipality the country's gateway to the Southern African Development Community (SADC) region, as well as the rest of Africa. Makhado Local

Municipality is located south of Musina and is considered an important bypass (mainly through the trans-Limpopo corridor) for people traveling between South Africa and the SADC region, as well as local destinations such as Polokwane, Musina, Thohoyandou, and the Kruger National Park (Musina Local Municipality, 2023). The trans-Limpopo corridor proceeds through Makhado Local Municipality and follows the N1-National Road from Polokwane in the south, through Makhado and into Musina and Zimbabwe in the north (Makhado Local Municipality, 2022). Other major routes bypassing the Local Municipality of Makhado include the R 523, R 522, R 524, R 578 roads (Makhado Local Municipality, 2022).

While Musina Local Municipality covers an area of approximately 11 297.41 km^2, therefore making it the largest Local Municipality in the Vhembe District, Makhado Local Municipality covers an area of 7 605.06 km^2, and is the second largest Local Municipality in the District (Musina Local Municipality, 2023). The prevailing land uses within the Municipalities include commercial, conservation, cultivated land, forestry, mining, residential, subsistence farming, as well as large pockets of land parcels zoned agricultural (Makhado Local Municipality, 2022). Both the settlements of Musina and Makhado (also known as Louis Trichardt) have been identified as Provincial Growth Points (Makhado Local Municipality, 2023; Musina Local Municipality, 2023). Musina and Makhado are the closest large formal settlements to the Musina-Makhado SEZ (PHSHDA).

In 2011, Musina Local Municipality recorded a population of 104 654, with 104 034 people located in settlements. The settlement-based population increased by 47.63% between 2001 and 2011, and is expected to increase by 106.12% between 2011 and 2030. In 2016, the Local Municipality recorded a total population of 132 009, about 9.47% of the total population in Vhembe District (Musina Local Municipality, 2023). Makhado Local Municipality had a settlement-based population of 401 524 in 2011, which increased by 6.72% between 2001 and 2011, and is expected to increase by 15.66% between 2011 and 2030. In 2019, the Local Municipality had a total population of 416 728 (Makhado Local Municipality, 2022).

Musina's leading economic sectors include Mining and Quarrying, Manufacturing, Retail and Agricultural sectors, with the Transport and Construction sectors constituting the fastest growing sectors in the Municipality (Musina Local Municipality, 2023). Makhado's Manufacturing sector was the biggest contributor to the Local Municipality's economy in 2011, with a contribution of 30% to the Municipality's total Gross Value Added (GVA). This was followed by the Finance and Trade and sectors, which contributed 29% and 15%, respectively. Makhado's top labour-absorbing sectors include the Community Services, Trade and Agricultural sectors which respectively employed 27.45%, 19.30% and 17.40% of the Local Municipality's working population (Makhado Local Municipality, 2022). In 2011, Musina had an unemployment rate of 18.7%, while Makhado Local Municipality recorded an unemployment rate of 36,7%, in the same time period (Stats SA, 2023).

The Musina Local Municipal Area is classified as a Savannah landscape, and four main types of vegetation are found within this landscape, including the Limpopo ridge bushveld, Musina mopane bushveld, Soutpansberg mountain bushveld and the subtropical alluvial vegetation (Musina Local Municipality, 2023). Fire plays a key part in the ecology of Savanna ecosystems, with the dry season being the main window for vegetation fires as fuel loads of dry plant material increase (BOTSOC, 2023). A variety of vegetation and animal habitats are present within the Musina Local Municipality; these are mostly located in environmental areas and are supported by ecological assets found in the Municipal Area, including Nwanedi Nature Reserve, Musina Nature Reserve, the Mapungubwe national park, Mogalakwena River, Nzhelele Dam and Shingwedzi River (Musina Local Municipality, 2023).

Large parts of the Makhado Local Municipal Area are covered in natural bushveld. In terms of the area's geomorphological landscape, 34% of the area comprises of Limpopo Flats, 26.02% is known as the Polokwane Plains, 17.24% as Soutpansberg Mountains, and 13.61% as the Lowveld (Makhado Local Municipality, 2022). Some of the key ecological areas, which house rich biodiversity and ecological assets that act as critical buffers against some of the impacts of climate change include the Happy Rest Nature Reserve, Langjan Nature Reserve, Nzhelele Nature Reserve, Studholme Nature Reserve, and Entabeni Nature Reserve. Major river systems in the Local Municipality include the Sand and Hout River system, the Luvuvhu River system, the Little Letaba river and Nzhelele River system (Makhado Local Municipality, 2022).

While no major settlements are evident in the Musina-Makhado SEZ (PHSHDA), several economic activities are present; these include livestock farming, commercial cattle farming, game farming and hunting, ecotourism, (tourism) accommodation and irrigation, with the expansion of mining and mining beneficiation sectors expected to produce numerous employment and economic activities. The main roads bypassing the SEZ / PHSHDA include N1 and R 525, with the Soutpansberg Mountains – an important ecological site – located parallel to the SEZ's southern border (HDA, 2022). The SEZ / PHSHDA has to a large extent been earmarked for industrial development, with a two large pockets of land, one in the south, and another in the northeast, demarcated as environmentally sensitive areas in need of protection, where development is not encouraged. A node is also envisaged in the area, particularly around the N1 and east-west bound R 525 road intersection, where high density residential and mixed-use developments are planned; this area will make up the SEZ's / city's core (HDA, 2022).

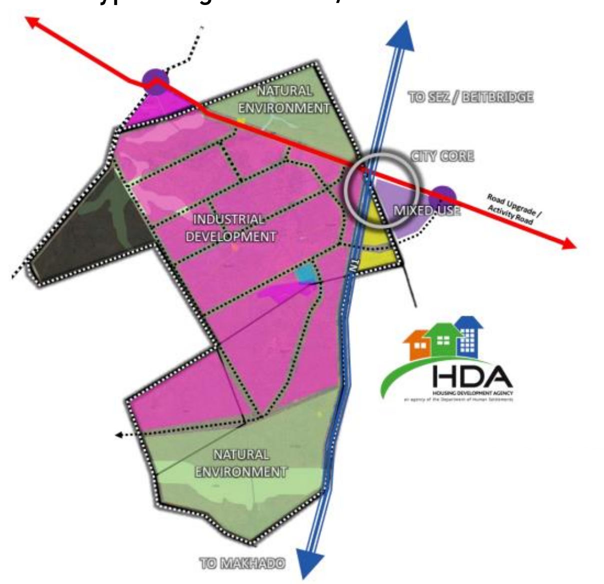

Figure 2: Musina-Makhado SEZ Spatial Vision (HDA, 2022)

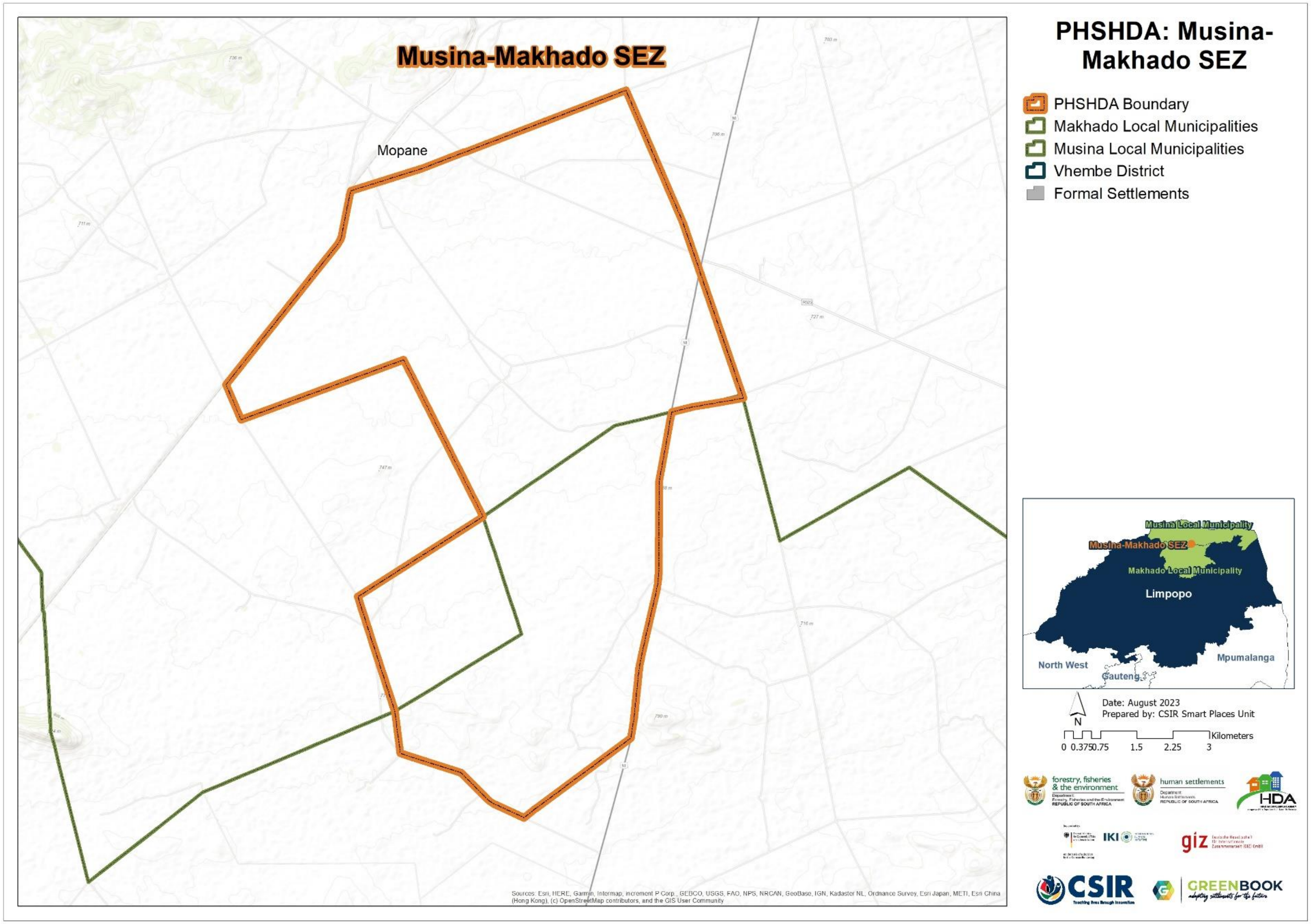

Figure 3: Musina-Makhado SEZ

2. Baseline and future climate risk

This section starts with an overview of vulnerability and population change projections, unpacking the components of vulnerability on both the municipal and settlement level as well future population pressures. Thereafter the current and future climate is discussed in terms of temperature and rainfall. Current as well as future exposure to drought, heat, wildfire, and flooding are also set out. Together, this information provides an overview of current and future climate risk for the Municipalities of Musina and Makhado, as well as the Musina-Makhado SEZ, to inform responsive planning and adaptation.

2.1. Vulnerability and population change

There are many factors that influence the vulnerability of our municipalities and settlements, some of which are unpacked in the following section. The current vulnerabilities for the Musina and Makhado Local Municipalities, as well as their settlements, are profiled using a framework which sets out indicators that can be used to profile the multi-dimensional and context-specific inherent vulnerability of settlements and municipalities in South Africa. The framework describes and quantifies, where possible, the inherent vulnerability of people, infrastructure, services, economic activities, and natural resources by setting out context and location-specific indicators that were specifically designed to support vulnerability risk assessments of South African municipalities. Population changes drives vulnerability into the future, and therefore population growth and decline of settlements across the Musina and Makhado Local Municipalities are projected to 2050. Spatial population projections are integral in determining the potential exposure and vulnerability of a population to hazards.

2.1.1. Municipal vulnerability

Municipal vulnerability is unpacked in terms of four vulnerability indices, each of which are described below, and in Table 1, the vulnerability scores are provided for Musina and Makhado Local Municipalities.

The Socio-Economic Vulnerability Index (SEVI) shows the vulnerability of households living in the municipality with regards to household composition, income composition, education, mobility, health, access to basic services, access to social government services, political instability, and safety and security of households. A high vulnerability score indicates that the municipality houses a high number of vulnerable households with regards to their ability to withstand adverse shocks from the external environment.

The Economic Vulnerability Index (EcVI) speaks toward the economic resilience of the municipality, and considers economic sector diversification, the size of economy, labour force, the GDP growth/decline pressure experienced in the municipality, and the inequality present in the municipality. The higher the economic vulnerability the more susceptible the municipality is to being adversely affected by external shocks.

The Physical Vulnerability Index (PVI) relates to the built environment and the connectedness of the settlements in the local municipality. It is a composite indicator that considers road infrastructure, housing types, the maintenance of the infrastructure, densities, and general accessibility. A high physical vulnerability score highlights areas of remoteness and/or areas with structural vulnerabilities.

The Environmental Vulnerability Index (EnVI) highlights municipalities where there is a high conflict between preserving the natural environment and accommodating the growth pressures associated with population growth, urbanisation, and economic development. The index considers the human influence on the environment, the amount of ecological infrastructure present that needs protection, the presence of critical water resources, environmental health, and environmental governance. A high vulnerability score highlights municipalities that experience increasing pressure relating to protecting the environment and allowing land use change due to growth pressures.

Musina Local Municipality and Makhado Local Municipality are provided with a score out of 10 for each of the vulnerability indices. A score higher than 5 indicates an above national average, and a score lower than 5 indicates a below national average for vulnerability. Scores are provided for both 1996 and 2011, where a lower score in 2011 compared to 1996 indicates an improvement and a higher score indicates worsening vulnerability. Trend data is only available for Socio-Economic Vulnerability (SEVI) and Economic Vulnerability (EcVI).

Table 1: Vulnerability indicators across Musina Local Municipality and Makhado Local Municipality

MUNICIPALITY	SEVI 1996	SEVI 2011	Trend	EcVI 1996	EcVI 2011	Trend	PVI	Trend	EnVI	Trend
Musina	5.11	4.73	↘	5.87	7.19	↗	6.27	N/A	6.83	N/A
Makhado	4.80	4.79	↘	4.79	6.19	↗	6.91	N/A	5.36	N/A

As outlined in Table 1, Musina Local Municipality's socio-economic vulnerability (SEVI) has decreased (improved) between 1996 and 2011, and is well below the national average. Therefore, when compared to the national average, the Local Municipality houses a considerably low amount of socioeconomically vulnerable households. The Municipality's economic vulnerability (EcVI), however, worsened in the same period, and peaked to a score that is noticeably higher than the national average (7.19). Musina Local Municipality's economy is therefore highly susceptible to the negative impacts of external shocks, including climate hazards. Despite the fact that the economy is composed of several sectors, it could benefit from further diversification, especially into sectors that are more climate-sensitive. Musina Local Municipality also has very high physical vulnerability (PVI), as well as the third highest environmental vulnerability (EnVI) score in the Province. While the remoteness of the settlements in the Municipality contributes to the high vulnerability score, the high environmental vulnerability (EnVI) score alludes to the large presence of ecological assets in the area, and the impact of development and urbanisation on them. Makhado Local Municipality's socio-economic vulnerability also decreased (improved) between 1996 and 2011, while the economic vulnerability increased in the same period. The Local Municipality's high unemployment rate of 36,7% contributed to this score. While the Municipality has an average environmental vulnerability score, its physical vulnerability is considerably high, the fifth highest in the Province, out of a total of 22 Local Municipalities. This alludes to the high structural vulnerabilities present in the Municipality, as well as the remoteness of the settlements found in the Municipal Area.

2.1.2. Settlement vulnerability

The unique set of indicators outlined below highlight the multi-dimensional vulnerabilities of the settlements located near the SEZ / PHSHDA, which is located within the Musina and Makhado Municipal Areas, with regards to six composite indicators. This enables the investigation of the relative vulnerabilities of the settlements located near, or linked to, the Musina-Makhado SEZ, compared to other settlements in the Local Municipality.

A high vulnerability score (closer to 10) indicates a scenario where an undesirable state is present e.g., low access to services, high socio-economic vulnerabilities, poor regional connectivity, environmental pressure or high economic pressures. An indicator of growth pressure, providing a temporal dimension (15-year trend), was added to show which settlements are experiencing growth pressures on top of the other dimensional vulnerabilities.

The Socio-economic Vulnerability Index comprises of three indicators (and eight variables) that show the vulnerability of households occupying a specific settlement with regards to their (1) household composition (household size, age dependency, female/child headed household), (2) income composition (poverty level, unemployment status, and grant dependency of the households), as well as (3) their education (literacy and level of education).

The Economic Vulnerability Index comprises of five variables grouped into three indicators that highlight the economic vulnerability of each settlement with regards to (1) its size (GDP per capita and GDP production rates), (2) the active labour force (taking note of unemployed and discouraged work seekers), and (3) the GDP growth rate for the past 15 years.

The Environmental Vulnerability Index considers the footprint composition of the settlement taking the ration of built-up versus open spaces into account.

The Growth-Pressure Vulnerability Index shows the relative (1996-2011 growth rates) and anticipated pressure on settlements.

The Regional Economic Connectivity Vulnerability Index looks at the regional infrastructure of each settlement (measured through a remoteness/accessibility index), as well as the role of the town in terms of its regional economy.

The Service Access Vulnerability Index comprises of 10 variables grouped into four indictors, that show the level of services offered and rendered within a settlement and includes the settlement's (1) access to basic services (electricity, water, sanitation, and refuse removal), (2) settlement's access to social and government services (health access, emergency service access, access to schools, and early childhood development), (3) access to higher order education facilities, and (4) access to adequate housing.

Figures 3 and 4 illustrate the multi-dimensional vulnerabilities of the settlements found within the Musina and Makhado Municipal Areas. This is followed by a brief description of the settlement vulnerability in the settlements of Musina and Makhado (Louis Trichardt) – which are directly linked to the SEZ / PHSHDA through the N1 – compared to other settlements in both Local Municipalities.

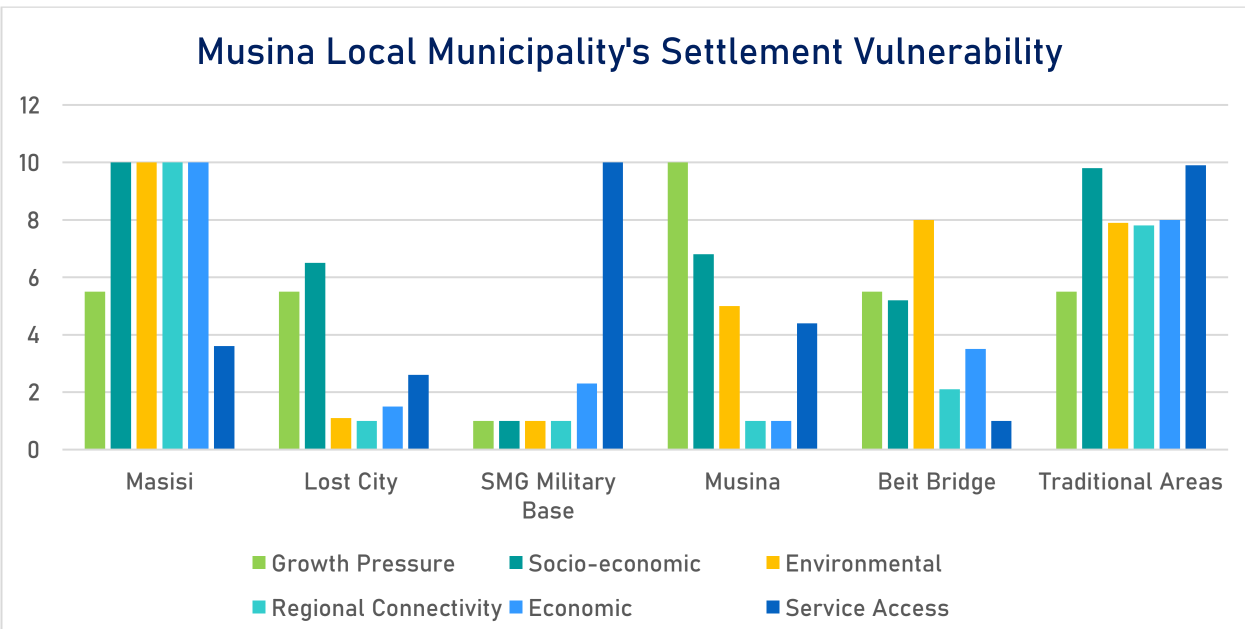

Figure 4: Musina Local Municipality's settlement vulnerability

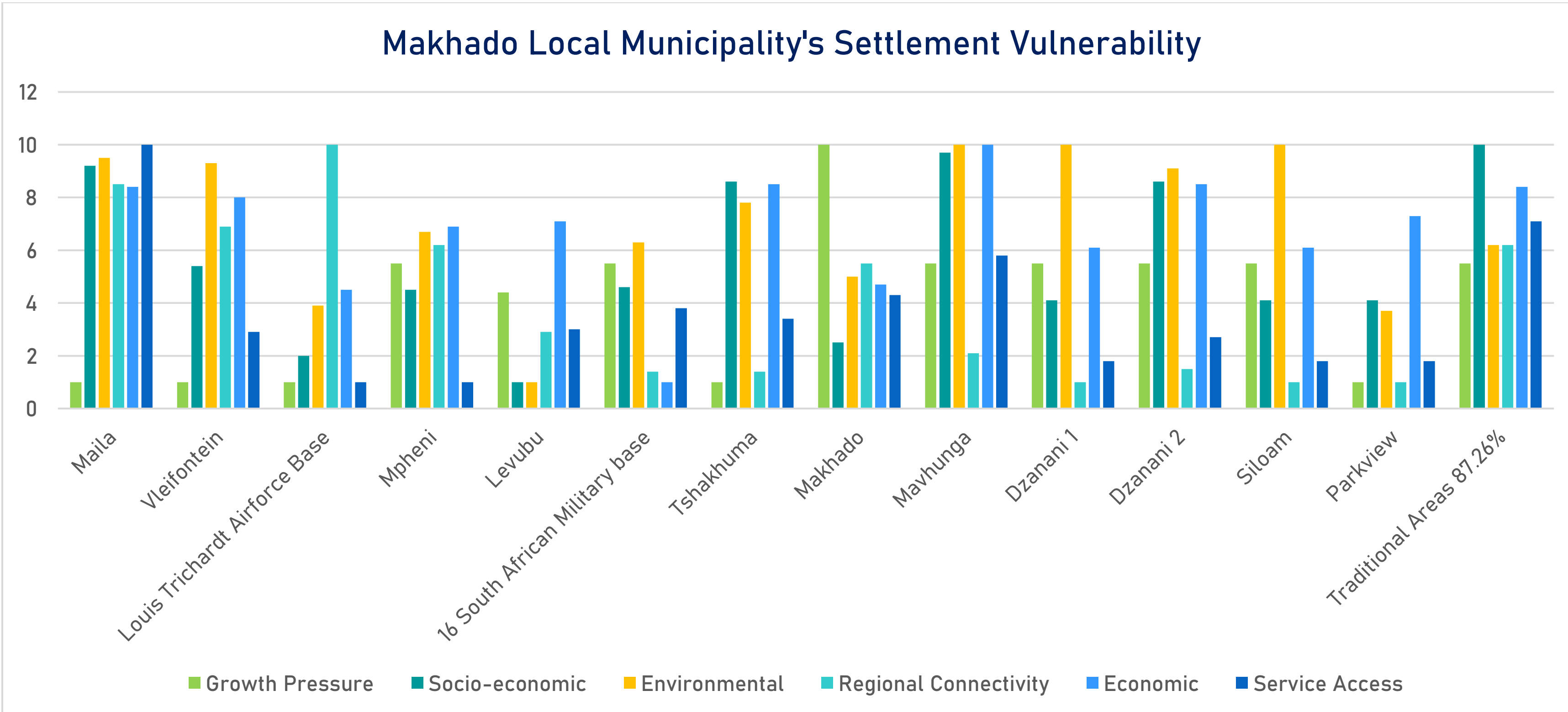

Figure 5: Makhado Local Municipality's settlement vulnerability

The major settlements in the Musina Local Municipality are Masisi, Lost City, SMG Military Base, Musina, Beit Bridge, as well as several traditional areas. As indicated in Figure 3, the settlement of Musina has the highest growth pressure vulnerability in the Local Municipality, and together with Lost City, regional connectivity vulnerability, as well as the lowest economic vulnerability. Musina is, therefore, a well-connected settlement, with a resilient economy, although its resources are under increasing pressure as a result of population growth. The major settlements in Makhado Local Municipality are Maila, Vleifontein, Louis Trichardt Airforce Base, Mpheni, Levubu, 16 South African Military base, Tshakhuma, Makhado, Mavhunga, Dzanani 1, Dzanani 2, Siloam, Parkview, and several traditional areas. As indicated in Figure 4 and similar to Musina, the settlement of Makhado has the highest growth pressure vulnerability in the Local Municipality.

2.1.3. Population growth pressure

The core modelling components of the settlement growth model are the demographic model and the population potential gravity model. The demographic model produces the long-term projected population values at the national, provincial and municipal scale using the Spectrum and Cohort-Component models. The spatially-coarse demographic projections were fed into the population potential gravity model, a gravity model that uses a population potential surface to downscale the national population projections, resulting in 1x1 km resolution projected population grids for 2030 and 2050. The availability of a gridded population dataset for past, current, and future populations enables the assessment of expected changes in the spatial concentration, distribution, and movement of people.

Using the innovative settlement footprint data layer created by the CSIR, which delineates built-up areas, settlement-scale population projections were aggregated up from the 1 x 1 km grids of South African projected population for a 2030 and 2050 medium and high growth scenario. These two population growth scenarios (medium and high) are differentiated based on their in- and out-migration assumptions. The medium growth scenario (see Table 2) assumes that the peak of population influx from more distant and neighbouring African countries into South Africa has already taken place. The high growth scenario assumes that the peak of migrant influx is yet to happen.

Table 2: Population growth pressure across Musina and Makhado Local Municipalities

Municipal Population Growth	2011	Medium Growth Scenario	
		2030	2050
Musina Local Municipality	104 034	214 438	375 566
Makhado Local Municipality	401 524	464 388	451 654

Musina Local Municipality's population is projected to increase by 261% between 2011 and 2050, under a medium growth scenario, while Makhado Local Municipality's population is projected to increase by 12.48% in the same period. For both Local Municipalities, most of the growth is expected to occur between 2011 and 2030. Table 3 provides, in addition to the expected growth pressure (under a medium population growth scenario), the baseline (2011) and projected (2030 and 2050) population figures for each settlement in the Musina Local Municipality. The expected growth pressure (under a medium population growth scenario), as well as the baseline (2011) and projected (2030 and 2050) population figures for each settlement in Makhado Local Municipality are provided in Table 4.

Table 3: Settlement-level population growth pressure across Musina Local Municipality

Musina Local Municipality				
Town	Pressure	2011	2030	2050
Masisi	Extreme	1,619	4,563	8,859
Lost City	No Change	762	774	757
SMG Military Base	No Change	129	131	128
Musina	No Change	41,800	42,465	41,545
Beit Bridge	Extreme	1,030	5,188	11,255

Table 4: Settlement-level population growth pressure across Makhado Local Municipality

Makhado Local Municipality				
Town	Pressure	2011	2030	2050
Maila	Medium	3,480	4,063	3,945
Vleifontein	Medium	5,881	6,839	6,645
Louis Trichardt Airforce Base	Medium	991	1,173	1,136
Mpheni	Medium	8,021	10,167	9,732
Levubu	No Change	366	366	366
16 South African Military base	Medium	4,196	5,158	4,960
Tshakhuma	Medium	3,827	4,658	4,490
Makhado	Medium	25,545	33,437	31,838
Mavhunga	Medium	3,896	4,701	4,537
Dzanani 1	Medium	2,747	3,124	3,048
Dzanani 2	Medium	3,823	4,362	4,253
Siloam	Medium	2,364	2,748	2,716
Parkview	Medium	956	1,268	1,204

As displayed in Tables 3 and 4, almost all settlements in Makhado Local Municipalities are projected to experience medium growth pressure, including the settlement of Makhado, which are directly linked to the SEZ / PHSHDA though the N1. The settlement of Musina is expected to experience no significant changes in population growth and population growth pressure.

2.2. Climate

An ensemble of very high-resolution climate model simulations of present-day climate and projections of future climate change over South Africa has been performed as part of the GreenBook. The regional climate model used is the Conformal-Cubic Atmospheric Model (CCAM), a variable-resolution Global Climate Model (GCM) developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). CCAM runs coupled to a dynamic land-surface model CABLE (CSIRO Atmosphere Biosphere Land Exchange model). GCM simulations of the Coupled Model Inter-Comparison Project 5 (CMIP5) and the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), obtained for the emission scenarios described by Representative Concentration Pathways 4.5 and 8.5 (RCP 4.5 and RCP 8.5) were first downscaled to 50 km resolution globally. The simulations span the period 1960–2100. RCP 4.5 is a high mitigation scenario (assuming a reduction in CO_2 emissions into the future), whilst RCP 8.5 is a low mitigation scenario (assuming "business as usual" emissions).

After completion of the 50 km resolution simulations described above, CCAM was integrated in stretched-grid mode over South Africa, at a resolution of 8 x 8 km (approximately 0.08° degrees in latitude and longitude). The model integrations performed at a resolution of 8 km over South Africa offer several advantages over the 50 km resolution simulations:

a) Convective rainfall is partially resolved in the 8 km simulations, implying that the model is less dependent on statistics to simulate this intricate aspect of the atmospheric dynamics and physics.
b) Important topographic features such the southern and eastern escarpments are much better resolved in the 8 km resolution simulations, implying that the topographic forcing of temperatures, wind patterns and convective rainfall can be simulated more realistically.

For more information on the climate simulations, see the GreenBook Climate Change Story Map and the full technical report.

For each of the climate variables discussed below:

a) The simulated baseline (also termed "current" climatological) state over South Africa calculated for the period 1961–1990 is shown (note that the median of the six downscaled GCMs are shown in this case).
b) The projected changes in the variable are subsequently shown, for the time-slab 2021–2050 relative to the baseline period 1961-1990.
c) An RCP 8.5 scenario (low mitigation) is shown.

2.2.1.Temperature

The model was used to simulate annual average temperatures (°C) for the baseline (current) period of 1961–1990, and the projected change for period 2021–2050 under an RCP 8.5 mitigation scenario.

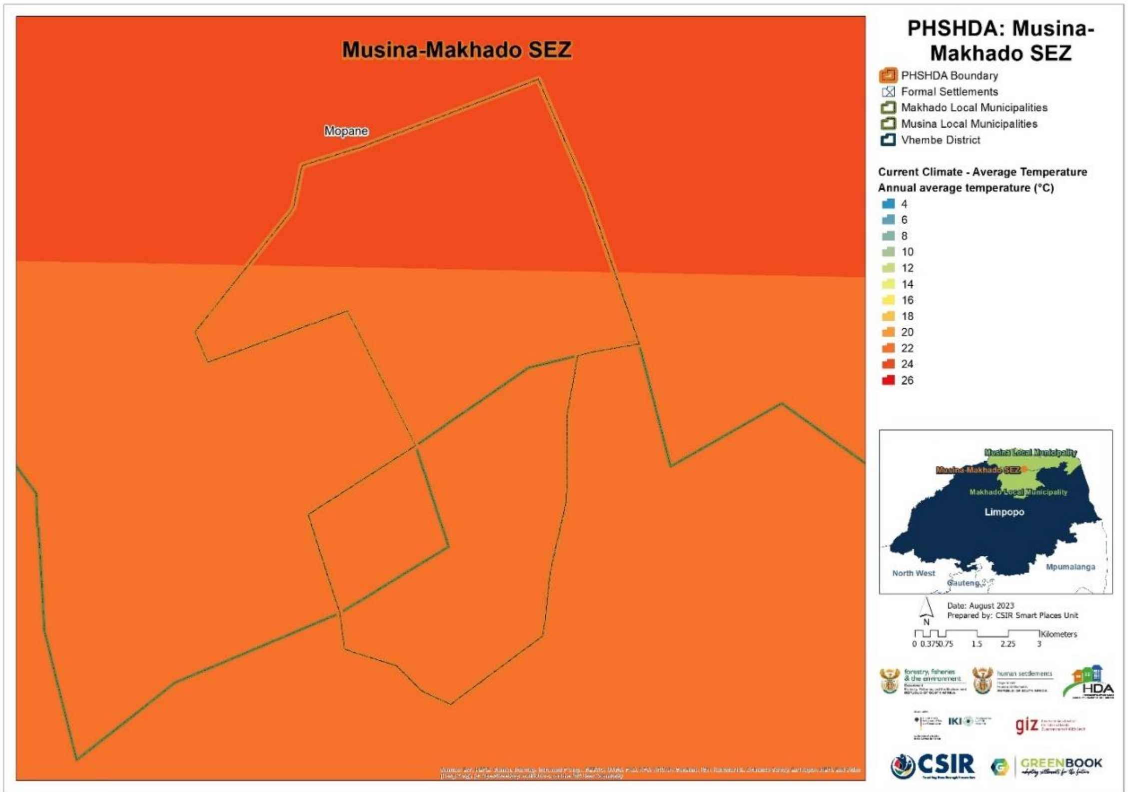

Figure 6: Average annual temperature (°C) for the baseline period 1961 – 1990 for the Musina-Makhado SEZ

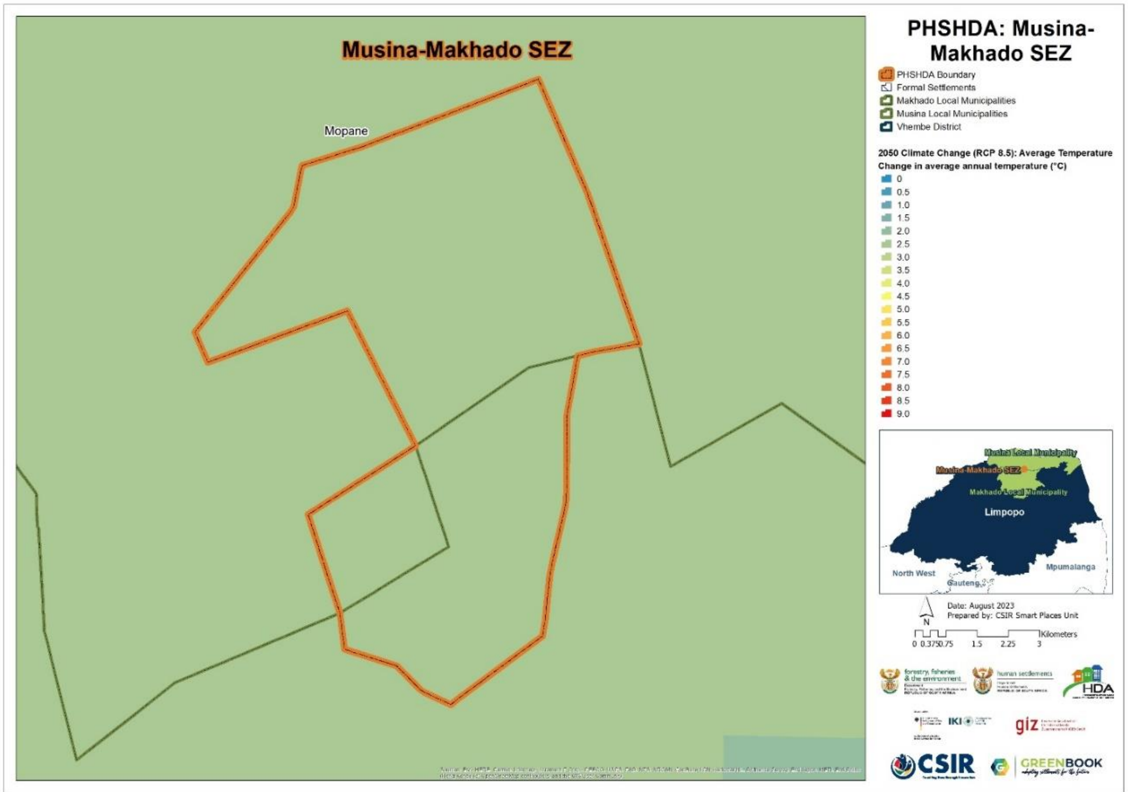

Figure 7: Projected change in average annual temperature (°C) from the baseline period to the period 2021 – 2050 for the Musina-Makhado SEZ, assuming an (RCP 8.5) emissions pathway

At the baseline (current), large parts of Musina Local Municipality experience average temperatures of between 22 and 24 °C, while Makhado Local Municipality experiences average annual temperatures of between 20 and 24°C, with higher temperatures prevalent in the western parts of the Municipality. The projections show average annual temperature increases of between 2.09 and 2.67°C in the Local Municipality of Musina and of between 2.35 and 2.69 °C in Makhado Local Municipality by 2050, under an RCP 8.5 "business as usual" emissions scenario. The Musina-Makhado SEZ (PHSHDA) experiences average annual temperatures of between 22 and 24 °C (Figure 5); this is expected to increase by 2.5 °C, by the year 2050, assuming an RCP 8.5 low emissions scenario (Figure 6).

2.2.2. Rainfall

The multiple GCMs were used to simulate average annual rainfall (depicted in mm) for the baseline (current) period of 1961–1990, and the projected change from the baseline to the period 2021–2050 under an RCP8.5 emissions scenario. Model projections of precipitation manifest uncertain due to several factors, including model sensitivity to spatial resolution at which processes are resolved. At 8x8km horizontal resolution, for example, some processes (such as convective systems) that contribute to rainfall are not adequately resolved by the climate models. The precipitation projections therefore could reflect uncertainty in some locations since fine-scale processes that contribute to precipitation and its extremes are not captured. When the modelling ensemble approach used in the online GreenBook is considered, and the 10th, 50th and 90th percentiles, per grid point, agree on the directional change relative to the reference period, the signal is considered well developed and conclusive. In the case where the respective model percentiles show conflicting signs, the model ensemble manifest uncertainty and therefore reflect low confidence on which future model realisation/outcome is more likely. It is therefore critical to consider the ensemble distribution uncertainty when devising long-term adaptation strategies.

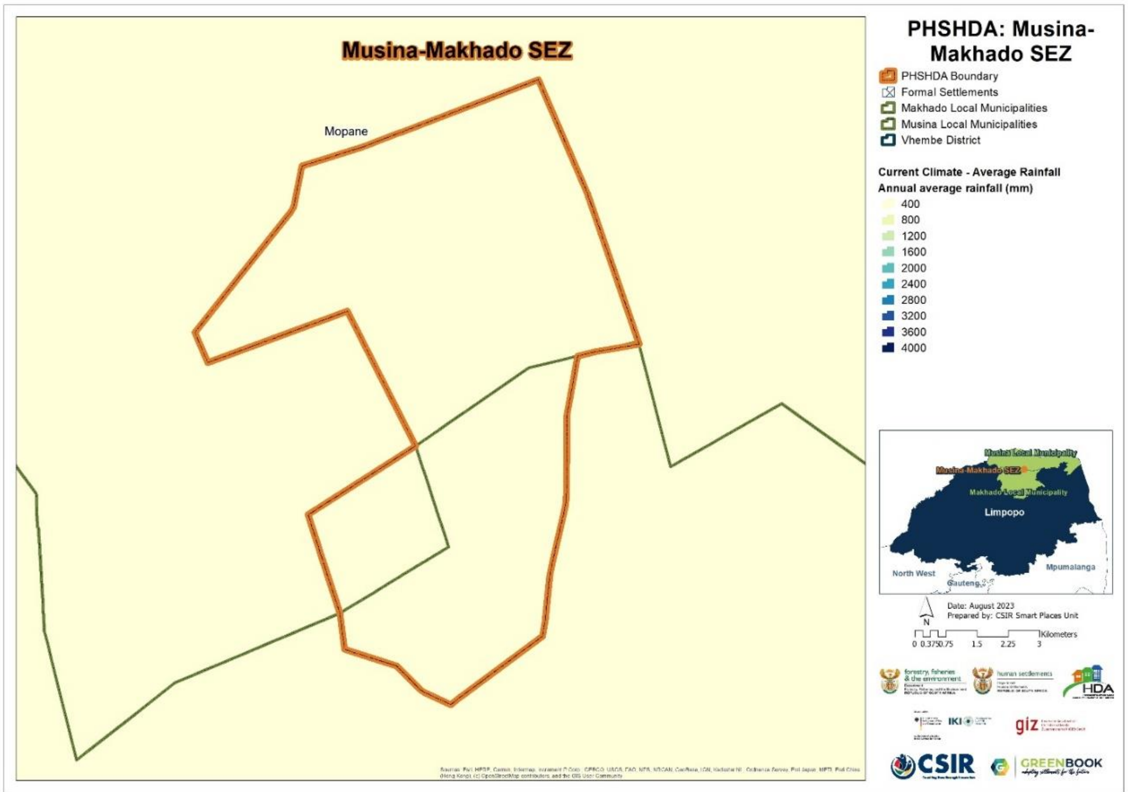

Figure 8: Average annual rainfall (mm) for the baseline period 1961 – 1990 for the Musina-Makhado SEZ

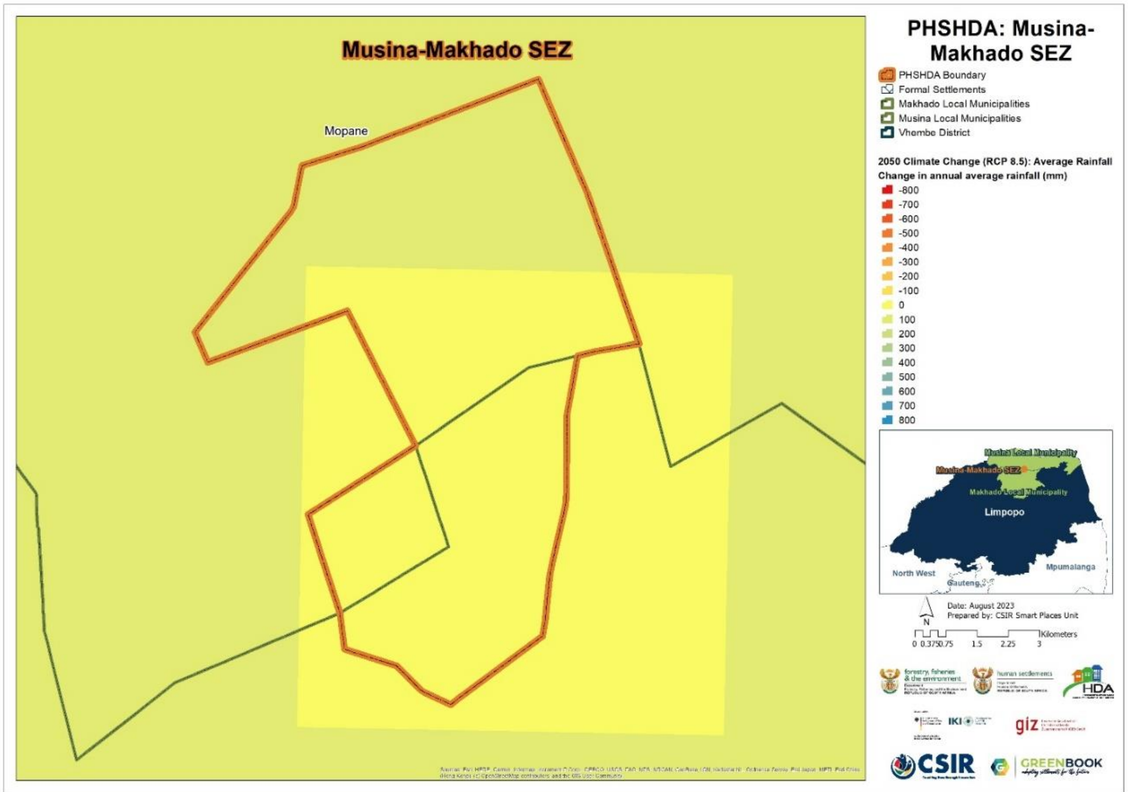

Figure 9: Projected change in average annual rainfall (mm) from the baseline period to the period 2021 – 2050 for THE Musina-Makhado SEZ, assuming an (RCP 8.5) emissions pathway

At the baseline (current), Musina Local Municipality experiences average annual rainfall of between 400 and 800 mm, with higher averages found in the eastern parts of the Local Municipality. Makhado Local Municipality experiences current average annual rainfall of between 400 and 1600 mm, with higher averages also prevalent in the eastern parts of the Municipality. The projections show changes in average annual rainfall of between 49.77 mm less and 113.29 mm more for Musina Local Municipality, as well as 28.28 mm less and 51.40 mm more for Makhado Local Municipality, by 2050, under an RCP 8.5 "business as usual" emissions scenario. The Musina-Makhado SEZ currently experiences average annual rainfall of 400 mm (Figure 7), with increases of between 0 and 100 mm per annum projected for the area, by 2050 (Figure 8).

2.3. Climate Hazards

This section showcases information with regards to the Musina-Makhado SEZ's exposure to climate-related hazards.

2.3.1.Drought

The southern African region (particularly many parts of South Africa) is projected to become generally drier under enhanced anthropogenic forcing, with an associated increase in dry spells and droughts. To characterise the extent, severity, duration, and time evolution of drought over

South Africa, the GreenBook uses primarily the Standardised Precipitation Index (SPI), which is recommended by the World Meteorological Organisation (WMO) and is also acknowledged as a universal meteorological drought index by the Lincoln Declaration on Drought. The SPI, with a two-parameter gamma distribution fit with maximum likelihood estimates of the shape and scale parameters, was applied on monthly rainfall accumulations for a 3-, 6-, 12-, 24- and 36-months base period. The SPI severity index is interpreted in the context of negative values indicating droughts and positive values indicating floods. These values range from exceptionally drier (<-2.0) or wetter (>2.0) to near-normal (region bounded within -0.5 and 0.5).

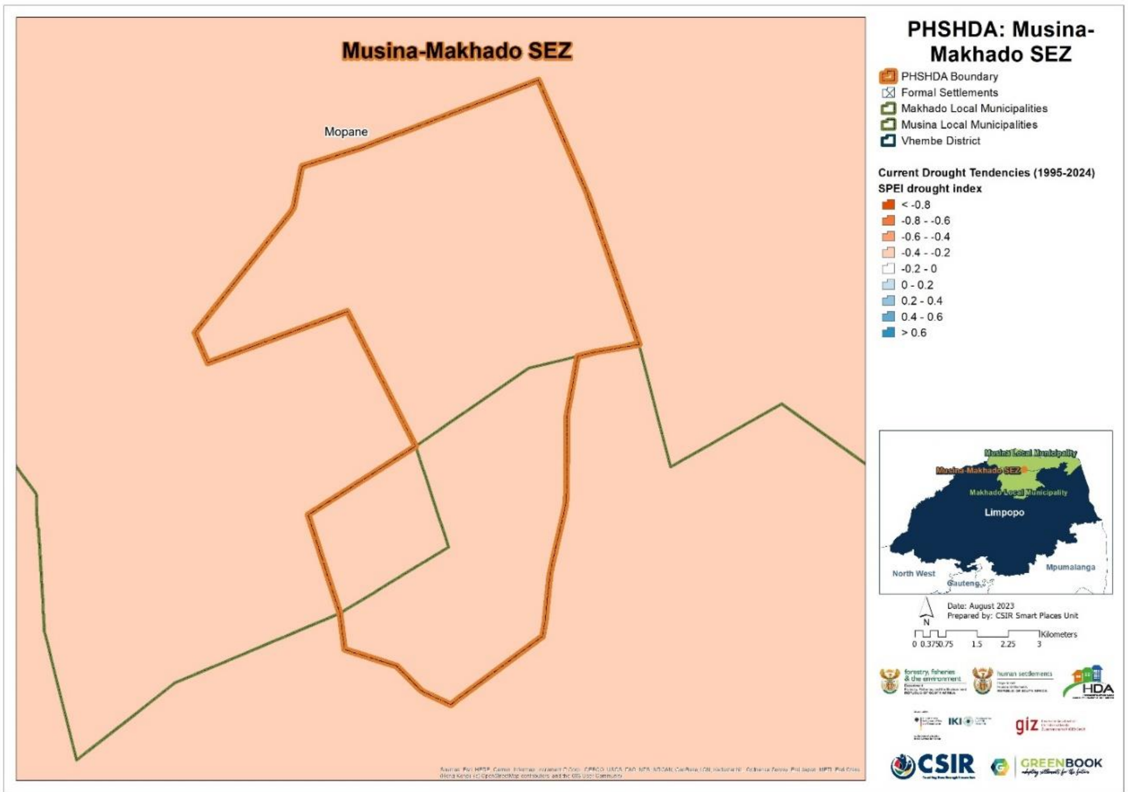

Figure 10: Projected changes in drought tendencies from the baseline period (1986 - 2005) to the current period (1995 - 2024) across THE Musina-Makhado SEZ

Figure 9 depicts the projected change in drought tendencies (i.e., the number of cases exceeding near-normal per decade) for the period 1995-2024, relative to the 1986-2005 baseline period, under an RCP 8.5 “business as usual” emissions scenario. A negative value is indicative of an increase in drought tendencies per 10 years (more frequent than the observed baseline), with a positive value indicative of a decrease in drought tendencies.

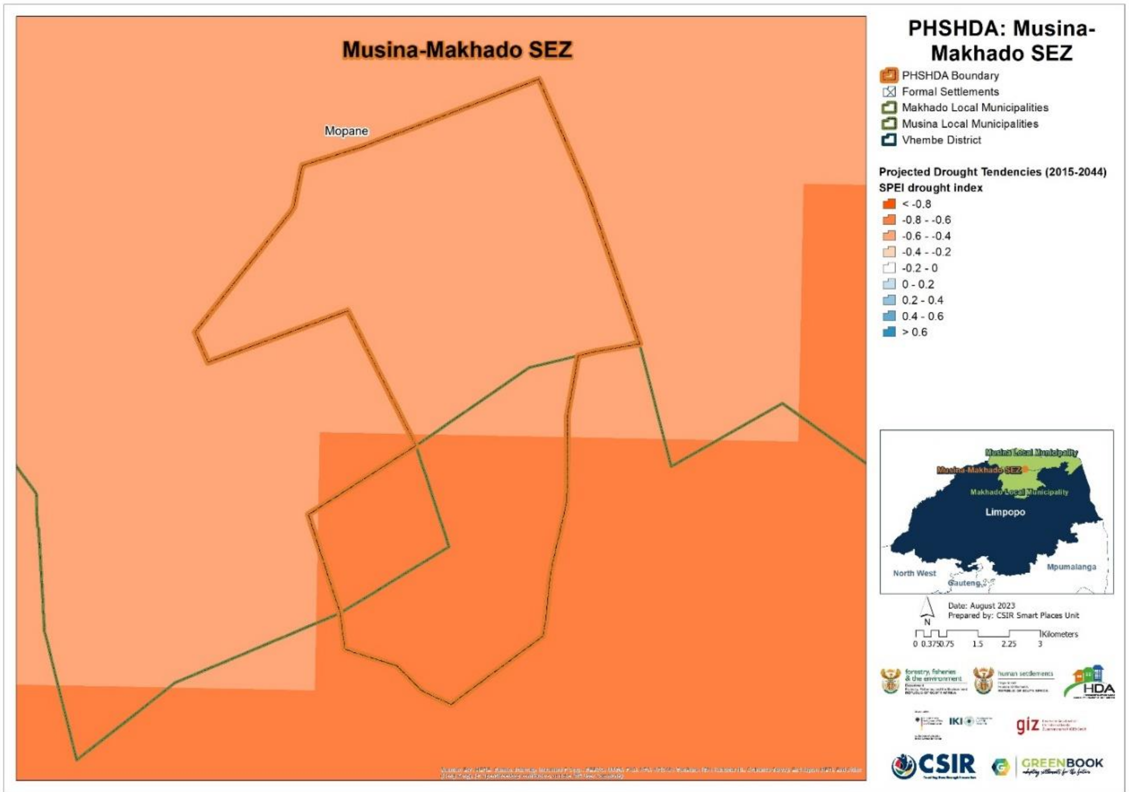

Figure 11: Projected changes in drought tendencies from the baseline period (1986 - 2005) to the future period (2015 - 2044) for the Musina-Malhado SEZ

Figure 10 depicts the projected change in drought tendencies (i.e., the number of cases exceeding near-normal per decade) for the period 2015–2044, relative to the 1986–2005 baseline period, under the low mitigation "business as usual" emissions scenario (RCP 8.5). A negative value is indicative of an increase in drought tendencies per 10 years (more frequent than baseline) into the future period and a positive value indicative of a decrease.

At the baseline, large parts of Musina Local Municipality are exposed to drought tendencies, with more intense droughts prevalent along the northern border of the Municipality, while the most intense droughts in Makhado occur along the western border of the Local Municipality. Both Local Municipalities can expect more frequent and intense droughts towards 2050. The Musina-Makhado SEZ currently experiences drought tendencies (Figure 9); these are expected to increase in frequency and intensity into a climate changed future (at least up to 2050), especially in the southern parts of the area (Figure 10).

2.3.2. Heat

The GCMs were used to simulate bias-corrected, annual average number of <u>very hot days</u>, defined as days when the maximum temperature exceeds 35°C per GCM grid point for the baseline (current) period of 1961–1990 (Figure 11), and for the projected change for period 2021–2050 (Figure 12), assuming a "business as usual" (RCP 8.5) emissions pathway.

The annual heatwave days map under baseline conditions (Figure 13) depicts the number of days (per 8x8 km grid point) where the maximum temperature exceeds the average maximum temperature of the warmest month of the year at that location by at least 5°C, i.e., for a period of at least three consecutive days. The projected change for the period 2021–2050 (Figure 14), assuming a "business as usual" (RCP 8.5) emissions pathway is also shown.

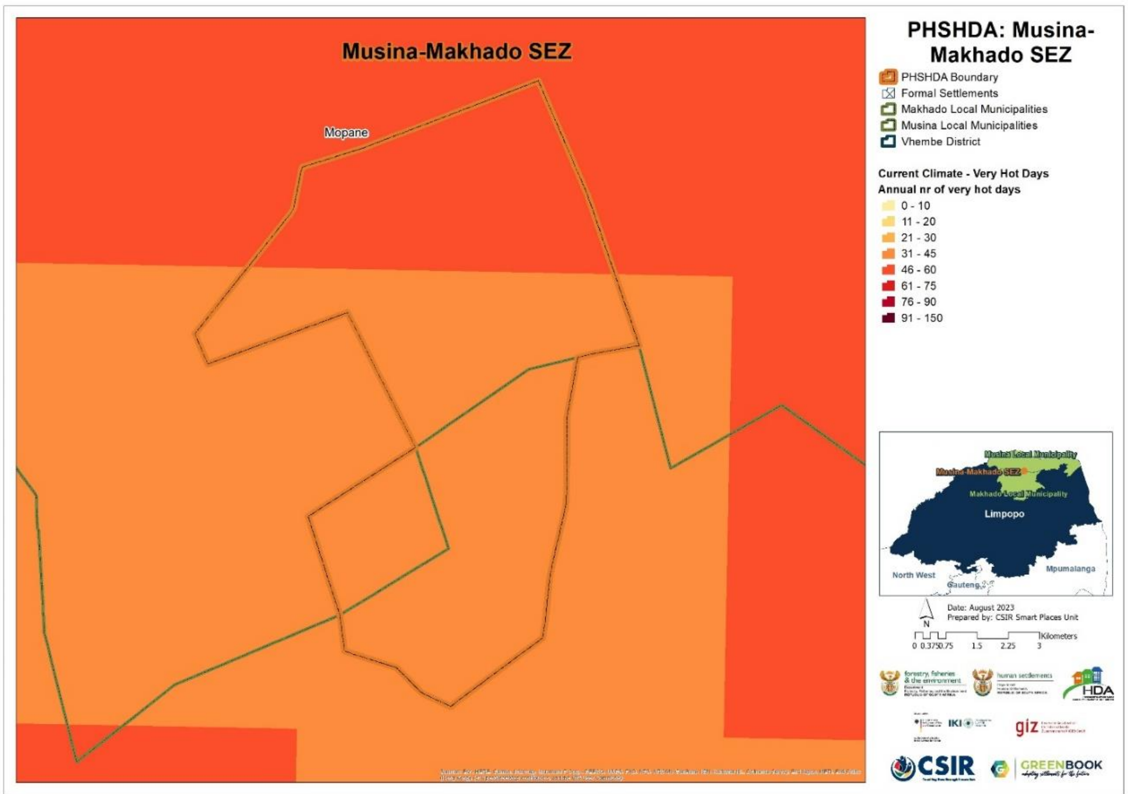

Figure 12: Annual number of very hot days under baseline climatic conditions across the Musina-Makhado SEZ with daily temperature maxima exceeding 35 °C

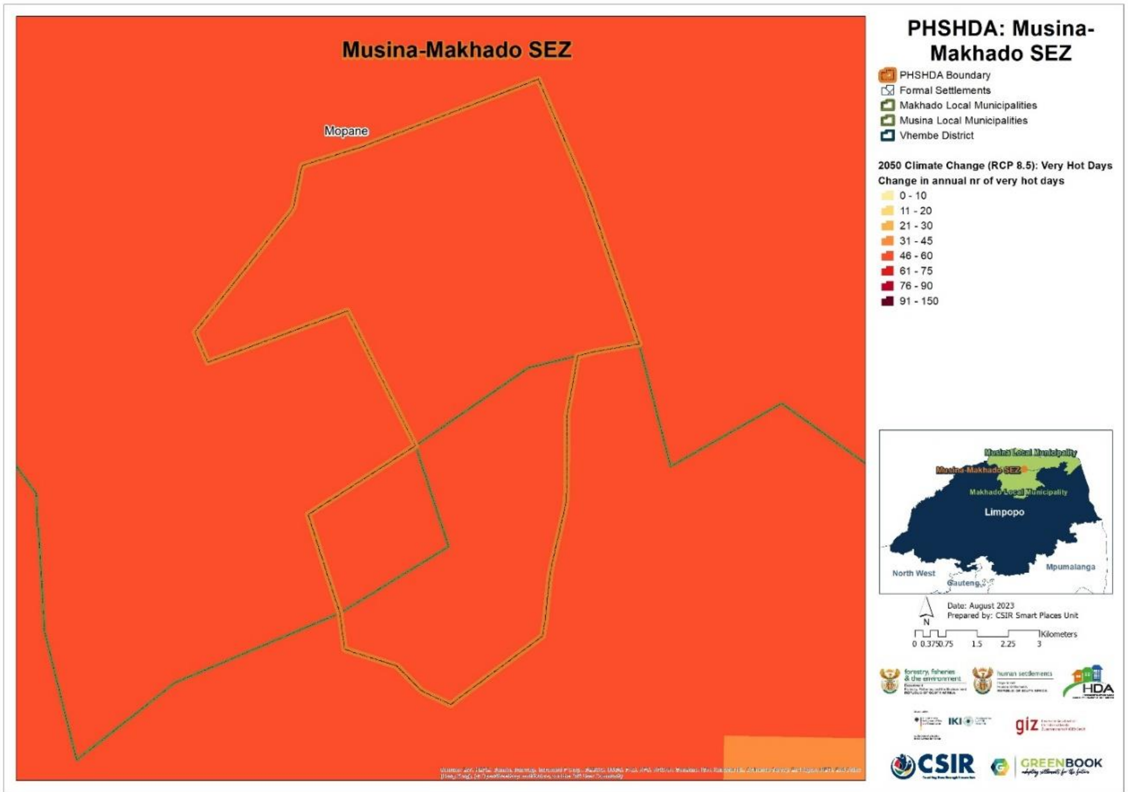

Figure 13: Projected change in annual number of very hot days across the Musina-Makhado SEZ with daily temperature maxima exceeding 35 °C, assuming an (RCP 8.5) emissions pathway

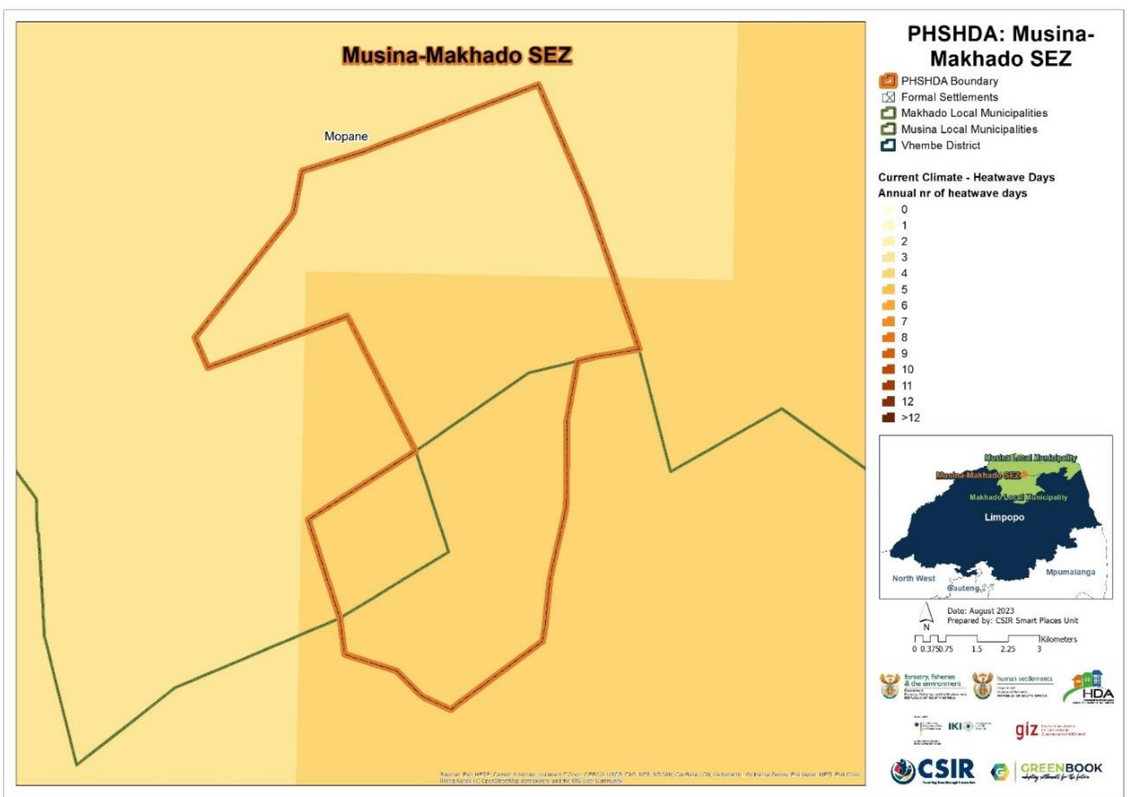

Figure 14: Annual number of heatwave days under baseline climatic conditions across the Musina-Makhado SEZ

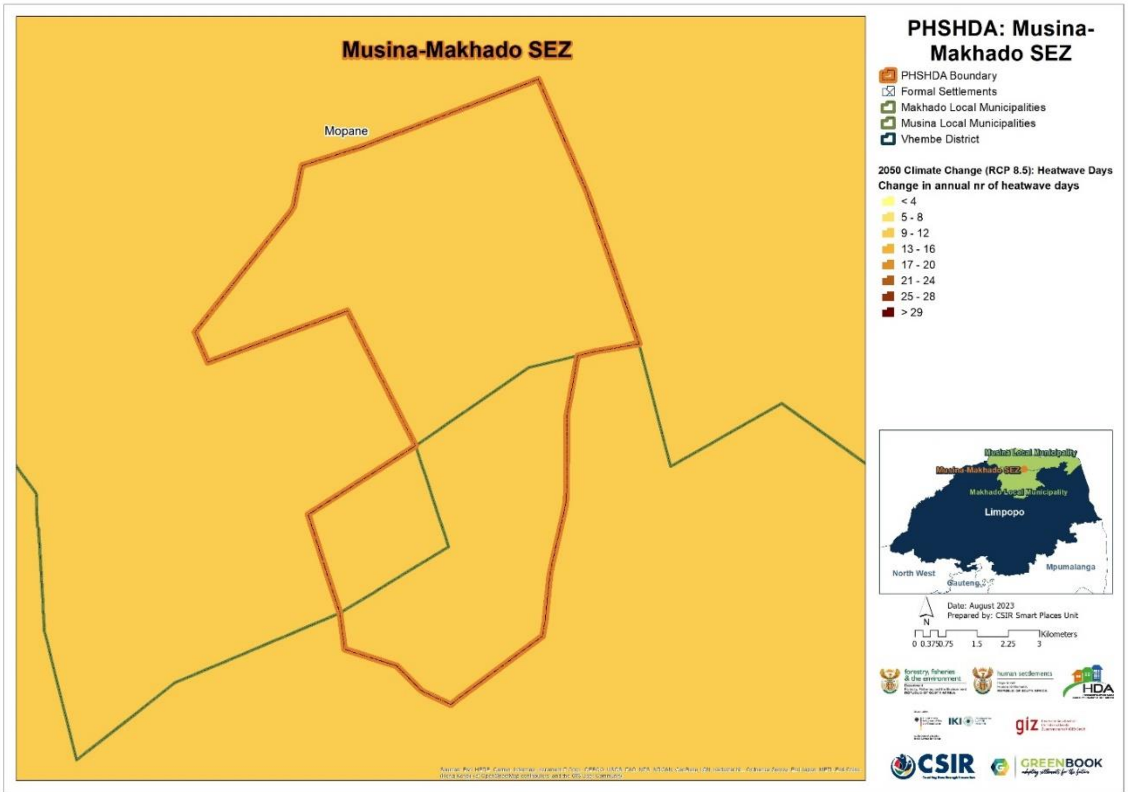

Figure 15: Projected change in annual number of heatwave days across the Musina-Makhado SEZ, assuming an (RCP 8.5) emissions pathway

Under baseline conditions, Musina Local Municipality experiences between 45 and 90 very hot days per year, which are expected to increase by between 12 and 58 days per annum by 2050, under an RCP 8.5 emissions scenario. Makhado Local Municipality experiences between 15 and 45 very hot days per year; these are expected to increase by 17 to 57 days per year, by 2050, under an RCP 8.5 "business as usual" emissions scenario. The Musina-Makhado SEZ currently experiences between 31 and 60 very hot days per annum (Figure 11), which are projected to increase by between 46 and 60 days per year, by 2050, under an RCP 8.5 emissions scenario. The SEZ also experiences 3 to 4 heatwave days annually, under baseline conditions (Figure 13); these are projected to increase by between 9 and 12 days per year under an RCP 8.5 emissions scenario (Figure 14). With the changing climate, it is expected that the impacts of heat will only increase in the future. The heat-absorbing qualities of built-up urban areas (which are planned for the Musina-Makhado SEZ) make them, and the people living inside them, especially vulnerable to increasingly high temperatures. The combination of the increasing number of very hot days and heatwave days over certain parts of South Africa is likely to significantly increase the risk of extreme heat in several settlements.

2.3.3. Wildfire

Wildfires occur regularly in South Africa and often cause significant damage. The main reasons for recurring wildfires are that we have climates with dry seasons, natural vegetation that produces sufficient fuel, and people who light fires when and where they should not. Much of the natural vegetation requires fires to maintain the ecosystems in good condition. At the same time fires are a threat to human lives, livelihoods, and infrastructure. More and more people, assets and infrastructure are placed on the boundary or interface between developed land and fire-prone vegetation – what we call the wildland-urban interface (WUI) – where they are exposed to wildfires. The combination of climate and vegetation characteristics that favour fires, and growing human exposure, results in significant wildfire risk across the country, especially in the southern and eastern parts.

Fire risk is determined by combining the typical fire hazard for a fire-ecotype (i.e., likelihood, fire severity) and the social and economic consequences (i.e., the potential for economic and social losses). The typical fire hazard was used to develop a plausible fire scenario for each fire-ecotype, i.e., what a typical wildfire would be like. The fire scenarios were then combined with the vulnerability to estimate the economic and social consequences. We used a scale where the likelihood was rated from 'rare' to 'almost certain' and the consequences were rated from 'insignificant' to 'catastrophic' to determine a level of fire risk which ranged from 'low' to 'high'. The risks were then summarised for all the settlements within a local authority. Changes in the fire risk in future were accommodated by adjusting either the fire scenarios or the likelihood, or both.

The projected number of fire danger days for an 8 x 8 km grid-point under an RCP 8.5 "business as usual" emissions scenario was calculated. A fire danger day is described as a day when the McArthur fire-danger index exceeds a value of 24. The index relates to the chances of a fire starting, its rate of spread, its intensity, and its difficulty of suppression, according to various combinations of air temperature, relative humidity, wind speed and both the long and short-term drought effects. Future settlement risk of wildfires is informed by the projected change in the number of fire danger days.

While no settlements are evident within the Musina-Makhado SEZ, the settlements of Musina and Makhado (commonly known as Louis Trichardt) are located near the SEZ (PHSHDA) and are directly connected to the area through the N1. While the settlement of Makhado is exposed to a medium fire likelihood under baseline conditions, the settlement of Musina faces a high fire likelihood. Moreover, both settlements face medium to high risk of wildfires into a climate changed future (2050). Therefore, considering the planned developments in the SEZ, which will likely increase the exposure of people and assets to climate hazards, as well as the role fire plays in the ecology of the Savannah landscape in which this SEZ finds itself, it may be necessary to build the resilience of the SEZ's planned developments against wildfires.

2.3.4. Flooding

The flood hazard assessment combines information on the climate, observed floods, and the characteristics of water catchments that make them more or less likely to produce a flood. The climate statistics were sourced from the South African Atlas of Climatology and Agrohydrology, and a study of river flows during floods in South Africa (Schulze et al. 2008). The catchment characteristics that are important are those that regulate the volume and rate of the water flowing down and out of the catchment. The SCIMAP model was used to analyse the hydrological responsiveness and connectivity of the catchments and to calculate a Flood Hazard Index. Changes in land cover, such as urbanisation, vegetation and land degradation, or poorly managed cultivation, reduce the catchment's capacity to store or retain water. More dynamic changes in land cover could not be considered in this analysis, such as for example, recent informal settlements that may increase exposure and risk. Additional local and contextual information should be considered to further enrich the information provided here.

Since the magnitude and intensity of rainfall are the main drivers of floods and rainfall intensity is likely to increase into the future, estimates of extreme daily rainfall into the future were obtained from high-resolution regional projections of future climate change over South Africa. The settlements that are at risk of an increase in floods were calculated using a risk matrix, that considered the flood hazard index and the change in extreme rainfall days from the baseline period of 1961-1990, to the 2050s.

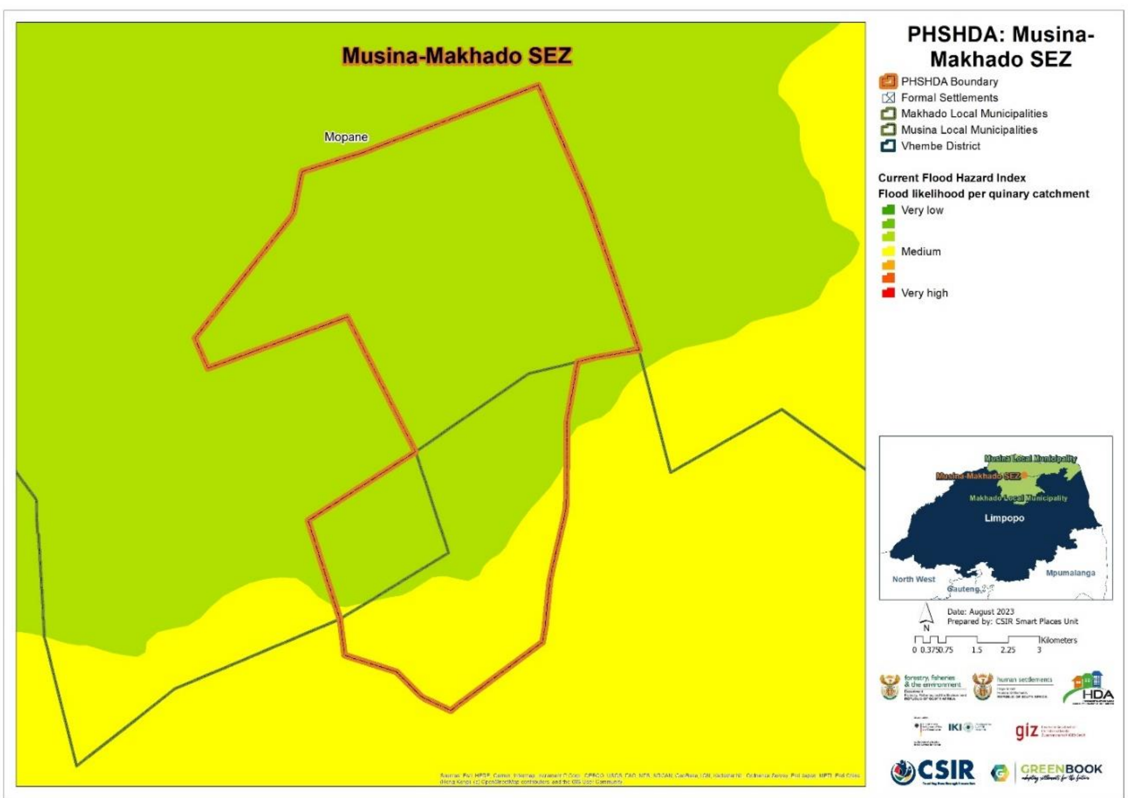

Figure 16: The flood hazard index across the Musina-Makhado SEZ, under current (baseline) climatic conditions

Figure 15 depicts the flood hazard index of the individual quinary catchments present or intersecting with the local municipality. The flood hazard index is based on the catchment characteristics and design rainfall, averaged at the quinary catchment level. Green indicates a low flooding hazard, while red indicates a high flood hazard. Large parts of Musina Local Municipality are exposed to a low and medium flood hazard index, while significant variation of the flood hazard index is evident in the Local Municipality of Makhado. Large parts of the latter Municipality are exposed to a medium flood hazard index, with pockets of medium to very high flood hazard index evident in the northeastern parts of the Local Municipality. The Musina-Makhado SEZ is exposed to a low and medium flood hazard index, under baseline conditions (Figure 15).

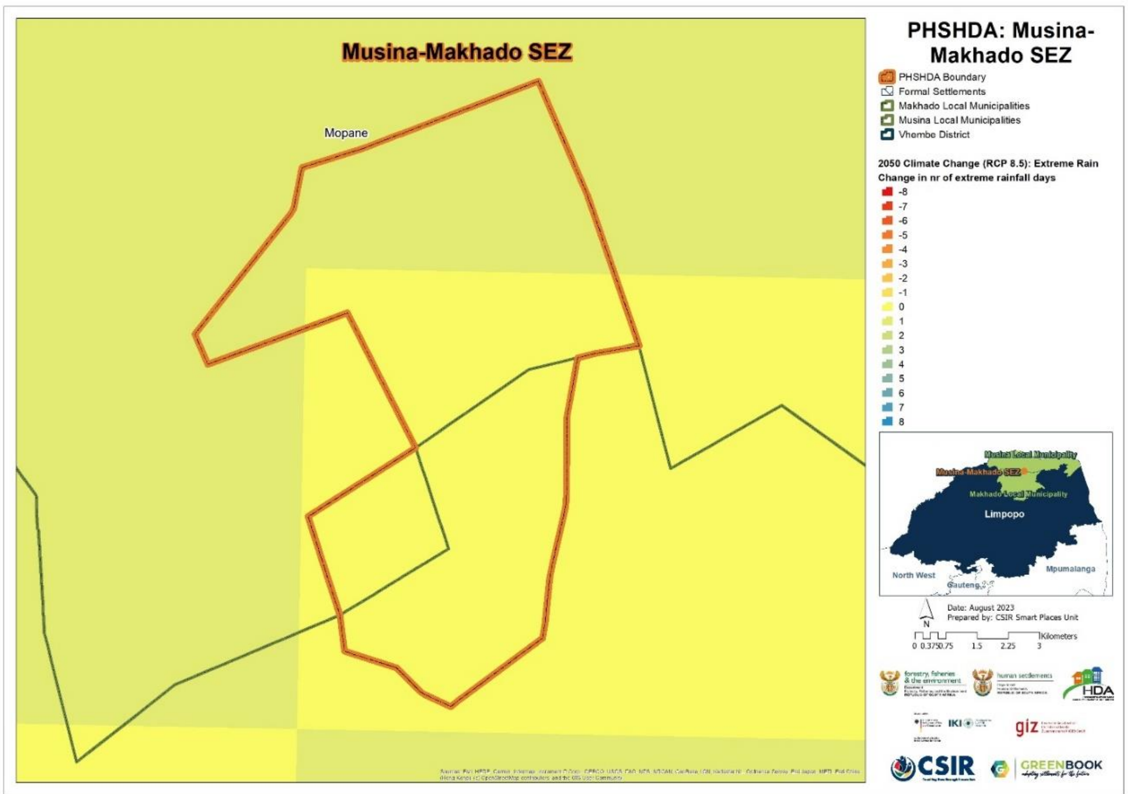

Figure 17: Projected change into the future in extreme rainfall days across the Musina-Makhado SEZ

Figure 16 depicts the projected change for the year 2050 in extreme rainfall days for an 8 x 8 km grid. This was calculated by assessing the degree of change when future rainfall extremes (e.g., 95th percentile of daily rainfall) are compared with those under the current rainfall. A value of more than one indicates an increase in extreme daily rainfalls. Both Musina and Makhado Local Municipalities are projected to experience slight decreases to slight increases in the annual number of extreme rainfall days. The number of extreme rainfall days across the Musina-Makhado SEZ are projected to increase by 0 to 1 day per year by 2050, assuming an RCP 8.5 emissions scenario.

While there currently are no settlements located within the SEZ, the settlement of Musina faces a low risk of flooding into a climate changed future (2050), while the settlement of Makhado faces a medium risk, i.e., assuming an RCP 8.5 (worst case emissions scenario).

2.4. Climate impacts on key resources and sectors

To understand the impact that climate change might have on major resources, this section explores the impact that climate change is likely to have on the resources and economic sectors of both Musina and Makhado Local Municipalities.

2.4.1. Water resources and supply vulnerability

South Africa is a water-scarce country with an average rainfall of approximately 450 mm per year, with significant annual and seasonal variability. Rainfall also varies from over 1900 mm in the east of the country and in the mountainous areas, to almost zero in the west and northwest of the country. Conversion of rainfall to runoff is also low with an average mean annual runoff (MAR) of only 40 mm, one seventh of the global average of 260 mm per year. Runoff is even more highly variable than precipitation, both in space and time. Furthermore, demand for water is not evenly distributed, with most of the major water demand centres located far from the available water resources. This has resulted in a need to store water and transfer water around the country to meet current and future demands.

Water availability is directly impacted by the climate and climate change. It is not just changes in precipitation that need to be considered, but also increasing temperatures that will lead to increased evaporation which could further reduce runoff and increase water losses from dams. Increasing temperatures will also impact on water demand, particularly for irrigation, but also from urban and industrial users. This could also contribute to reduced water security if existing systems are not able to meet these increasing demands. Increasing air temperatures will also increase water temperatures and hence increase pollution and water quality risks.

To obtain a high-level first order assessment of the relative climate change risks for water supply to different towns and cities across South Africa, a general risk equation was developed to determine the current and future surface water supply vulnerability that combines both climate change and development risks (i.e., due to an increase in population and demand). The current vulnerability of individual towns was calculated based on the estimated current demand and supply as recorded across the country by the Department of Water and Sanitation's (DWS) All Towns study of 2011 (Cole, 2017). The future vulnerability was calculated by adjusting the water demand for each town proportional to the increase in population growth for both a high and medium growth scenario. The level of exposure was determined as a factor of the potential for increasing evaporation to result in increasing demands, and for changes in precipitation to impact directly on the sustainable yield from groundwater, and the potential for impacts on surface water supply. These were then multiplied by the proportion of supply from surface and groundwater for each town. Exposure to climate change risk for surface water supply was calculated in two ways. The first was by assuming surface water supply was directly related to changes in streamflow in the catchment in which the local municipality was located (E1) and alternatively (E2) taking into account the potential benefits offered by being connected to a regional water supply system by using the result from a national study of climate change impacts on regional water supply derived from a high level national configuration of the Water Resources Yield Model (WRYM) that calculated the overall impacts on urban, industrial and agriculture water supply to each of the original 19 (now 9) Water Management Areas (WMAs) in South Africa.

In South Africa, groundwater plays a key strategic role in supporting economic development and sustaining water security in several rural and urban settlements that are either entirely or partially dependent on groundwater supply. Groundwater is, however, a natural resource the availability and distribution of which are highly influenced by climate variability and change. An analysis of the impact of climate change on potential groundwater recharge was conducted for the period 2031 to 2050. The Villholth GRiMMS (Groundwater Drought Risk Mapping and Management System) formulation (Vilholth et al. 2013), which implemented a composite mapping analysis technique to produce an explicit groundwater recharge drought risk map, was adapted to formulate a series of potential groundwater recharge maps for the far-future across South Africa. Finally, the future period 2031 to 2050 was compared with the historical period 1961 to 1990.

Table 5 provides and overview of current water supply vulnerability (i.e., demand versus supply) in the Musina and Makhado Local Municipalities based on the data compiled for the Department of Water and Sanitation's (DWS) All Town's Study (Cole, 2017). A water supply vulnerability score above 1 indicates that demand is more than supply, while a score below 1 indicates that supply is meeting demand.

Table 5: Current water supply and vulnerability across Musina Local Municipality and Makhado Local Municipality

Local Municipality	Water Demand per Capita (l/p/d)	Water Supply per Capita (l/p/d)	Current Water Supply Vulnerability
Musina	148.71	283.21	0.53
Makhado	87.49	91.83	0.95

Current and future water supply vulnerability estimations are based on: 1) a local water supply perspective incorporating changes to population growth coupled with exposure to climate risk and 2) a regional water supply perspective, based on impacts of regional water supply assuming supply is part of the integrated regional and national bulk water supply network. The water supply vulnerability estimations do not consider current state of water supply and reticulation infrastructure. The current context and conditions within each of the local municipalities need to be considered when interpreting the information provided in this report. The water supply vulnerability of Musina and Makhado Local Municipalities is discussed below. Figures 17 and 18 show Musina and Makhado Local Municipalities' estimated current and future water supply vulnerability, under the two water supply vulnerability estimation scenarios. The factors contributing to the estimated water supply vulnerability in each Local Municipality are outlined in Tables 6 and 7.

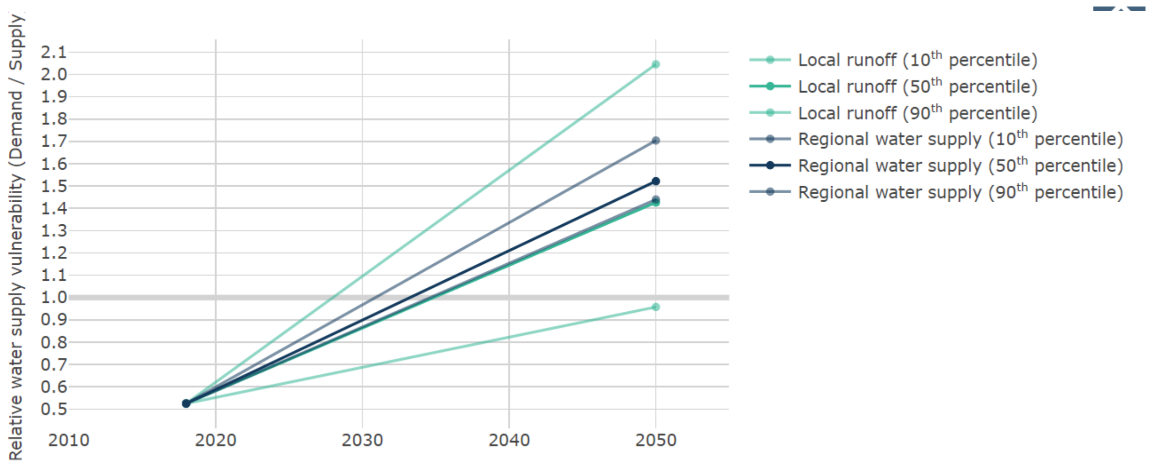

Figure 18: Future water supply vulnerability in Musina Local Municipality

Table 6: Future water supply vulnerability contributing factors for Musina Local Municipality

VULNERABILITY CONTRIBUTION FACTORS		PERCENTAGE CHANGE	
	Mean annual precipitation	⌄	-2.78%
	Mean annual evaporation	⌃	8.74%
	Mean annual runoff	⌃	43.63%
	Regional urban water supply	⌃	28.53%
	Population growth	⌃	200.84%

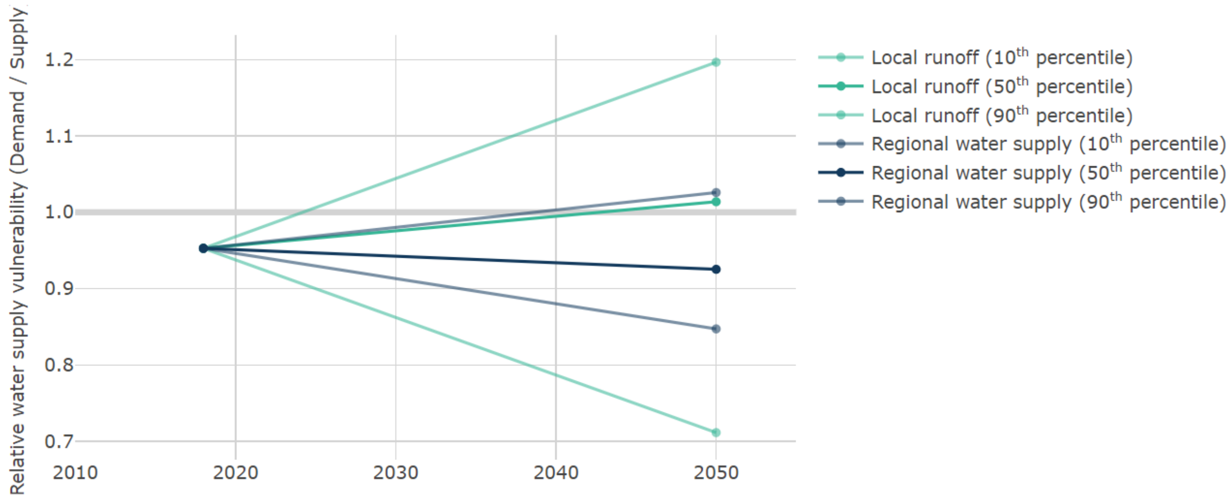

Figure 19: Future water supply vulnerability in Makhado Local Municipality

Table 7: Future water supply vulnerability contributing factors for Makhado Local Municipality, under a medium population growth scenario

VULNERABILITY CONTRIBUTION FACTORS		PERCENTAGE CHANGE
Mean annual precipitation	⌄	-6.88%
Mean annual evaporation	⌃	10.75%
Mean annual runoff	⌃	4.54%
Regional urban water supply	⌃	28.53%
Population growth	⌄	-6.26%

In 2011, Musina Local Municipality's water demand was considerably lower than supply (Table 5). This is still the case, according to projections made under the medium population growth scenario (Figure 17). However, the Local Municipality's water supply vulnerability is expected to increase to between 0.9 and to 2.5 in the future (Figure 17), due to the projected decrease in mean annual precipitation, as well as the projected increases in mean annual evaporation and population growth (Table 6). Makhado Local Municipality's water demand was also lower than supply in 2011 (Table 5), and according to estimations, the Municipality water demand vulnerability is expected to increase to between 0.7 and 1.2 by 2050 (Figure 18). This is mainly due to the projected decrease in mean annual precipitation, as well as the projected increase in mean annual evaporation.

2.4.2. Agriculture, forestry, and fisheries

Agriculture and food production is arguably the sector most vulnerable to climate impacts in South Africa. Many settlements in South Africa owe their existence to the primary sector of the country. Agriculture, forestry, and fisheries (AFF) form the bulk of the primary sector and act as catalysts for the economic development of secondary and tertiary sectors. Where these sectors are the primary economic activity in an area, they contribute to the local economy, employment, food security, and livelihoods. They also indirectly benefit from services such as health care, education, and basic infrastructure. In such regions, social and economic stability are linked with the profitability of the agricultural sector.

Climate change, through increased temperature and changing rainfall patterns, can have fundamental impacts on agriculture if the climatic thresholds of the commodities being farmed are breached. However, the nature and extent of these impacts depends on the type of commodity being farmed and the relative geographic location of the farmer in relation to the industries served, and on the resources available to the farmer. The same climate impact can have different impacts on different commodities and farms. Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as we have done in the past.

The methodological approach to understanding the impact of climate and climate change on AFF consisted of four components. Firstly, the most important areas in terms of Gross Value Added (GVA) and employment for the AFF sector relative to the other sectors of the South African economy were determined. Secondly, an analysis of climate change scenarios was done using historical climate variables, as well as multi-model projections of future climates to help identify specific climate-related risk factors for agriculture within specific regions. Thirdly, crop suitability modelling was done to indicate how the area suitable for crop production under the present climate conditions might shift or expand under the scenarios of future climate change, in addition to using the Temperature Humidity Index (THI) to assess heat stress in livestock. Finally, the climate change analysis was used in conjunction with the crop modelling outputs to assess the potential impacts of climate change over a specific area, or for a specific crop, to give more detail on how predicted climate changes translate into location/crop specific impacts. This was developed at a local municipal level and guided by the outcome of the agricultural industry sector screening and climate scenario analysis.

In Musina Local Municipality the AFF sector contributes 8.62% to the local GVA, which is a contribution of 0.52% to the national GVA for the AFF sector. Of the total employment, 36.14% is within the AFF sector. The main commodities are citrus and subtropical fruit, as well as cotton. Climate projections show a generally hotter and drier climate for the Local Municipality, with wetter conditions projected into the future (towards the 2100s). This will likely result in increased evapotranspiration and irrigation requirements for citrus and subtropical fruit, as well as cotton, while an increase in temperature will benefit a more heat-tolerant disease vector. High temperatures also contribute to poor tree flowering, fruit set and decreases in production, while cotton production viability is subject to water availability.

In Makhado Local Municipality the AFF sector contributes 4.06%% to the local GVA, which is a contribution of 0.7% to the national GVA for the AFF sector. Of the total employment, 13.76% is within the AFF sector. The main commodities are citrus fruit, beef cattle, as well as maize for grain. Climate projections show hotter and wetter conditions, with more extreme rainfall events. Hot and moist conditions increase the exposure to pests and diseases which threaten fruit production. The same conditions will likely cause increased spread of disease and parasites for cattle as well. Hot conditions will also likely result in reduced growth and reproduction performance due to heat stress. However, due to increased water availability, the projected conditions could favour the potential increase in maize yield, at least in the near future.

3. Recommendations

The greatest risks faced across the Musina-Makhado SEZ / PHSHDA are increased temperatures, heat extremes and drought. The area may also face a high risk of wildfire on the wildland-urban interface once development intensifies. The water supply vulnerability in both Local Municipalities is expected to increase into a climate-changed future. Moreover, the planned high-density settlement and expansion of industrial development in the area, may further exacerbate this. Therefore, to protect the area from water shortage and insecurity, there may be a need to diversify portable water supply and conserve available water.

Both Musina and Makhado Local Municipalities have highly vulnerable economies (EcVI), settlement fabrics (PVI) – in term of remoteness and structural vulnerabilities – and natural environments (EnVI), which undermine their ability (as well as the SEZ in its current state) to recover from external shocks, including climate hazards, if not addressed. The high unemployment rate and undiversified economy are key contributors to the high economic vulnerability. It is, therefore, essential to manage these factors by diversifying the local economy into sectors that absorb the existing labour force, and have a minimal impact on climate change. The SEZ's existing and envisaged mining beneficiation (industrial development), ecotourism and agri-tourism sectors, emerge as catalytic sectors with the potential to grow the economy and create jobs, while having a minimal impact on the climate and the environment, although climate-sensitive design principles will have to be applied when developing and expanding the industrial sector. There is therefore value in also adapting these sectors to the impacts of climate change. The development of (climate proof) infrastructure, and provision of services and adequate housing in close proximity to areas of employment, as well as the conservation of ecological assets (some of which play a critical role in buffering the impacts of climate change), will also reduce some of the other vulnerabilities present in both Municipal Areas and the SEZ.

Therefore, in response to these climate risks and impacts, the following adaptation goals are recommended:

1. To ensure water security in the face of climate change: Given the water scarcity challenges in the country, as well as the effects that the projected increase in temperatures (which increase evaporation and reduce runoff, thus reducing the amount of water captured and stored for future consumption), drought tendencies and population growth will have on both Local Municipalities' (and by default the SEZ's) future water supply – developing comprehensive strategies for water resource management is crucial. As part of these strategies, both Local Municipalities, and the custodians of the Musina-Makhado SEZ, could therefore prioritize water infrastructure maintenance; invest in efficient water supply infrastructure to meet future demand; promote water conservation practices by implementing strategies such as public awareness campaigns, leak detection and repairs, water metering and billing; as well as explore measures to secure alternative water sources such as rainwater (harvesting), groundwater (recharge and extraction) and wastewater (reuse).

2. To reduce the exposure and vulnerability of human and natural systems to climate change and extreme weather events: To minimise the damage and loss stemming from the unavoidable impacts of climate change, it is essential to reduce the exposure and vulnerability of elements found in both human and natural systems present in the Musina-Makhado SEZ / PHSHDA, to climate-related hazards and extreme events. Reducing exposure and vulnerability will therefore involve a combination of infrastructural, behavioural, and institutional changes. For human systems, this might involve building climate-resilient infrastructure, providing climate-proof housing, developing or improving existing disaster risk reduction strategies, and enhancing social safety nets for the most vulnerable. For natural systems, this can involve protecting and restoring ecosystems and ecological assets that provide natural buffers against climate impacts, such as wetlands that absorb flood waters and natural fire breaks (e.g., creeks, bluffs).

3. To develop a climate-resilient, low-carbon, diverse and inclusive rural economy that is socially responsible, environmentally sustainable and that provides job opportunities for unskilled, semi-skilled and skilled local residences: A climate-resilient rural economy would be one that can absorb and recover from climate shocks; that also contributes minimally to climate change. This might involve promoting sustainable agricultural practices that are adaptive to changing climate conditions, investing in renewable energy sources, and encouraging diversification of the rural economy into sectors that are less climate-sensitive (e.g., ecotourism). Furthermore, efforts to create more inclusive economies, that also provide job opportunities at all skill levels, may involve training programs for local residents, policies to support small and medium enterprises, as well

as the implementation of measures designed to ensure that economic opportunities and the benefits of economic activities are equitably distributed (e.g., rural development and services provision).

These goals are not exhaustive and could be complemented by other strategies tailored to the specific context and needs of Musina and Makhado Local Municipalities, as well as the Musina-Makhado SEZ in particular. The potential for success lies in integrating the goals (or the principles behind them) into all aspects of municipal decision-making and operations, as well as in engaging communities in these efforts.

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Annexure A: Sector-specific impacts

Considering the proposed spatial vision for the Musina-Makhado SEZ (Figure 19), there are several sectors that play a critical role in the realisation of this spatial vision. These sectors are discussed in the subsections that follow, with the various climate impacts summarised in the tables provided. Since a warmer and drier climate can generally be assumed for the PHSHDA, the respective impacts (such as increased temperature and heat extremes, decreased rainfall, and drought) should be given special consideration.

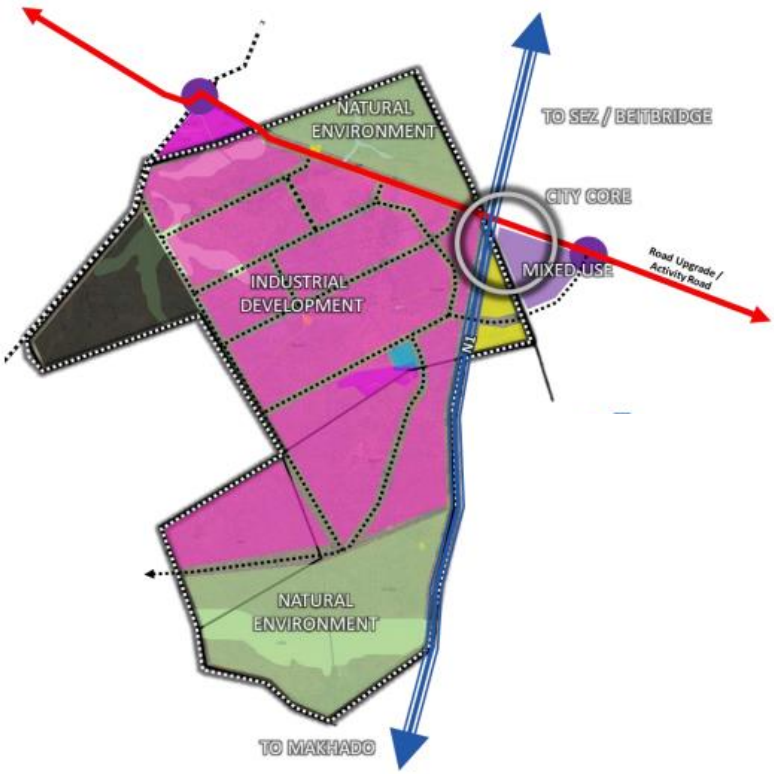

Figure 20: Musina-Makhado SEZ Spatial Vision

Ecosystem services

Urban areas are dependent on natural ecosystems in and around towns to provide communities with services such as safe and plentiful drinking water, increased food security, better health, decreased exposure to natural disasters and extreme weather, and increased recreational opportunities. For these ecosystems to continue to provide these services they need to be in a healthy condition. Unfortunately, many ecosystems have been degraded because of misuse and overuse of soil, water, plant, and animal species. At the same time global climate change is aggravating the vulnerabilities of these ecosystems and therefore diminishing the benefits that ecological infrastructure can provide. It is therefore critical to rehabilitate and maintain ecological infrastructure in the urban environment to help residents adapt to risks posed by future climate change. The table below outlines the cascading effects of selected climate change impacts on ecosystem services.

Increased temperatures and heat extremes	Drought and decreased rainfall	Increase in rainfall and inland flooding
• Increased risks of water shortages increasing demand for irrigation of gardens and agriculture. • Increased evapotranspiration rates with rising temperatures, reducing the water available in reservoirs and water available for reliant ecosystems. • Increase in temperature leading to water loss via evapotranspiration resulting in decreased water quality and loss of wetlands. • Loss or degradation of indigenous species, including threatened species or ecosystems. • Increased threat from invasive species as competition for water increases. • Dieback or death of susceptible plants (e.g., street trees) and animals (e.g. fish). • Increased water temperature leading to increased growth of aquatic weeds which increases breeding of disease vectors and reduces water oxygen levels. • Milder winters and reduced frost increase	• Decreased amounts of rainfall reaching ecosystems as settlements use rainwater harvesting techniques for increased household use. • Increased reliance on irrigation and greater demand for water to maintain public open space and gardens. • Reduced planting and pollination leading to greater risk of erosion and soil loss. • Increasing temperatures together with increased intensity of drought will potentially increase the occurrence of algal blooms in reservoirs and dams which are damaging to ecosystem functioning and water services. • Drought and decreased rainfall causing wetland habitat loss. • Reduced soil moisture availability increasing moisture stress leading to dieback and death of plants and the loss or degradation of indigenous communities, including threatened species or ecosystems. • Drying up of aquatic systems, perennial	• Rainfall in shorter and more violent spells making recharging groundwater difficult. • Increase in intensity of rainfall and flooding leading to increased surface runoff, resulting in increased soil erosion, soil loss and degradation. • Increasingly saturated soils leading to more standing water (ponding) which can result in more insect (pest) activity and their potential to carry diseases.

the duration of the growing season, increasing the survival rate of insects and diseases.	systems will become seasonal and seasonal systems will die off and be replaced by terrestrial plants. • Increased spread of drought-adapted alien invasive plant species.	

Stormwater

A stormwater drainage system collects, conveys and discharges stormwater with the aim to reduce the risk of flooding in settlements and control water quality (traditional pollutants that are commonly associated with municipal and industrial discharges, e.g., nutrients, sediment, and metals). Conventionally rainwater falling onto a hard surface will be collected and drained through surface channels to a collection point or culvert where it will enter a storm water pipe. The pipe will use gravity to discharge the water into a watercourse or a dam. Where a gravity-fed system cannot be used the water will be collected into a storage dam and pumped to the discharge location. Sustainable Urban Drainage Systems (SUDS) seeks to minimize the volume of storm water entering the drainage system. It does this in three ways: first, collect and store as much rainwater at source as possible; second, filtrate as much surface water into the ground as possible as close to the source as possible; third, collect storm water at grade in various storage systems (weirs, wetlands, attenuation ponds, etc.). The table below outlines the secondary effects of selected climate change impacts on stormwater infrastructure and processes.

Increased temperatures, heat extremes, and drought	Increase in rainfall and inland flooding
• Potential risk of undermining the temperature regime of temperature-sensitive stormwater ponds and receiving waters, resulting in a decrease in water quality. • Increased corrosion in stormwater drains due to a combination of higher temperatures, increased strengths, longer retention times, and stranding of solids. • Increased shrinking soils increasing the potential for cracking, increased infiltration and exfiltration of water mains and sewers, which in turn exacerbates	• Increased risk of flooding due to pressure on stormwater systems. • Increased risk of litter entering the stormwater systems. • Increased risk of damage and failure of stormwater systems due to overloading during floods and intense rainfall events. • Failure of stormwater treatment devices during high flow events leading to by-pass and / or flushing of contaminated water. • High wet-weather hydraulic loads and bottle-necks in stormwater and networks due to inflow and sewer

treatment and groundwater or storm water contamination.	infiltration, leading to local inundation and overflows of untreated wastewater. • Increased rainfall causes soil erosion thus damaging underground stormwater systems. • Increased surface and stream erosion causing deposition of sediments in receiving environments. • Stream morphology for undeveloped, developing and fully developed urban areas may change, hence affecting existing outfall structures and potential stormwater pond locations.

Solid waste

Human settlements generate massive amounts of solid waste that needs to be managed effectively so as not to cause air, water, and soil pollution.

As cities grow and need more land, suitable collection and disposal sites can be difficult to acquire and develop. Most households in South Africa (64% in 2015) receive a waste removal service at least once a week, but there are still households that rely on their own or communal rubbish dump sites. Illegal dumping and littering are problems in most municipalities resulting in solid waste often accumulating in waterways and areas otherwise intended for water run-off and flood control. These conditions make municipalities vulnerable to flooding, contamination of water resources, adverse health effects and rehabilitation costs that may overwhelm the resilience of cities. The table below outlines the secondary effects of selected climate change impacts on the solid waste sector.

Increased temperatures and heat extremes	Increase in rainfall and inland flooding
• Increased risk of combustion at open waste disposal sites and illegal dumps, and increase in explosion risk associated with methane gas. • Increased rate of decay of putrescible waste resulting in increased odour, breeding of flies, and attracting of vermin. • Increased health and safety concern regarding heat stroke to staff collecting waste. • Increased risk of landfill site instability and failure due to changes in consumption patterns with increased waste creation (i.e., glass, plastic and paper cups).	• Increased risk of flooding due to pressure on stormwater and leachate management systems at landfills. • Increased demand for capacity to cope with large volumes of waste generated by flood events. • Increase in soil saturation causing decreased stability of slopes and landfills linings (if clay or soil based) at waste management facilities. • Inundation of waste releasing contaminants to waterways, pathways and low elevation zones.

	• Potential loss of value and degradation of paper and cardboard for recycling due to increased moisture content. • Increased flooding causing the risk of localised disruption of waste collection rounds. • Flooding in areas with untreated, dumped waste causing the risk of groundwater contamination. • Increased flooding causing the risk of litter entering the storm water systems.

Sanitation

Sanitation and wastewater management poses several operational challenges to governments and settlements. Managing water resources involves contributions from various stakeholders at different points in the value chain. The sanitation value chain comprises eight broadly defined stages, as follows: collection/containment; storage; transport; treatment; distribution; wastewater treatment; and discharge. Re-use of wastewater is becoming more acceptable and feasible because of increasing water shortages, improved purification technology and decreasing treatment costs. A water reuse strategy that is forward thinking over ten to twenty years needs to take these possible changes into account. The direct re-use of treated wastewater can pose a risk to public health and safety and thus must be managed carefully and be subject to water quality management and control. Advanced treatment technologies, sufficient operating capacity and proper monitoring of all processes, and quality of potable water produced is essential. The table below outlines the cascading effects of selected climate change impacts on the sanitation sector.

Increased temperatures and heat extremes, as well as drought and decreased rainfall	Increase in rainfall and inland flooding
• Increased heat waves, accompanied by dry weather, can exacerbate already stressed water supply systems leading to competition between sectors for water services; affecting sanitation. • Decrease in water supply for sanitation through decrease in available water to flush sewage systems adequately. • Declining annual rainfall threatening the viability of water-borne sanitation systems, and the capacity of surface	• Increased wet-weather hydraulic loads and bottlenecks in stormwater and sanitary sewer networks due to inflow and sewer infiltration, causing local inundation and overflows of untreated wastewater. • Increased rainfall and heavy rainfall events increasing the washing of faecal matter into water sources due to flooding of wastewater treatment works.

water to dilute, attenuate and remove pollution. • Sewers are structurally vulnerable to drying, hence shrinking soils increase the potential for cracking, increased infiltration and exfiltration, which in turn exacerbates treatment and groundwater or storm water contamination. • Increased corrosion in sewers due to a combination of higher temperatures, increased strengths, longer retention times, and stranding of solids.	• Increased risk of flooding resulting in both infrastructure damage and contamination of surface and groundwater supplies. • Increased groundwater levels due to flooding, putting at risk sewage treatment plants (which are often positioned on low-lying ground as sewerage systems rely on gravity). • Increased vulnerability of sewerage pipe systems due to their size and complexity, and their exposure to multiple flood damage threats from source, through treatment, to delivery. • Increased vulnerability of pit toilets (widely used in rural areas) due to flooding, causing serious environmental contamination. • Increase in groundwater recharge and groundwater levels causing flooding of subsurface infrastructure such as pit toilets or septic tanks.

Energy

South Africa's energy mix is primarily dominated by the use of fossil fuels to derive grid supplied electricity and imported crude oil and petroleum products. Regarding access to energy within our human settlements, grid-supplied electricity is transmitted from power stations to sub-stations to settlements typically through overhead powerlines. Electricity supply is not equally distributed within the country with many people within informal settlements still not connected to the electricity grid. Many thus rely on the combustion of fuels within or near their homes to meet their cooking, heating, and lighting needs. Electricity infrastructure is exposed to weather and climate and is vulnerable to the effects of climate change. Variations in temperature (hotter and colder days) will increase the demand for energy for both cooling and heating within homes and buildings, as will urban growth. Thus, both the electricity supply and demand of a settlement are likely to be impacted by climate change. The table below outlines the cascading effects of selected climate change impacts on the energy sector.

Increased temperatures and heat extremes	Increase in rainfall and inland flooding
• Increased heat causing expansion of overhead cables, and cable sag. Sagging below a certain amount can result in a reduction in the amount of electricity transmitted.	• Increase in flooding causing damage to electricity transmission and distribution infrastructure, poles, lines and sub-stations.

• Increased heat stress on electricity transmission networks (overhead cables). • Increase in heat island effect increasing energy demand for cooling, leading to grid stress. • Increased threat of wildfires causing widespread damage to infrastructure and causing disruptions to service provision.	• Increase in frequency and cost of maintenance of concrete structures due to frequent and intense rainfall and flooding events. • Increased repair events increasing stress put on service crews and resulting in delays to power restoration.

Information and communication technology

Information and communications technology (ICT), or telecommunications, plays a critical role in society and is central to the operations of every industry and sector, and society relies on it for social and leisure purposes as well as work. Climate change impacts on ICT infrastructure in settlements include the impacts of increased warming and precipitation, extreme weather events, strong winds, and sea-level rise and storm surges. The ICT industry experiences weather-related impacts which are expected to worsen due to ongoing climate variability and climate change. Compared to 'heavy' infrastructure sectors like energy, water or transportation, the ICT sector has smaller infrastructure and shorter lifetimes, reliance on a combined network instead of individual structures, redundancy of service and infrastructure and service providers, and fast-paced technological change and innovation. While technologies in the ICT sector in the future may converge towards wireless technologies and reduce dependence on current infrastructure, this will not negate the need for infrastructure altogether, for example, there will still be a requirement for equipment such as mobile or fixed wireless towers to operate this technology. The table below outlines the cascading effects of selected climate change impacts on the ICT sector.

Increased temperatures and heat extremes	Increase in rainfall and inland flooding
• Increased weathering and deterioration of infrastructure resulting in increased maintenance and repair costs. • Heat stress causing structural damage to infrastructure. • Increased energy demands during heatwaves resulting in power outages which can impact on delivery of telecommunications services. • Increases in temperature and higher frequency, duration, and intensity of heat	• Increased risk of flooding of low-lying infrastructure, access holes and underground facilities. • Increases in storm frequency or intensity increasing the risk of damage to aboveground transmission infrastructure and impacting on telecommunications service delivery. • Increases in storm frequency leading to more lightning strikes, consequently

waves increasing the risk of overheating in data centres, exchanges, and base stations, which can result in increased failure rates of equipment. • Increased mean temperature increasing operating temperature of network equipment which may cause malfunctions if it surpasses design limits. • Decreased precipitation leading to land subsidence and heave, reducing the stability of telecommunications infrastructure above and below ground (foundations and tower structures).	damaging transmitters and overhead cables, causing power outages. • Increased cost of insurance for infrastructure in areas with repeated incidents of flooding, as well as withdrawal of risk coverage in vulnerable areas by private insurers. • Road closures due to flooding thus inhibiting service and/or restoration efforts.

Transport and mobility

Within settlements, transport networks comprise of nodes (e.g., buildings and public transport stops and stations) and various connector links (e.g., walkways, roads, bridges, railways, tunnels, and waterways). Apart from being a large asset base in themselves, these networks are indispensable conduits for the movement of people and goods for social, economic, political, health and recreational purposes. Within the context of climate change, therefore, climate resilient transport networks are necessary to ensure unimpeded functioning of society. Vulnerability of transport networks to climate change depends on infrastructure age, its materials, construction practices, design features, and maintenance history. Societal level of risk to infrastructure failure is dependent on individual functions of different parts of the transport network. Therefore, spatial differentiation should be an integral component of adaptation strategies. Disruption to transport networks due to climatic extreme events may lead to social exclusion, trade interruption, and consequently social disorder. It is imperative, therefore, that the design and in-situ upgrading of transport networks and their operations be responsive to threats posed by climate change, especially in high-risk areas. It is equally important to ensure transport networks do not add to landscape vulnerability – for example increasing erosion of steep slopes, landslides or increasing vulnerability of natural habitats to fragmentation and overharvesting. The table below outlines the cascading effects of selected climate change impacts on the transport sector.

Increased temperatures and heat extremes	Increase in rainfall and inland flooding
• Increased rate of infrastructure deterioration leading to pavement failure including cracking, rutting, potholes, flushing, and stripping. • Increased stress on bridges, particularly expansion joints, through thermal expansion and increased movement.	• Increased rate of infrastructure deterioration, especially in areas with poor infrastructure maintenance history. • Temporary and permanent flooding of road, rail, port and airport infrastructure.

• Corrosion of steel reinforcing in concrete structures due to increase in surface salt levels in some locations. • Increased infrastructure maintenance cost for road repair and reconstruction work, causing traffic delays and emergency service response delays. • Increased frequency and intensity of wildfires leading to more road closures. • Increased vehicle accidents, due to low pavement adhesion, leading to higher rates of transport-related fatalities.	• Structural integrity of roads, bridges and tunnels could be compromised by higher soil moisture levels. • Potential destruction of bridges and culverts. • Erosion of embankments and road bases leading to undermining of roads or railways. • Increased risk of landslides, slope failures, road washouts and closures. • Undermining of bridge structures (scouring). • Closure of roadways and tunnels leading to traffic delays. • Transportation system disruptions, impacts to traffic signalling and low water crossings. • Increased weather-related accidents.

Human health

Settlements are faced with a variety of challenges, which may include rapid unplanned urbanization, climate-related pressures such as floods and heat waves, as well as unequal economic growth between different communities. This affects the health and development status within settlements. Climate-health linkages are complex and multi-faceted, and it can confidently be stated that climate change will amplify some of the existing health threats that are already faced by communities. Certain people and communities are especially vulnerable, including children, the elderly, the sick and the poor. Natural disasters (e.g., floods, drought, fires) can have immediate and long-term impacts on health. Poor emergency service delivery immediately after disaster can impact health, as well as damage to services such as water reticulation can have longer-lasting impacts on public health. Natural disasters can also create a conducive environment for the occurrence of mental health problems. The table below outlines the cascading effects of selected climate change impacts on the community/human health sector.

Increased temperatures and heat extremes	Drought and decreased rainfall	Increase in rainfall, and inland flooding
• More exposure to high temperatures causing increased health risks including heat strokes. • Heat waves increase threat of cardiovascular,	• Decreased soil moisture potentially creating more wind-blown dust which has negative impacts on air quality.	• Wetter climate combined with increased temperatures may have negative health impacts as many diarrheal diseases vary seasonally,

kidney, and respiratory disorders. • Increase in fire danger days causing increased loss of life and damage to health infrastructure. • Wildfire smoke significantly reducing air quality, both locally and in areas downwind of fires. Smoke exposure increases respiratory and cardiovascular hospitalizations; emergency department visits; medication dispensations for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease, and respiratory infections; and medical visits for lung illnesses. • Increased emissions in biogenic volatile organic compounds from vegetation causing increases in air pollution. • Increase in evaporative emissions from cars contributing to exposure to, and health impacts from, air pollution. • Increase in distribution of vector-borne diseases in warmer areas. • Increased water temperatures leading to an increase in algal blooms which can likely lead to increases in food-	• Increase in water-washed diseases and diarrhoeal diseases due to inadequate water availability. • Decreased precipitation causing changes in salinity of water, resulting in an increase in algal blooms which can likely lead to increases in food- and waterborne exposures. • Increase in stagnant air, decreasing air quality.	typically peaking during the rainy season. • Extreme rainfall and higher temperatures increasing the prevalence of fungi and mould indoors, with increased associated health concerns. • Increased flooding increasing the risk of drinking and wastewater treatment facilities being flooded, meaning that diarrhoeal diseases can be transmitted as wastewater systems overflow or drinking water treatment systems are breached. • Increase in natural disasters (e.g. floods) creating a conducive environment for the occurrence of mental health problems.

and waterborne exposures. • Increased temperatures combined with fewer clouds (e.g., from increased subsidence that is projected for parts of South Africa) causing increased exposure to UVR which will have negative impacts on health. • Increased temperatures increasing the reaction between certain pollutants and sunlight and heat, resulting in more severe hazardous smog events.		