Vhembe District Municipality

Climate Risk Profile Report based on the GreenBook

April 2024

Report compiled by the CSIR
Funded by the CDRF with Santam

Title:	Vhembe District Municipality: Climate Risk Profile Report
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Date:	9 April 2024
Citation:	CSIR, 2024. Vhembe District Municipality: Climate Risk Profile Report. Climate and Disaster Resilience Fund, Santam.
Version:	Draft 1

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Acronyms

°C	Degree Celsius
AFF	Agriculture, Forestry, and Fisheries
AR5	Fifth Assessment Report
CABLE	CSIRO Atmosphere Biosphere Land Exchange model
CCAM	Conformal-cubic atmospheric model
CDRF	Climate and Disaster Resilience Fund
CMIP5	Coupled Model Intercomparison Project 5
CoGTA	Department of Cooperative Governance and Traditional Affairs
CRVA	Climate Risk and Vulnerability Assessment
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEA	Department of Environmental Affairs
DM	District Municipality
DRR	Disaster Risk Reduction
DWS	Department of Water and Sanitation
EcVI	Economic Vulnerability Index
EnVI	Environmental Vulnerability Index
GCM	General circulation model
GRiMMS	Groundwater Drought Risk Mapping and Management System
GVA	Gross Value Added
GDP	Gross Domestic Product
IDP	Integrated Development Plan
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
km	Kilometre
KPA	Key Performance Area
l/p/d	Litres Per Person Per Day
LM	Local Municipality
MAR	Mean Annual Runoff
mm	Millimetre
NDMC	National Disaster Management Centre
PVI	Physical Vulnerability Index
RCP	Representative Concentration Pathways
SCIMAP	Sensitive Catchment Integrated Modelling and Prediction
SEVI	Socio-Economic Vulnerability Index
SMMEs	Small, medium and micro enterprises
SPI	Standardised Precipitation Index
SPLUMA	Spatial Planning and Land Use Management Act, 2013 (Act No. 16 of 2013)
THI	Temperature Humidity Index
VDM	Vhembe District Municipality
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 Climate Change Adaptation Plan, were developed specifically for Vhembe District Municipality (VDM), 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 Green Book l Adapting settlements for the future).

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

- Build and further the climate change response agenda,
- Inform strategy and planning in the district and its local municipalities,
- Identify and prioritise risks and vulnerabilities,
- Identify and prioritise climate interventions and responses, as well as
- Guide and enable the mainstreaming of climate change response, particularly adaptation.

The Climate Risk Profile report provides an overview of the unique climate change needs and risks of the district based on the science, evidence, and information from the GreenBook. Climate change trends, hazards, and vulnerabilities are spatially mapped for the district, its local municipalities, and settlements. Finally, the report identifies the major risks that need to be prioritised and sets out adaptation goals to further inform the adaptation plan and its implementation framework.

1.1. Approach followed

The approach used in the GreenBook, and the Climate Risk Profile 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 and 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.

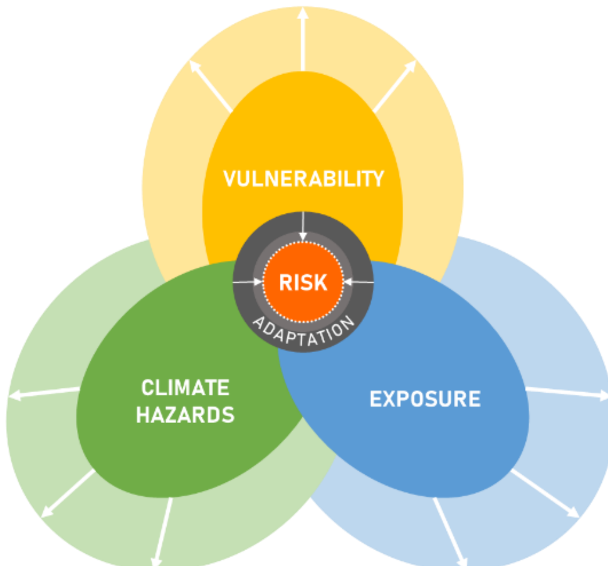

Figure 1: The interaction between the various components of risk, indicating the opportunity to reduce risk through adaptation (based on IPCC, 2014 and IPCC, 2021)

To understand climate risk across a municipal area, the exposure of settlements to certain climate hazards and their vulnerability are unpacked. In this Climate Risk Profile report, multiple vulnerability indices are provided on the municipal and settlement level, as well as variables for the current and future projected climate. Climate-related hazards such as drought, heat extremes, wildfire and flooding, and the impact of climate on key resources, are also set out for the district and its local municipalities.

All information contained in this report is based on the GreenBook, unless otherwise specified. Information and data were derived using GIS analysis and modelling techniques using secondary data and is not based on local surveys. Additional information to this report is available for local municipalities through the GreenBook Municipal Risk Profile Tool. Municipalities are encouraged to consider both the information available in this report and on the Municipal Risk Profile tool to understand their risk profile. Access the GreenBook and its various resources and tools here: https://greenbook.co.za/

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" – 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 (B9-2022) takes it further by setting out institutional arrangements for climate change response. Section 7. (1) of the Bill requires that all organs of state affected by climate and climate change align their policies, programmes, and decisions to ensure that the risks of climate change impacts and associated vulnerabilities are considered. Local governments are identified as key players in climate change response, and ideal facilitators and implementers to achieve effective climate response. The Bill requires existing District Intergovernmental Forums to serve as Municipal Forums on climate change, that coordinate climate response actions and activities in their respective Municipalities. The Bill also sets out requirements for each district municipality to undertake a climate change needs assessment and develop a climate change response implementation plan. The Climate Risk Report and related Adaptation Plan, provided here, meet most of these requirements and provide the essential information needed by district municipalities to fulfil their obligations in terms of the Bill.

The National Climate Change Adaptation Strategy outlines several actions in support of climate change adaptation, 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 measures into municipal development plans and relevant sector plans. 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.

1.3. District Municipal context

The Vhembe District Municipality (VDM) is one of five district municipalities in the Limpopo province. Vhembe is also the country's most northern district, and it shares borders with the Capricorn District Municipality in the west, as well as the Mopani District Municipality in the east. VDM also shares borders with Zimbabwe in the north, as well as Botswana in the north west and Mozambique in the south east through the Kruger National Park (CoGTA, 2020). The Vhembe district's main towns include Musina, Makhado (formerly known as Louis Trichardt), Thohoyandou, and Malamulele. The only National Road that traverses the district is the N1; however, there are more than six regional roads, which provide economic participants with much needed access to the district (DEA, 2018).

Meaning "Limpopo River" in TshiVenda, the eastern parts of 'Vhembe' were declared a Bantustan in 1979; however, these were reintegrated into the country in 1994. The Vhembe district currently comprises of four local municipalities (LMs), namely, Musina LM in the north, Makhado LM in the south west, Collins Chabane LM in the south east, as well as Thulamela LM, located in the central parts of the district (VDM, 2020; VDM, 2023). Vhembe covers an area of 25 597 km^2, with the total population of 1 402 779 as of 2019. In that period, Thulamela was the DM's most populous LM with a total population of 497 237, while Musina constituted the least populous LM in the district, with a total population of 32 009. The district's settlement-based population is projected to increase by an additional 496 270, between 2011 and 2050.

VDM's Gross Domestic Product (GDP) was around R63,4 billion in 2018 (up from R27,8 billion in 2008), which made up 17.71 % of Limpopo province's GDP, and 1.30 % of the country's GDP in the same period. In 2019, the Community Services sector was the largest contributor to the district's economy, accounting for 33 % of the total Gross Value Added (GVA) for the Vhembe district. The Finance sector was the second largest contributor to the district's economy, accounting for 18 % of the total GVA. This was followed by the Trade sector, which made up 17 % of the local economy's GVA (CoGTA, 2020). The district's key primary sectors are Mining and Agriculture. The key secondary economic sectors are Manufacturing, Electricity and Construction. VDM's leading tertiary sectors include Community Services, Trade, Finance and Transport (CoGTA, 2020). The number of formally employed people in Vhembe stood at 202 000 in 2018, representing 67.20% of the total number of employed people in the district at the time, while the number of people employed in the informal sector stood at 98 800, making up 32.80% of the total number of people employed in VDM. Moreover, while Community Services was the largest formal employer in the district, i.e., in 2018, the Trade sector recorded the highest number of informal jobs in the same period. Unemployment in the district currently stands at 29.0% (CoGTA, 2020; VDM, 2023).

The VDM falls within four vegetation biomes, with the Savanna biome, commonly known as Bushveld, covering most of the district (97.65 %). The district also has small pockets of Azonal Vegetation (1.49 %), Forests (0. 65%) and Grassland (0.22%). Within these biomes, there are 24 different vegetation types, 13 of which are endemic, and 5 of which are near endemic. Alien vegetation and urbanisation have significant impacts on the terrestrial biodiversity (DEA, 2018; VDM, 2023). The fire-ecotypes found in the district are Moist- and Arid Woodlands, which are fire-dependent and carry sufficient fuel for fires, thus making the likelihood of wildfires in the region high.

There are also a variety of wetlands in the district, including the Sambandou wetlands and Makuleke wetlands in the Thulamela LM, with the latter being one of two RAMSAR recognised wetlands in the province (see https://www.ramsar.org/). The most prominent features within the Makuleke wetlands include the riverine forests, riparian floodplain forests, floodplain grasslands, river channels and flood-pans. Flood-pans are of significant importance in this area as they hold water right into the very dry seasons, thus acting as refuge zones for wildlife and birds during both winter and summer seasons (DEA, 2018). Wetlands also provide other critical ecosystem services, including flood attenuation.

VDM's 2022/23-2026/27 Integrated Development Plan (IDP) Key Priority Areas (KPAs) and strategic objectives, which form part of the district's strategic framework, are outlined below.

KPA 1: Services delivery and infrastructure development

- Strategic Objective 1.1: To improve access to water and sanitation services through provision, operation and maintenance of socio-economic and environmental infrastructure.
- Strategic Objective 1.2: To promote an integrated and coordinated approach to disaster management with special emphasis on prevention and mitigation.
- Strategic Objective 1.3: To improve access to fire fighting and rescue services through provision, operation and maintenance of socio-economic and environmental infrastructure.
- Strategic Objective 1.4: To promote social development through sport, arts and culture.
- Strategic Objective 1.5: To provide a safe, reliable, efficient, effective and integrated transport system for both passengers and freight that will enhance the quality of life for all.
- Strategic Objective 1.6: To improve access to HIV and AIDS services through provision, operation and maintenance of socio-economic and environmental infrastructure.

KPA 2: Economic Development

- Strategic Objective 2.1: To create enabling environment to attract investment to generate economic growth and job creation.

KPA 3: Spatial planning and management

- Strategic Objective 3.1: To be a spatially integrated district striving towards effective sustainable development, service delivery and improving accessibility to economic resources.
- Strategic Objective 3.2: To ensure a spatially coordinated development that takes the environment into consideration.

KPA 4: Governance and Management

- Strategic Objective 4.1: To establish an efficient and productive administration that prioritizes quality service delivery.
- Strategic Objective 4.2: To ensure sound financial management of the municipality.
- Strategic Objective 4.3: To promote a culture of accountability, participatory, responsiveness, transparency and clean governance.
- Strategic Objective 4.4: To restore, retrieve, manipulate, transmit or receive information electronically or in a digital form for planning and management.
- Strategic Objective 4.5: To create enabling communication services/environment and coordinating mainstreaming programmes.

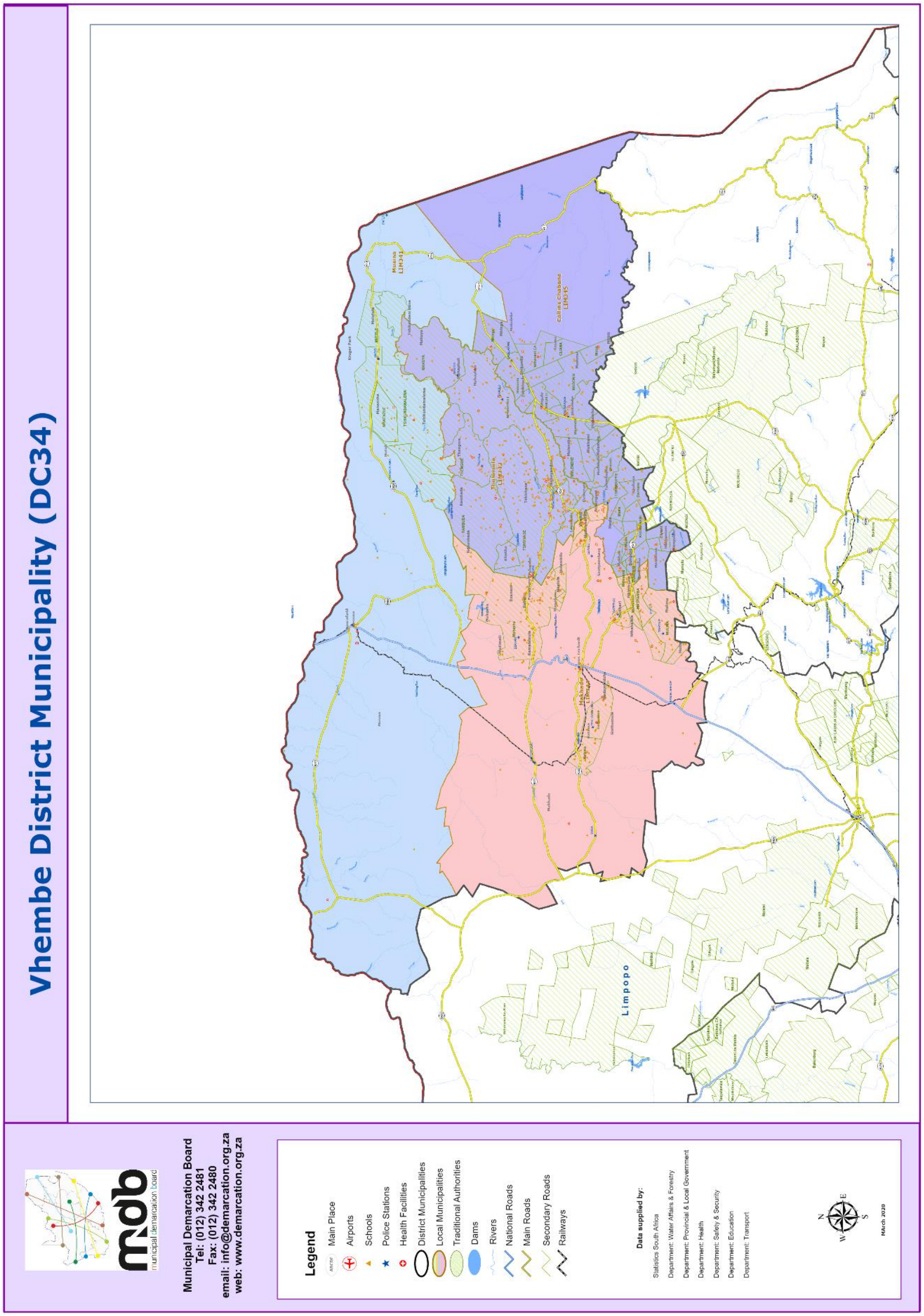

Figure 2: Vhembe District Municipality (Municipal Demarcation Board, 2022), with Local Municipalities shaded in different colours

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 across the district. Current, as well as future, exposure to drought, heat, wildfire, and flooding are also set out. The impact of climate on key resources such as water and agriculture are also discussed for the local municipalities in the district. Together this information provides an overview of current and future climate risk across the Vhembe district 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 Vhembe district, its local municipalities, and 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 drive vulnerability into the future, and therefore population growth and decline of settlements across the district 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 each of the local municipalities in Vhembe district.

The Socio-Economic Vulnerability Index (SEVI) shows the vulnerability of households living in a 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 municipalities that house 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 a municipality, and considers economic sector diversification, the size of economy, labour force, the GDP growth/decline pressure experienced in the municipality, as well as the inequality present in the municipality. The higher the economic vulnerability the more susceptible these municipalities are to being adversely affected by external shocks.

The Physical Vulnerability Index (PVI) relates to the built environment and the connectedness of the settlements in a 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.

Each local municipality in the Vhembe district is provided 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 are only available for socio-economic vulnerability (SEVI) and economic vulnerability (EcVI).

Table 1: Vulnerability indicators across Vhembe District Municipality for 1996 to 2011

LOCAL MUNICIPALITY	SEVI 1996	SEV 2011	Trend	EcVI 1996	EcVI 2011	Trend	PVI	Trend	EnVI	Trend
Collins Chabane	5.38	6.11	↗	5.24	7.14	↗	6.52	No Trend	4.05	No Trend
Makhado	4.80	4.79	↘	4.79	6.19	↗	6.91	No Trend	5.36	No Trend
Musina	5.11	4.73	↘	5.87	7.19	↗	6.27	No Trend	6.83	No Trend
Thulamela	4.93	4.89	↘	4.98	6.22	↗	6.19	No Trend	6.87	No Trend

Socio-economic vulnerability (SEVI) has decreased (improved) across all LMs in Vhembe, between 1996 and 2011 – with the exception of Collins Chabane LM, which experienced an increase (worsened vulnerability) in the same time period. The latter LM also recorded the second highest SEVI score in the province, thus making Collins Chabane home to some of the most vulnerable households in the Limpopo province, particularly with regards to their ability to withstand adverse shocks from the external environment. All LMs also experienced significant increases in economic vulnerability (EcVI), with all four Municipalities recording above national average EcVI scores in 2011, meaning that the district's local economies are highly susceptible to being adversely affected by external shocks, including those induced by the impacts of climate change. The district's high unemployment rate of 29.0 % emerges as a key indicator of the region's worsening economic vulnerability. The four LMs in Vhembe had above national average physical vulnerability (PVI) scores in 2011, thus alluding to high structural vulnerabilities and/or areas of remoteness in the district. In 2011, Thulamela had the second highest environmental vulnerability (EnVI) score in Limpopo, while Musina had the third highest EnVI score. Both LMs recorded above national average scores, indicating a high level of conflict between preserving the natural environment and accommodating the growth pressures associated with population growth, urbanisation, and economic development.

2.1.2. Settlement vulnerability

The unique set of indicators outlined below highlight the multi-dimensional vulnerabilities of the settlements within the Vhembe district and its local municipalities, with regards to six composite indicators. This enables the investigation of the relative vulnerabilities of settlements within the district.

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 were experiencing growth pressures on top of the other dimensional vulnerabilities up until 2050.

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.

A brief description of each local municipality within the district follows below. Figures 3 to 6 illustrate the multi-dimensional vulnerabilities of the settlements found within the Collins Chabane, Makhado, Musina and Thulamela Local Municipal areas.

Collins Chabane Local Municipality

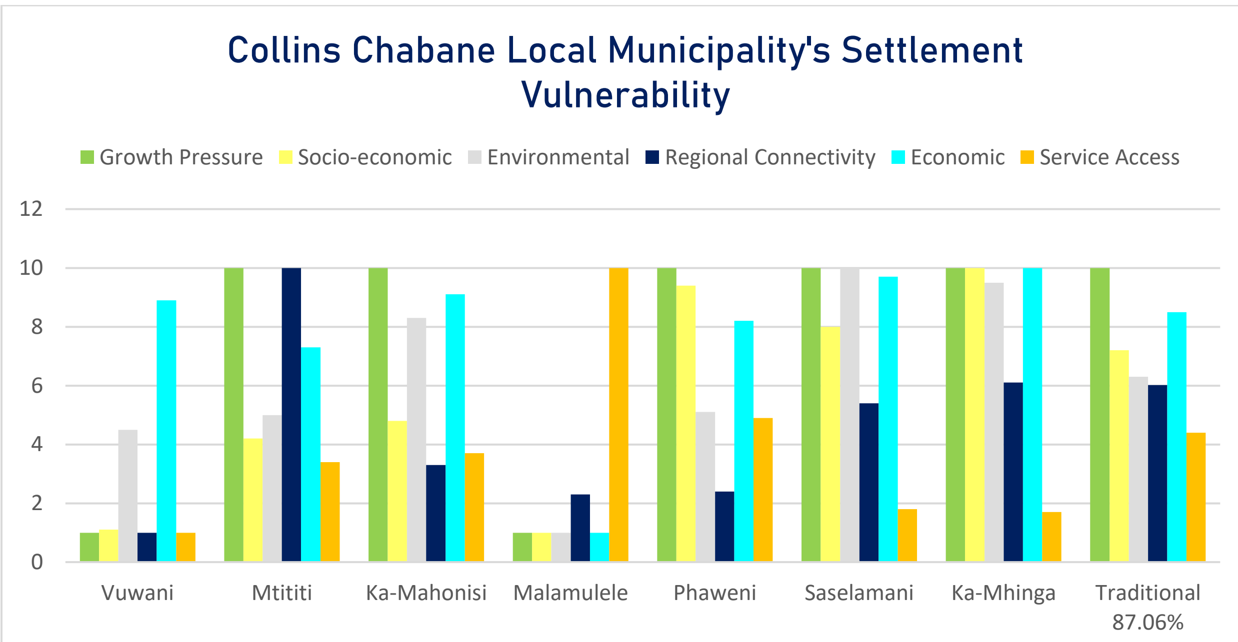

Figure 3: Collins Chabane Local Municipality's Settlement Vulnerability

The major settlements in Collins Chabane are Vuwani, Mtititi, Ka-Mahonisi, Malamulele, Phaweni, Saselamani, Ka-Mhinga, as well as several traditional areas (making up 87% of the LM's surface area). The settlements facing the greatest growth pressure are Mtititi, Ka-Mahonisi, Phaweni, Saselamani, Ka-Mhinga and several traditional areas. Ka-Mhinga also has the highest economic and socio-economic vulnerability in Collins Chabane. Saselamani also has the highest environmental vulnerability, alluding to the high conflict between the need to preserve the natural environment and accommodate the growth pressures present in the Municipality. In addition to growth pressure, Mtititi has the highest regional connectivity vulnerability in the LM, therefore highlighting the remoteness of the settlement, as well as its potentially weak regional economy. The town of Malamulele has the highest service access vulnerability in the LM.

Makhado Local Municipality

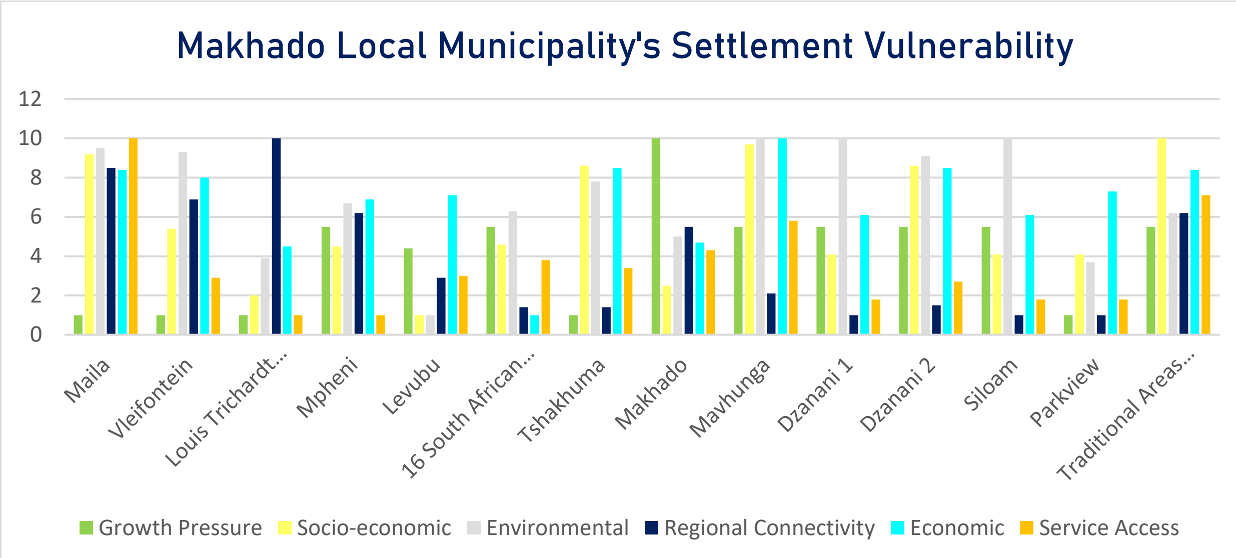

Figure 4: Makhado Local Municipality's Settlement Vulnerability

The major settlements in Makhado LM are Maila, Vliefontein, Louis Trichardt Airforce Base, Mpheni, Levubu, 16 South African Airforce Base, Tshakhuma, Makhado, Mavhunga, Dzanani 1, Dzanani 2, Siloam, Parkview, as well as several traditional areas (which cover 87 % of the LM's total surface area). While the settlement of Makhado has the greatest growth pressure in the LM, traditional areas house the most socio-economically vulnerable populations in the LM. Mavhunga, Siloam and parts of Dzanani have the highest environmental vulnerability in Makhado LM, alluding to the intense conflict present in both settlements, particularly with regards to the need to preserve the natural environment, while accommodating the growth pressures. Louis Trichardt Airforce Base emerged as the settlement with the highest regional connectivity vulnerability, which indicates the settlement's level of remoteness. Mavhunga has the highest economic vulnerability, while Maila has the highest service access vulnerability in the LM.

Musina Local Municipality

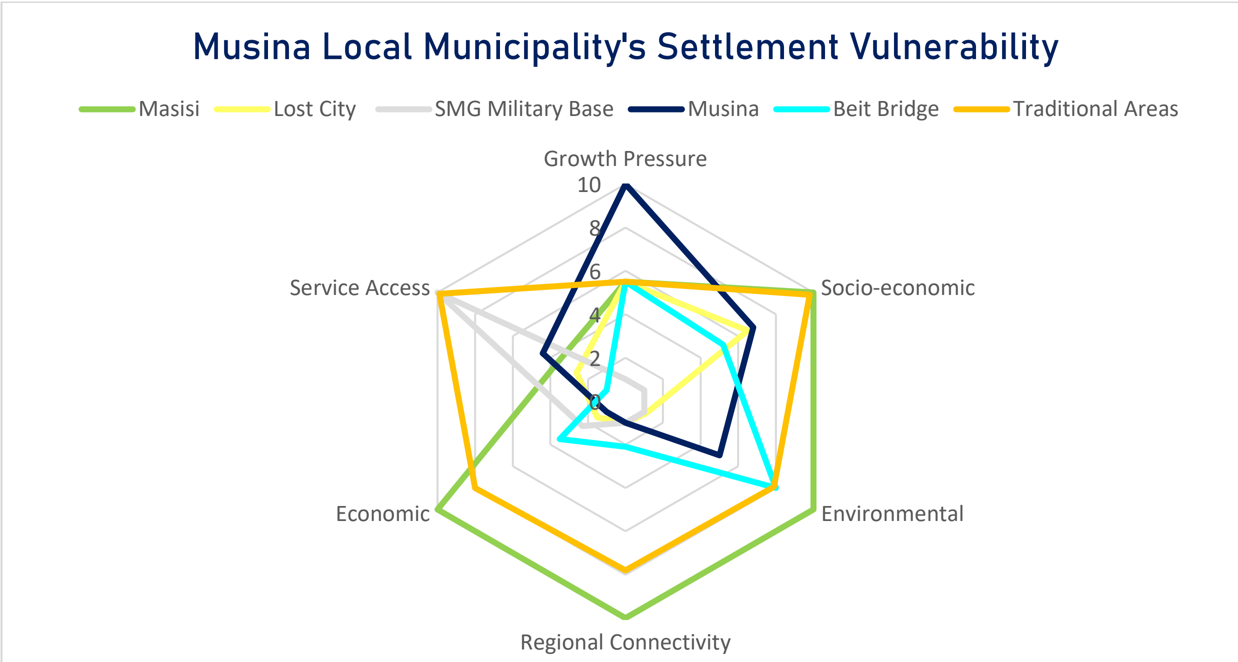

Figure 5: Musina Local Municipality's Settlement Vulnerability

The major settlements in Musina LM are Masisi, Lost City, SMG Military Base, Musina, Beit Bridge, as well as several traditional areas. The settlement of Musina has the highest growth pressure, while Masisi, as well as the several traditional areas found within the Musina Municipal area, are home to the largest number of socio-economically vulnerable households. Traditional areas also have the highest service access vulnerability. Moreover, in addition to socio-economic vulnerability, Masisi has the highest environmental, economic and regional connectivity vulnerability in the LM.

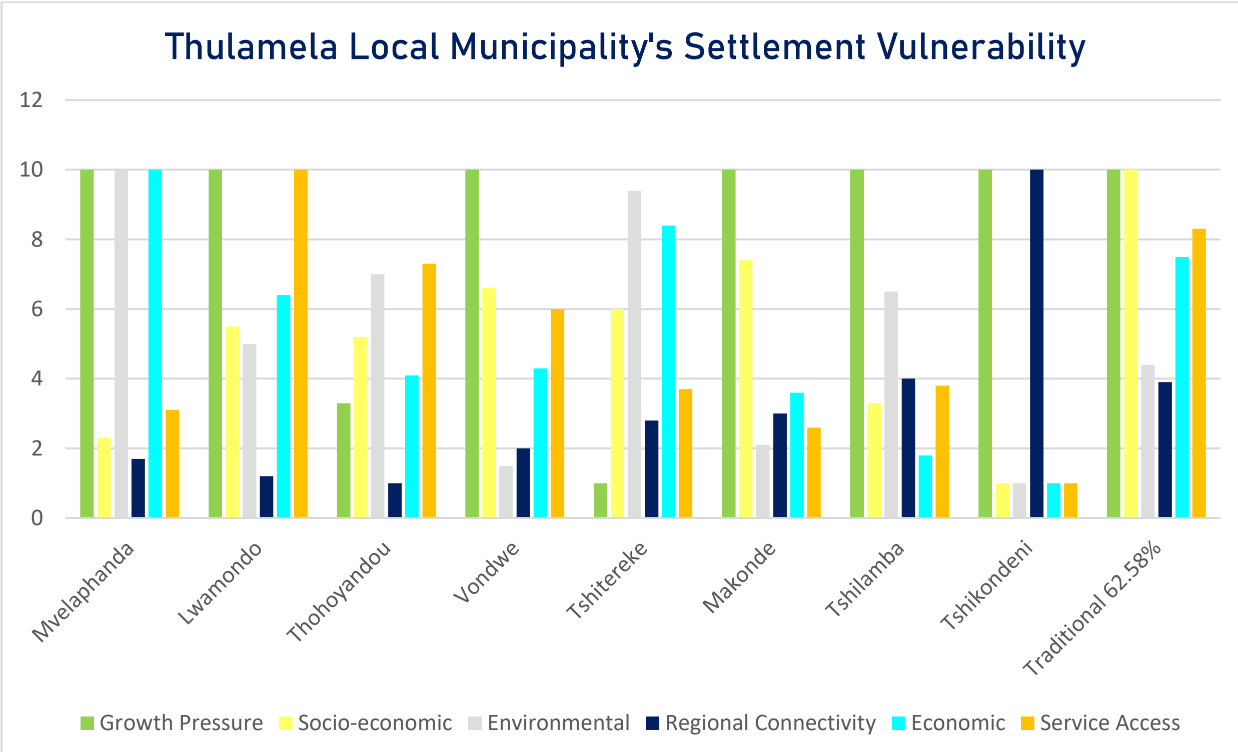

Figure 6: Thulamela Local Municipality's Settlement Vulnerability

The major settlements in Thulamela LM are Mvelaphanda, Lwamondo, Thohoyandou, Vondwe, Tshitereke, Makonde, Tshilamba, Tshikondeni as well as several traditional areas, which cover 62.58 % of the LM's total surface area. Mvelaphanda, Lwamondo, Vondwe, Makonde, Tshilamba, Tshikondeni, as well as traditional areas found within the Local Municipal area very high growth pressure. Traditional areas are also home to the largest number of socio-economically vulnerable households in the LM. In addition to high growth pressure, Mvelaphanda also has the highest environmental and economic vulnerability in the LM, while Lwamondo and Tshikondeni have the highest service access and regional connectivity vulnerability, respectively.

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 assumptions of their in- and out-migration assumptions. The medium growth scenario (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: Settlement population growth pressure across Vhembe District Municipality

Population per municipality	2011	Medium Growth Scenario	
		2030	2050
Collins Chabane LM	327 961	388 594	377 287
Makhado LM	401 524	464 388	451 654
Musina LM	104 034	214 438	375 566
Thulamela LM	460 333	564 948	569 736
Vhembe DM Total	1 293 852	1 632 368	1 774 243

Vhembe district's total population is projected to increase by 38.83 % between 2011 and 2050, under a medium growth scenario, which is an actual increase that amounts to 1 774 243 by 2050. Most of this growth will take place in the settlements within Thulamela and Musina LMs. Figure 7 depicts the growth pressures that the settlements across the district are likely to experience. Most settlements in Vhembe are likely to experience medium growth pressures up to 2050, including Thohoyandou, Vyeboom and Xitlhtlani.

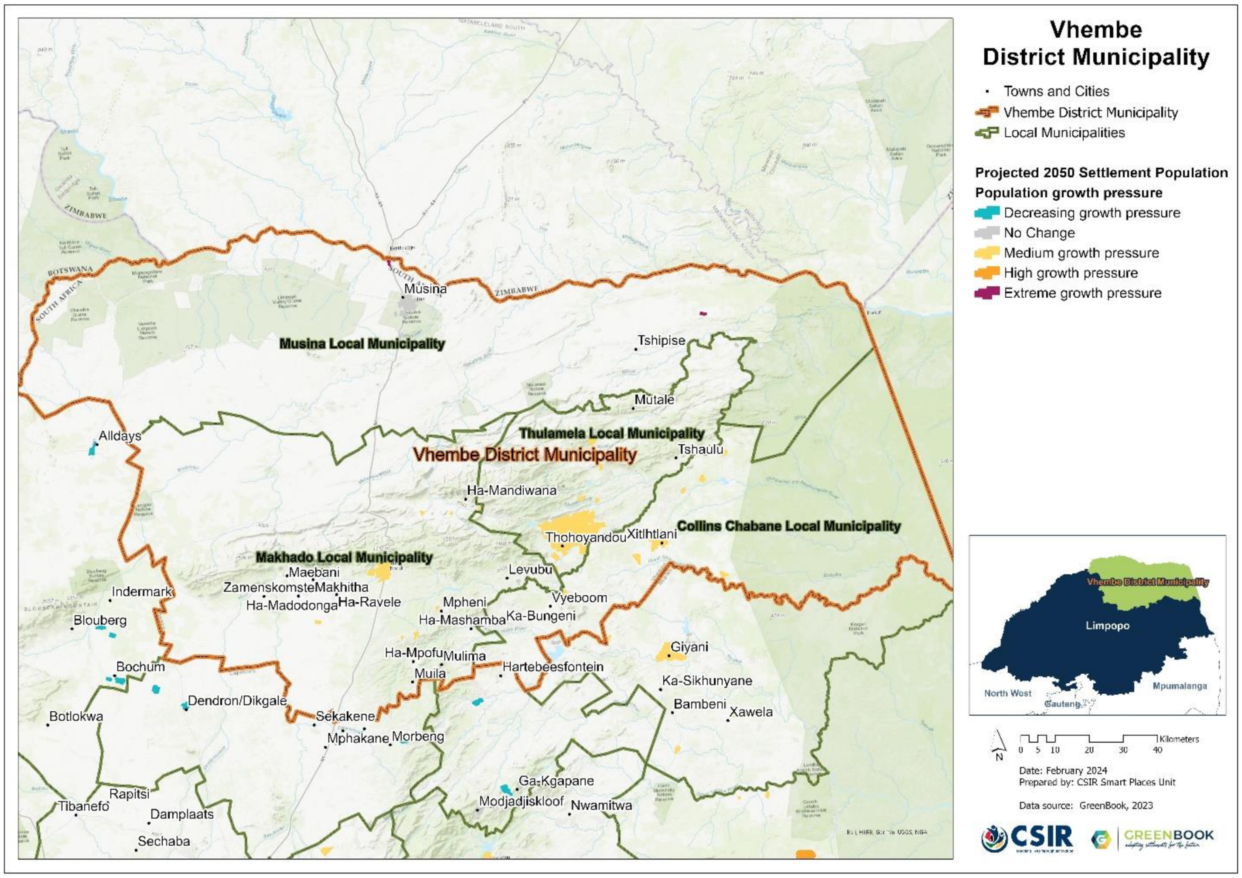

Figure 7: Settlement-level population growth pressure across Vhembe District Municipality

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 a number of 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 6 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 average annual temperatures (°C) for the baseline (current) period of 1961–1990, and the projected change for period 2021–2050 under an RCP8.5 low mitigation scenario.

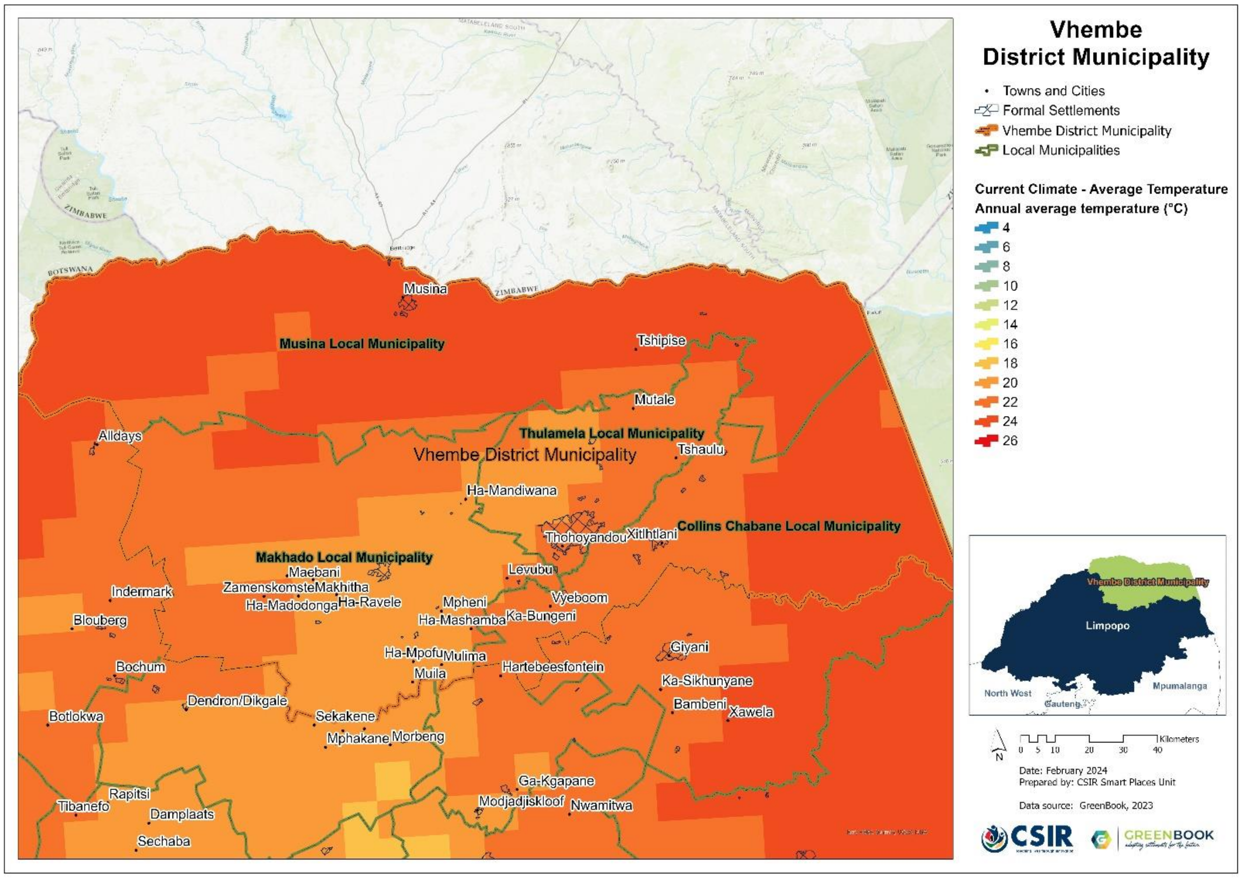

Figure 8: Average annual temperature (°C) for the baseline period 1961-1990 for Vhembe District Municipality

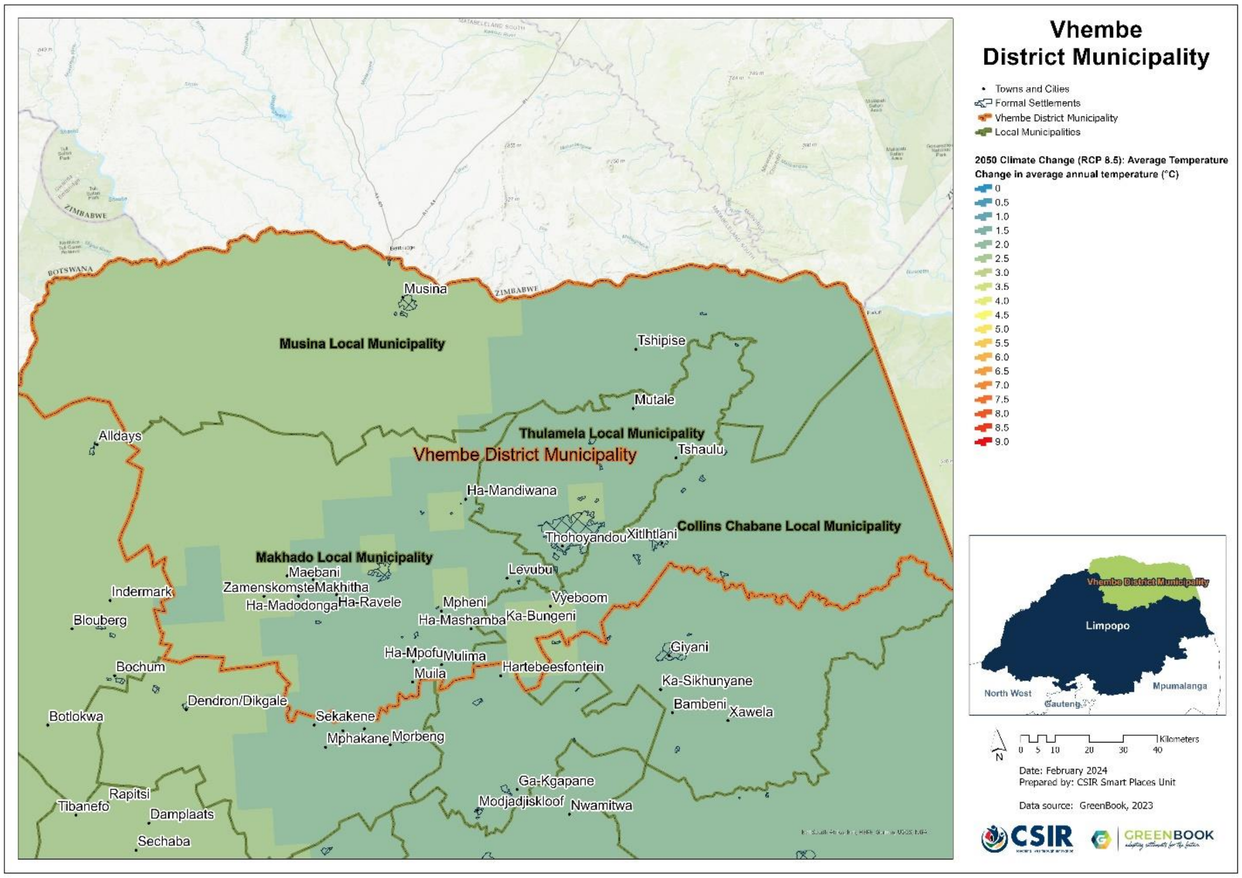

Figure 9: Projected changes in average annual temperature (°C) from the baseline period 1961-1990 to the future period 2021-2050 for Vhembe District Municipality, assuming an RCP 8.5 emissions pathway

At the baseline, the VDM experiences average annual temperatures between 18 and 22 °C, with lower averages found in the south-central parts of the district, particularly in Thulamela and Makhado LMs. The projections show average annual temperature increases of between 2 and 2.5 °C under a low mitigation, and GHG high emissions scenario. The largest increases are expected in the north western parts of the district, affecting parts of Makhado LM, as well as Musina LM.

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 high emissions scenario.

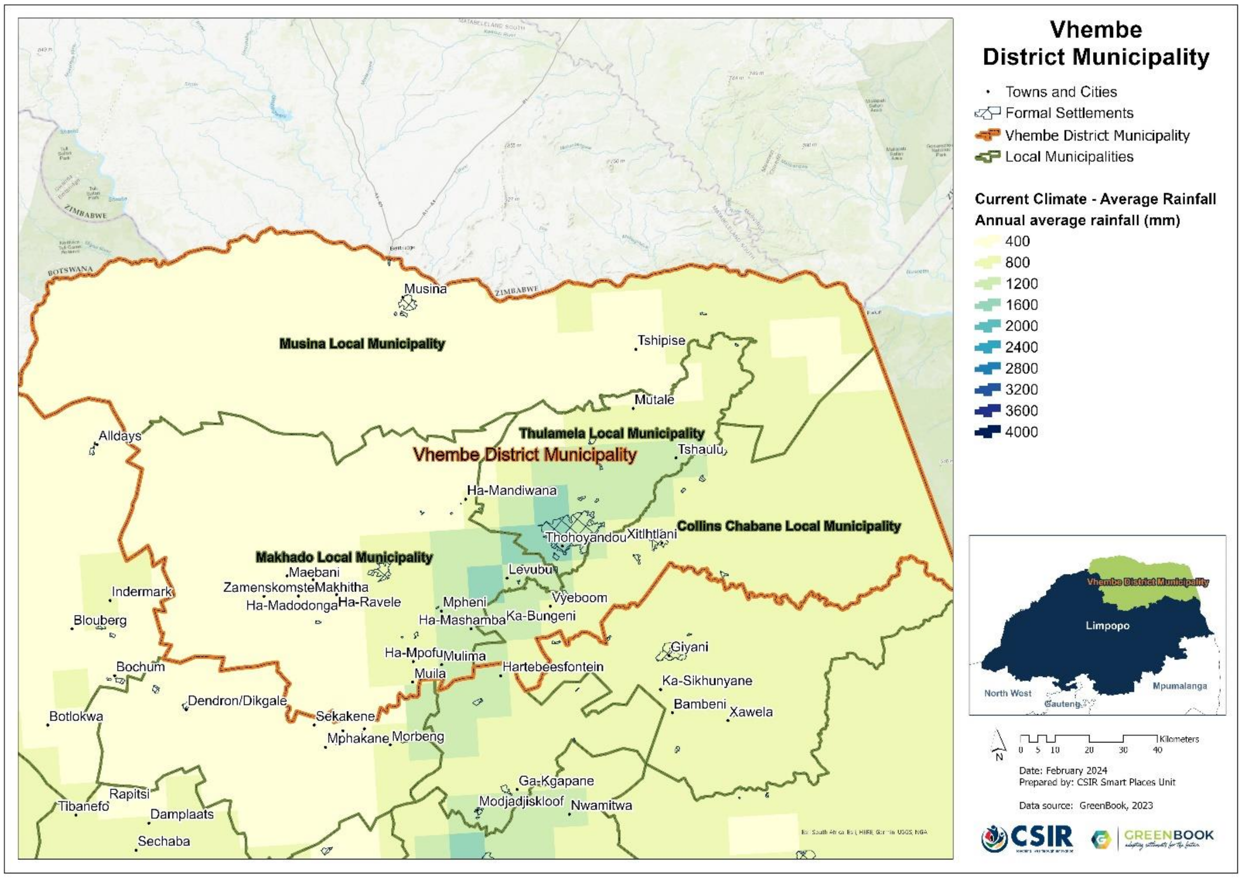

Figure 10: Average annual rainfall (mm) for the baseline period 1961-1990 for Vhembe District Municipality

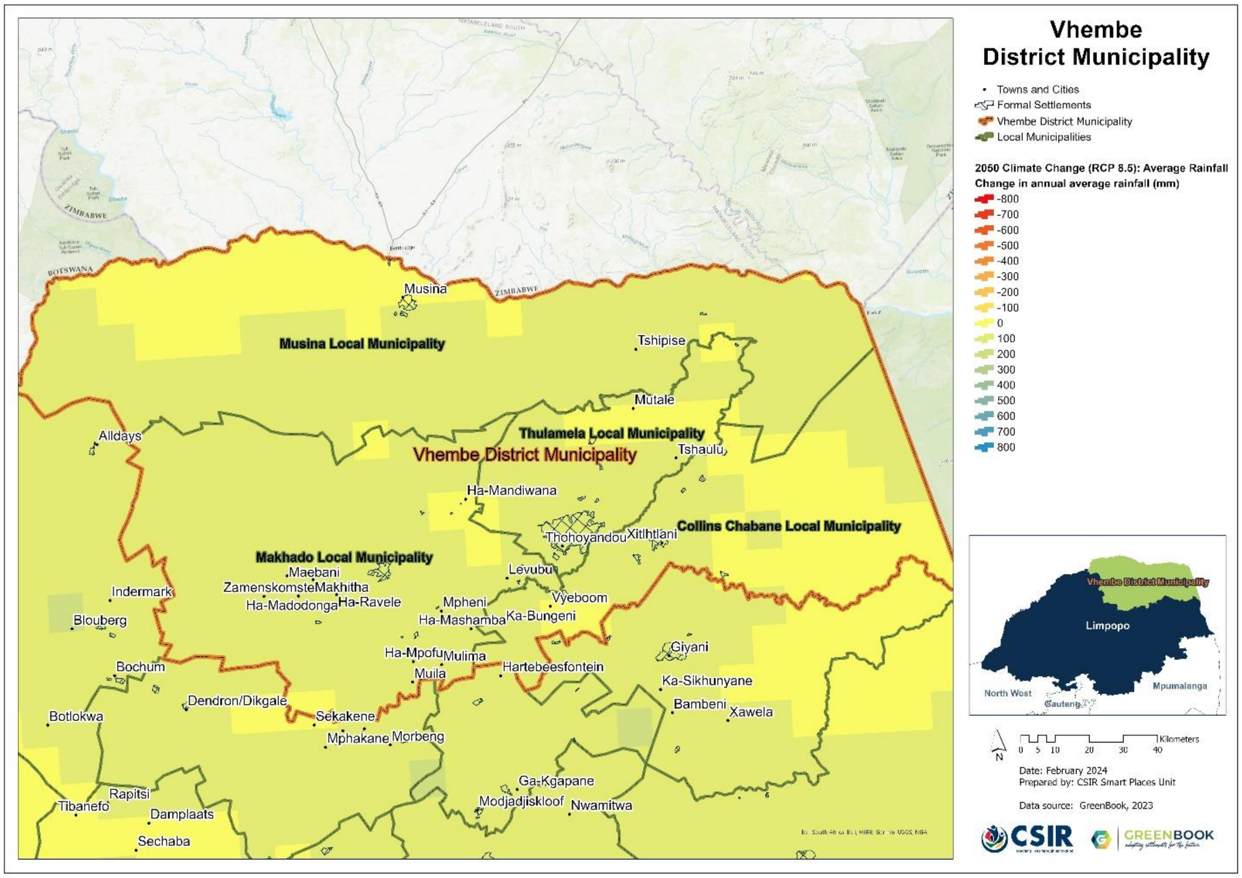

Figure 11: Projected change in average annual rainfall (mm) from the baseline period to the period 2021-2050 for Vhembe District Municipality, assuming an RCP8.5 emission pathway

The Vhembe district experiences current GCM derived average annual rainfall of between 400 and 1600 mm, with higher averages found over the central parts of the district. Lower levels of rainfall are prevalent on the Western side of the district. Future projections show an average annual rainfall decline of up to 200 mm across the district, under a low mitigation, high emissions, scenario (Figure 11).

2.3. Climate Hazards

This section showcases information with regards to Vhembe District Municipality'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).

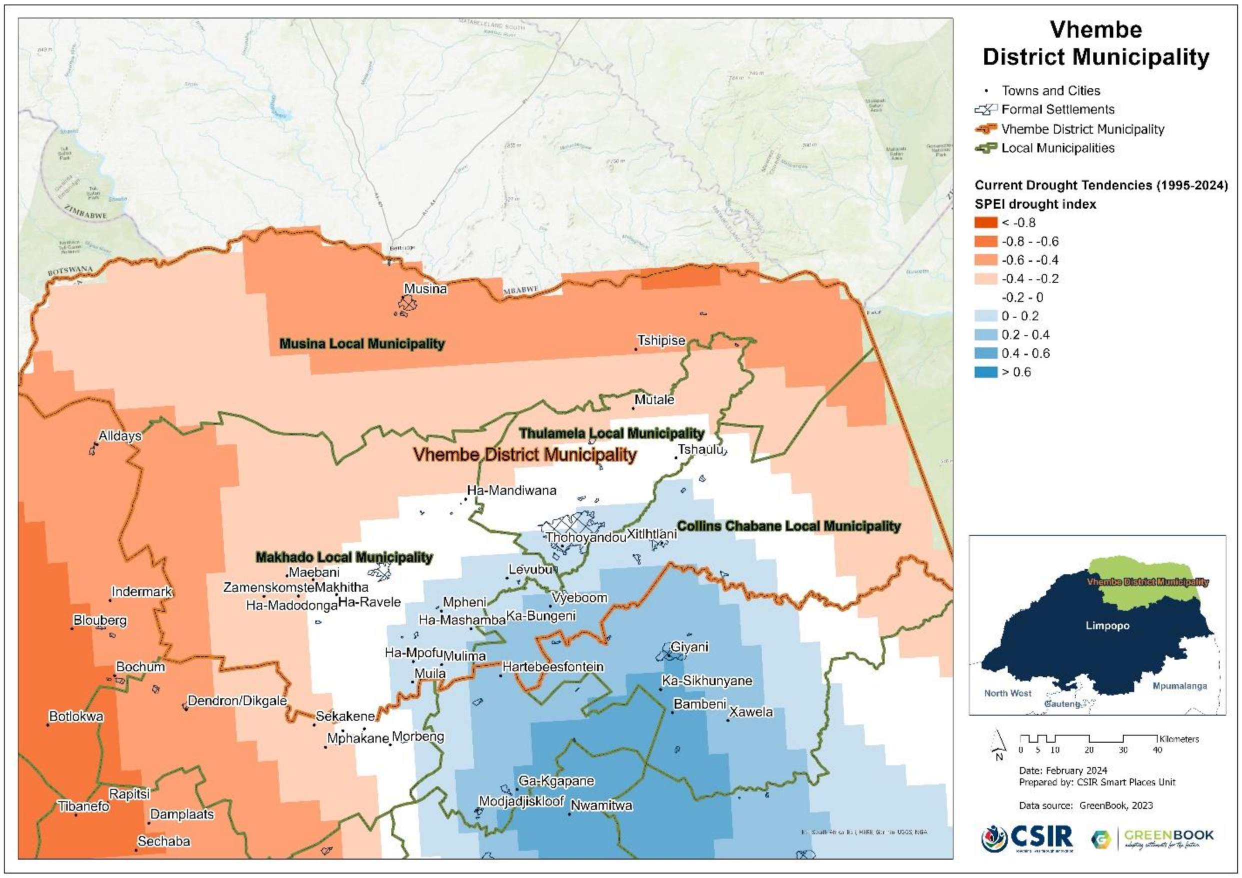

Figure 12: Projected changes in drought tendencies from the baseline period (1986–2005) to the current period (1995-2024) across Vhembe District Municipality

Figure 12 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.

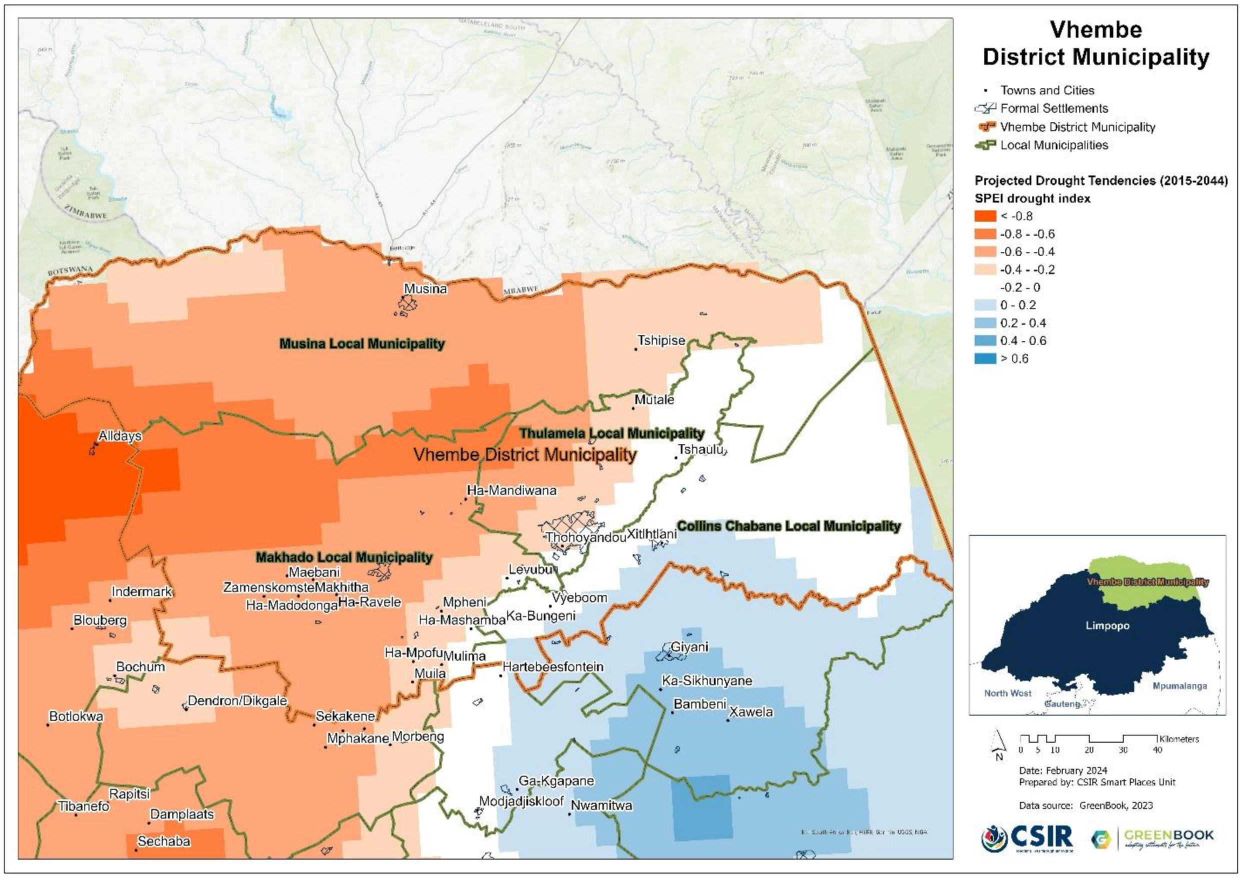

Figure 13: Projected changes in drought tendencies from the baseline period (1986–2005) to the future period 2015-2044 for Vhembe District Municipality

Figure 13 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 and a positive value is indicative of a decrease. Figure 14 depicts the settlements that are at risk of increases in drought tendencies.

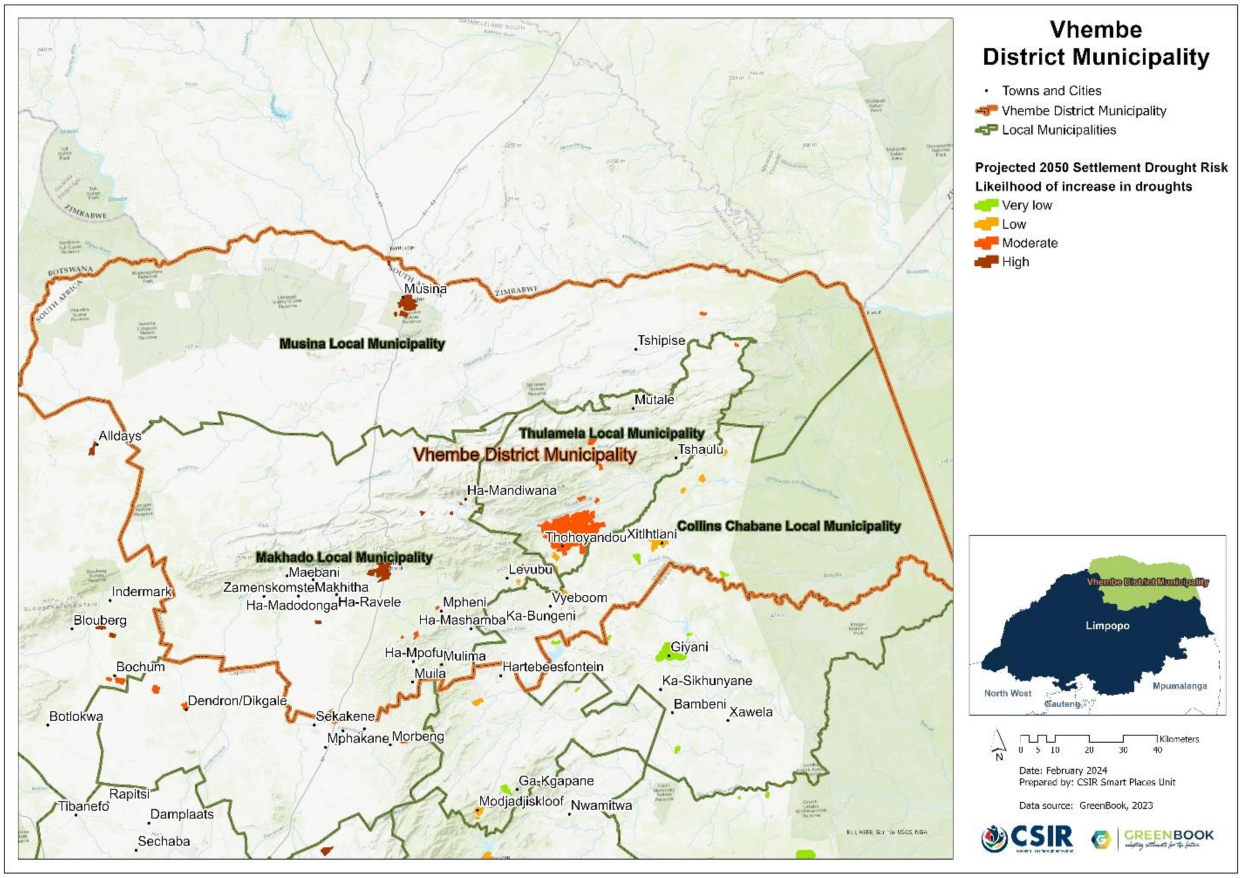

Figure 14: Settlement-level drought risk for Vhembe District Municipality

Large parts of the West Rand district (with the exception of several settlements occupying the southern portions of Makhado, Thulamela and Collins Chabane LMs), are exposed to drought tendencies, with more intense droughts prevalent along the western border of Makhado, as well as the northern border of Musina LMs (Figure 12). The entire district can expect more frequent and intense droughts towards 2050 (Figure 13). The settlements of Musina and Makhado face an increased risk of drought into the future (Figure 14).

2.3.2. Heat

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 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.

The GCMs were used to simulate bias-corrected, average annual number of very hot days, defined as days when the maximum temperature exceeds 35° C per GCM grid point for the baseline (current) period of 1961–1990 (Figure 15), and for the projected changes for period 2021–2050 (Figure 16). The annual heatwave days map under baseline conditions (Figure 17) 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, for a period of at least three consecutive days. The projected change in the number of days belonging to a heatwave for the period 2021–2050 (Figure 18), assuming a "business as usual" (RCP 8.5) emissions pathway, is also shown.

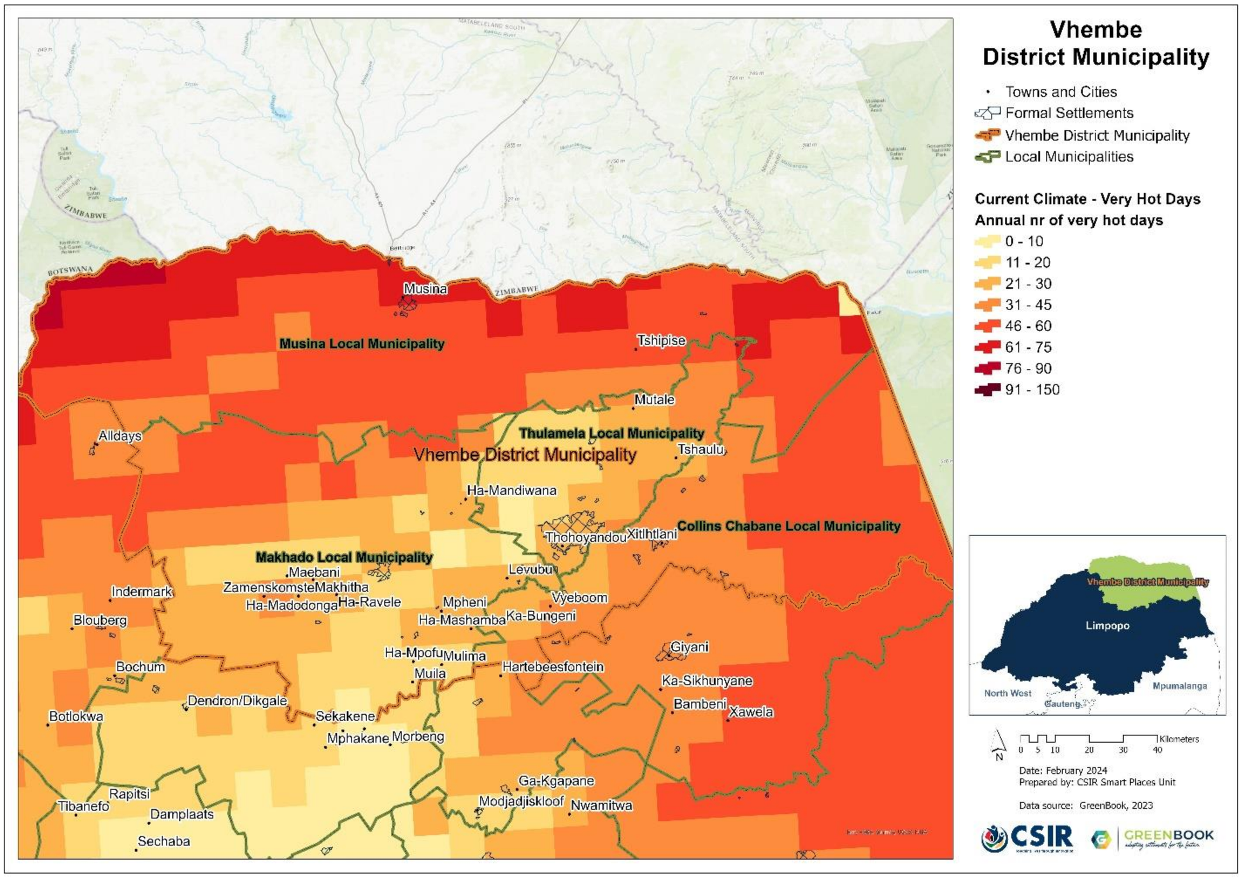

Figure 15: Annual number of very hot days under baseline climatic conditions across Vhembe District Municipality, with daily temperature maxima exceeding 35°C

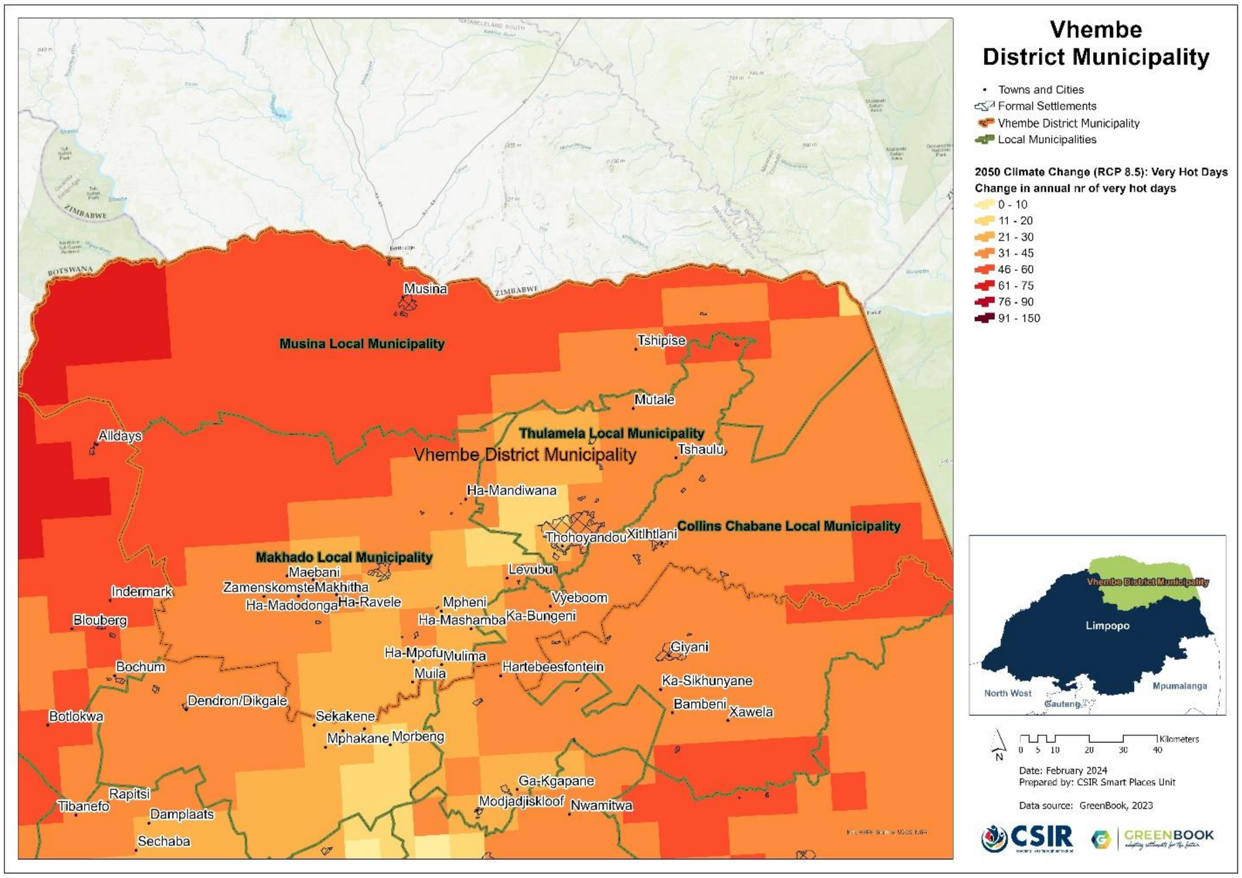

Figure 16: Projected change in annual number of very hot days across Vhembe District Municipality, with daily temperature maxima exceeding 35°C , assuming and RCP 8.5 emissions pathway

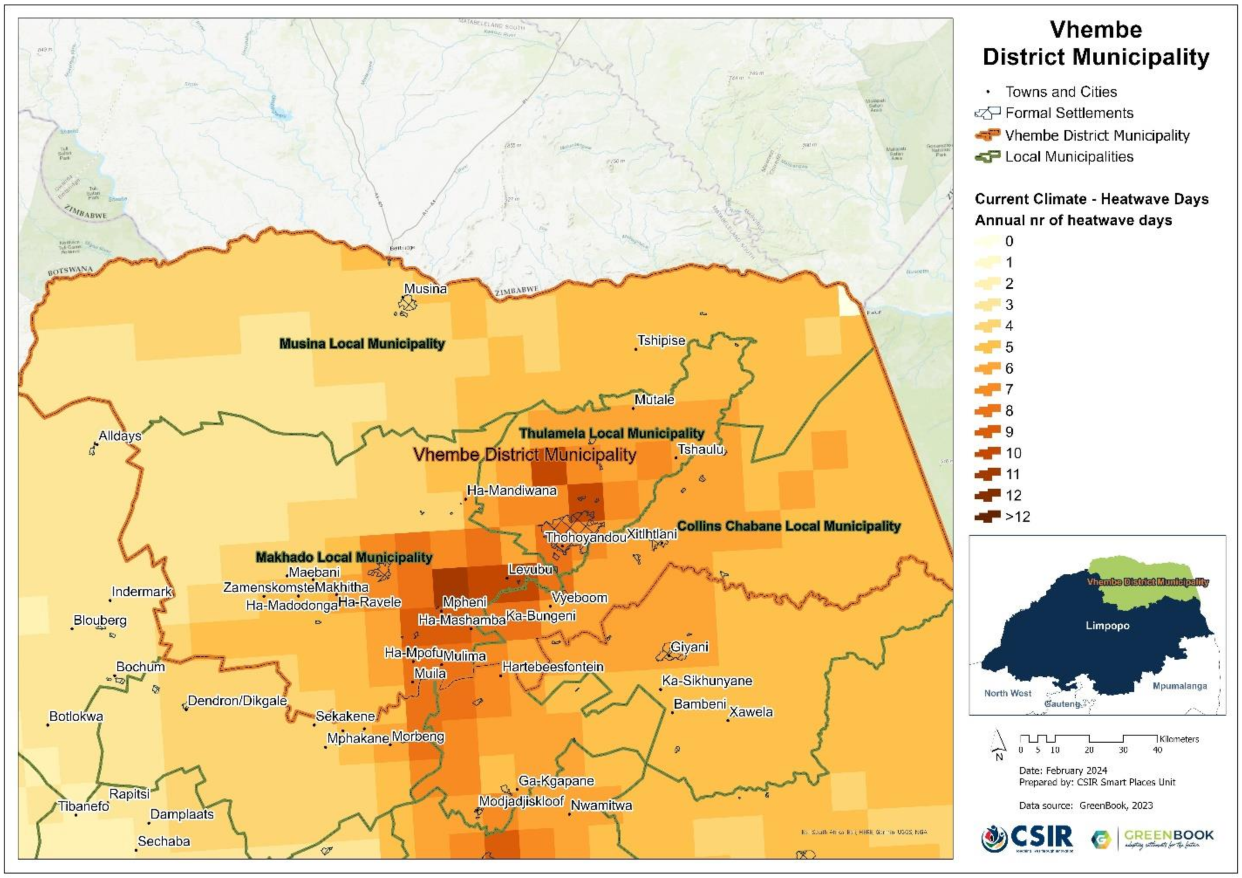

Figure 17: Number of heatwave days under baseline climatic conditions across Vhembe District Municipality

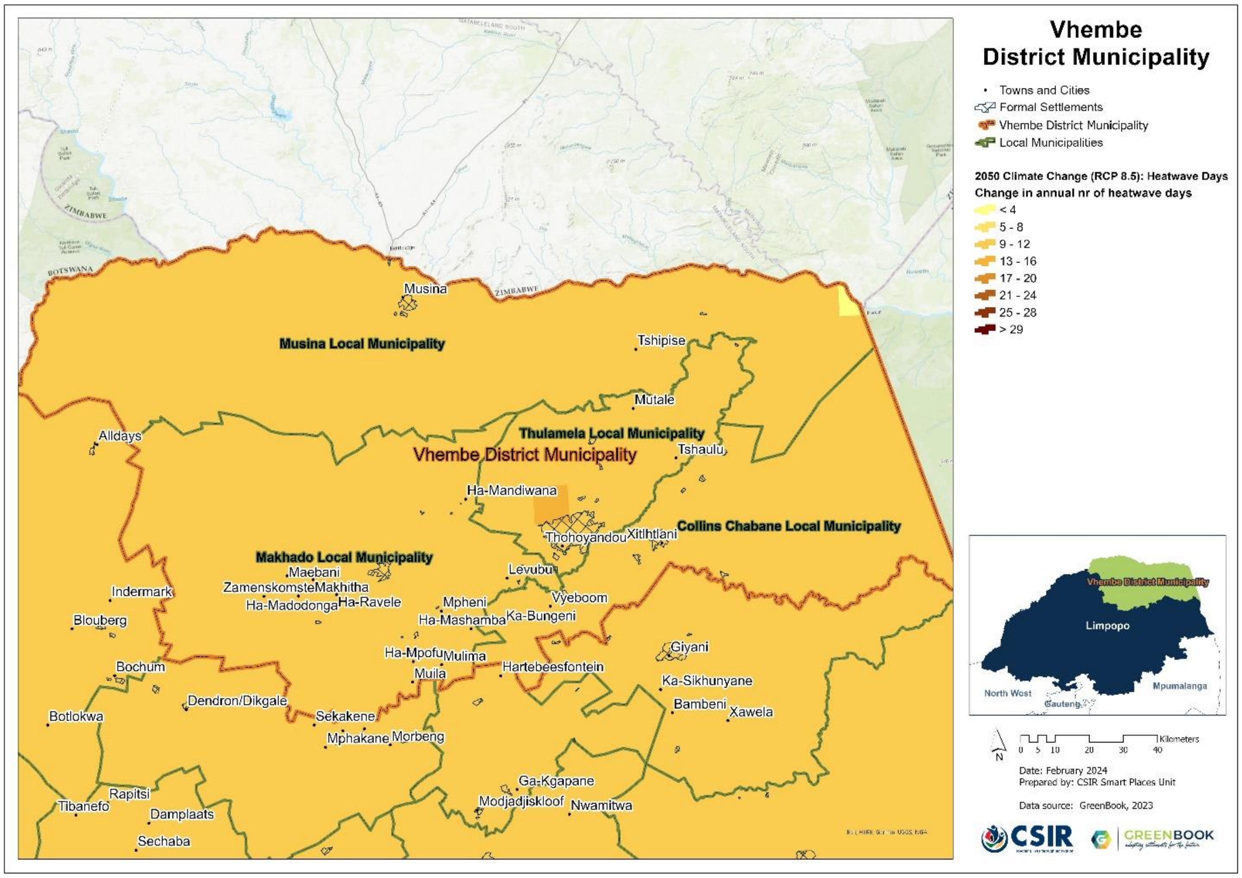

Figure 18: Projected change in annual number of heatwave days across Vhembe District Municipality, assuming an (RCP 8.5) emissions pathway

Under baseline climatic conditions, Vhembe district experiences up to 75 very hot days per annum (Figure 15). The number of very hot days is expected to increase by up to 60 days per annum by 2050, under an RCP 8.5 "business as usual GHG emissions" scenario, with the most significant increases expected across the Musina LM (Figure 16). The Vhembe DM also experiences between 2 and 9 heatwave days per year, with most heatwave days occurring in the central parts of the district, mostly affecting Thulamela LM, as well as the south eastern parts of Makhado LM (Figure 17). The annual number of heatwave days in the district is expected to increase by between 13 and 16 days by 2050, assuming an RCP 8.5 low mitigation, high GHG emissions scenario (Figure 18).

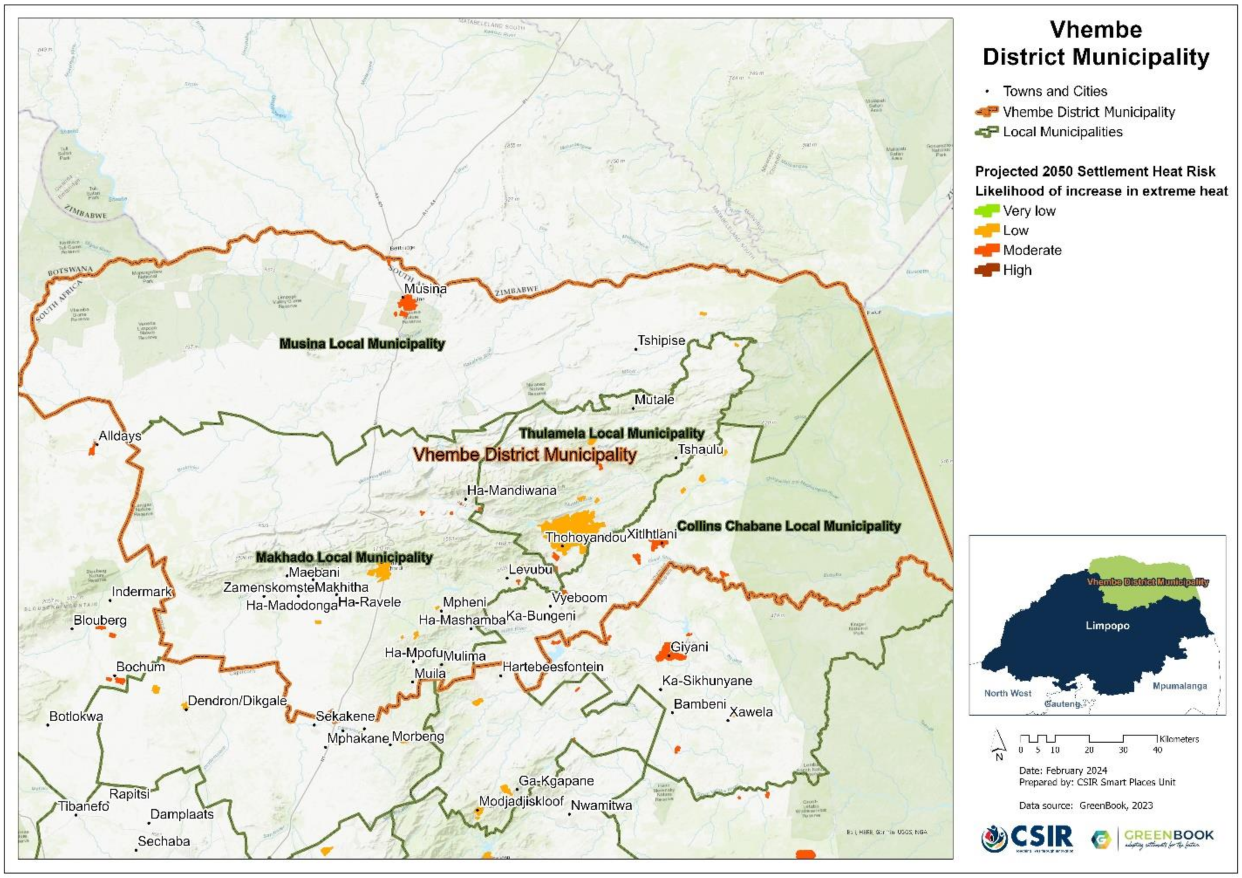

Figure 19: Settlement-level heat risk across Vhembe District Municipality

Figure 19 depicts the settlements that are at risk of increases in heat stress. Some of the settlements that are projected to be most exposed to heat stress in the future in the district include Musina and Xitlhtlani.

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 they should not. Much of the natural vegetation requires fires to maintain the ecosystems and keep them 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. A scale was used 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. Figure 20 depicts the likelihood and the risk of wildfires occurring in the wildland-urban interface (the boundary or interface between developed land and fire-prone vegetation) of the settlement.

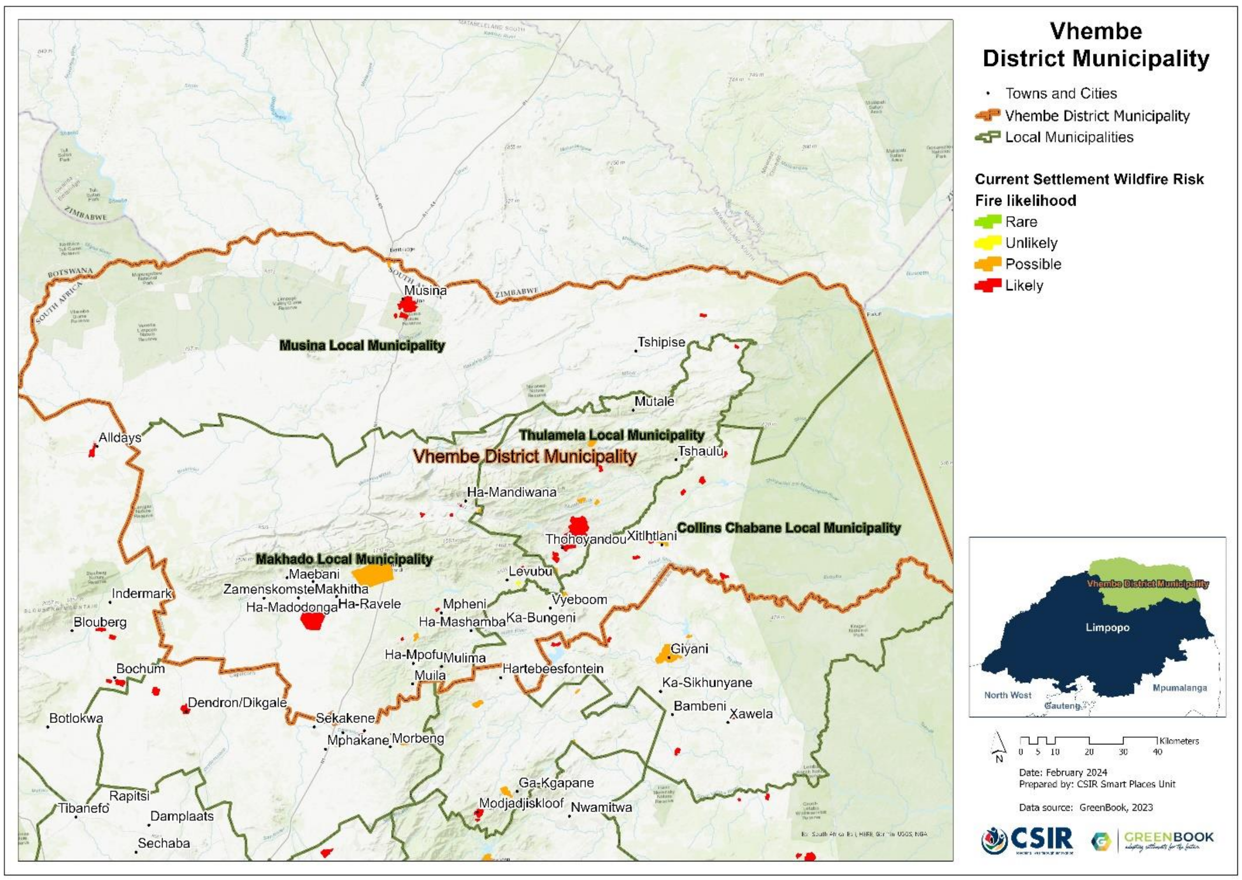

Figure 20 The likelihood of wildfires under current climatic conditions across settlements in Vhembe District Municipality

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 (McArthur 1967) 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. Figure 21 depicts the settlements that could be at risk of increases in wildfires by the year 2050.

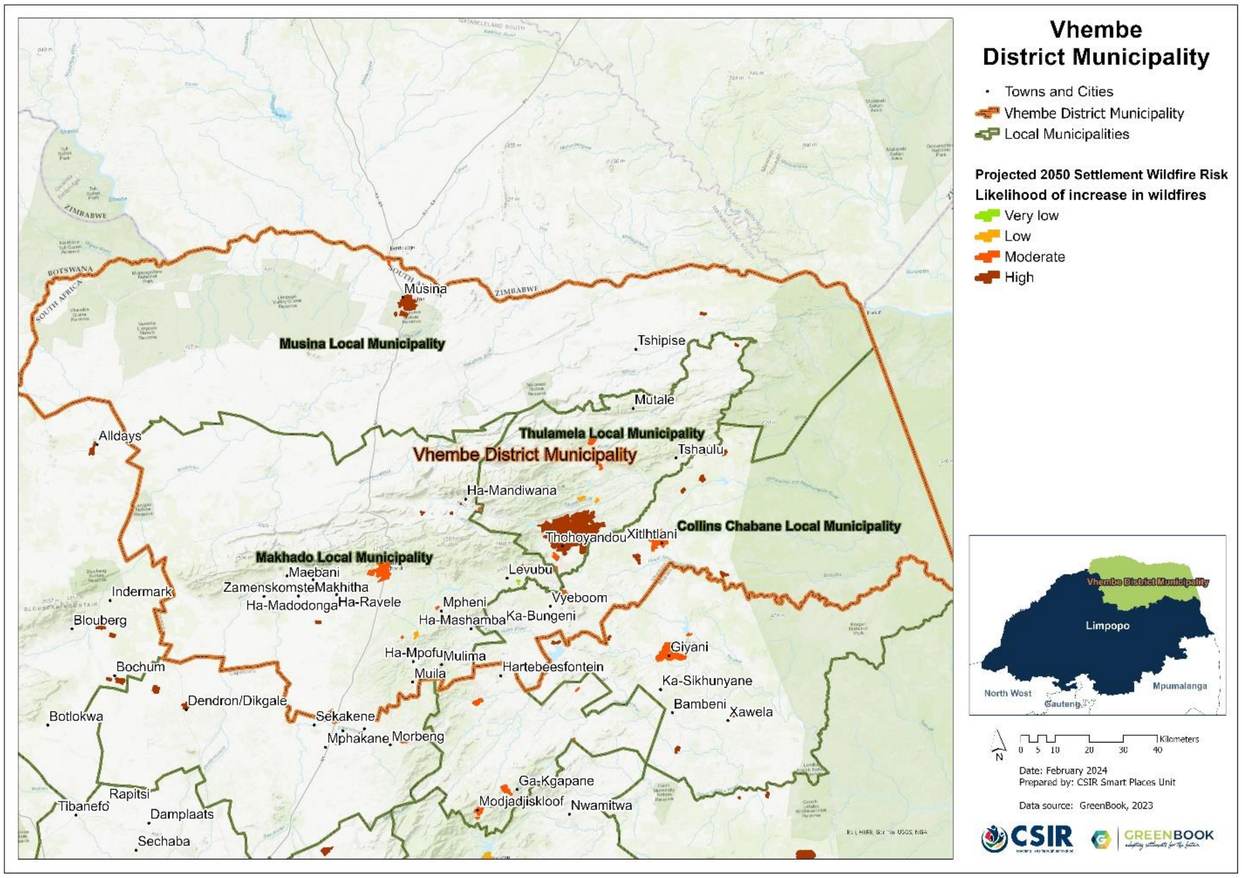

Figure 21: The likelihood of wildfires under projected future climatic conditions across settlements in Vhembe District Municipality

Several settlements across the district are likely to experience wildfires in their wildland-urban interface. These include Musina, Thohoyandou, the Makhado Airport Air Force Base, as well as several small settlements scattered across the district (Figure 20). Almost all settlements that face a high likelihood of wildfire occurrence at the baseline (with the exception of the Makhado Airport / Air Force Base), face an increased risk of wildfires into a climate-changed future (Figure 21).

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, 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 the 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, it is projected that flood events are likely to increase into the future as well. Estimates of the 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 identified using a risk matrix, which considered the flood hazard index and the projected change in extreme rainfall days from 1961-1990 to the 2050s.

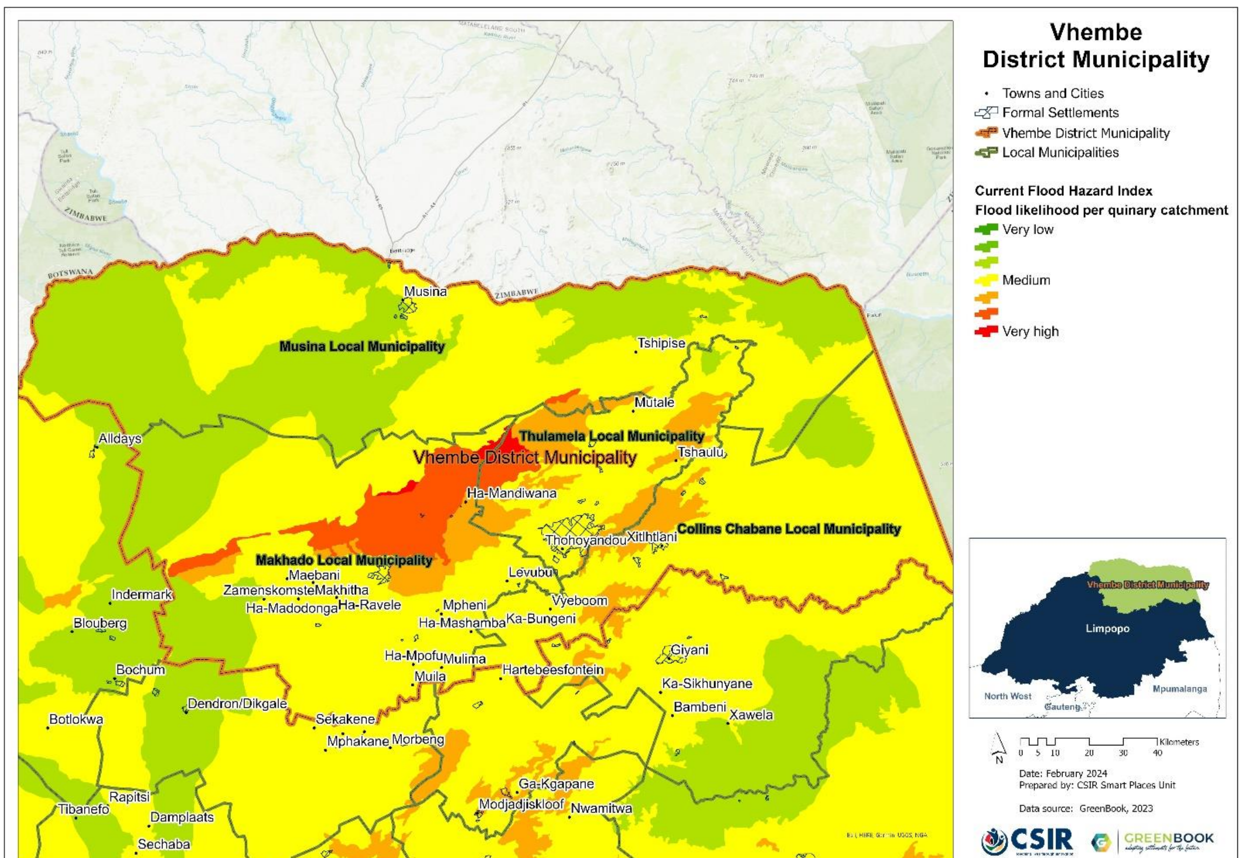

Figure 22: The current flood hazard index across Vhembe District Municipality under current (baseline) climatic conditions

Figure 22 depicts the flood hazard index of the individual Quinary catchments present or intersecting with the district. 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. There is significant variation of the flood hazard index across the Vhembe district. Most parts of the district have a low to medium flooding hazard, with small pockets of high to very high flooding hazard.

Figure 23 depicts the projected change into the future in extreme rainfall days for an 8 x 8 km grid. This was calculated by assessing the degree of change when projected future rainfall extremes (e.g., 95th percentile of daily rainfall) are compared with those under the current rainfall extremes. A value of more than 1 indicates an increase in extreme daily rainfalls. Slight increases in the annual number of extreme rainfall days are expected across large parts of the district, with considerably small portions projected to experience slight decreases in the number of extreme rainfall days by 2050, assuming an RCP "business as usual" emissions scenario. Some parts of the district are projected to experience no changes in the annual number of extreme rainfall days (Figure 23).

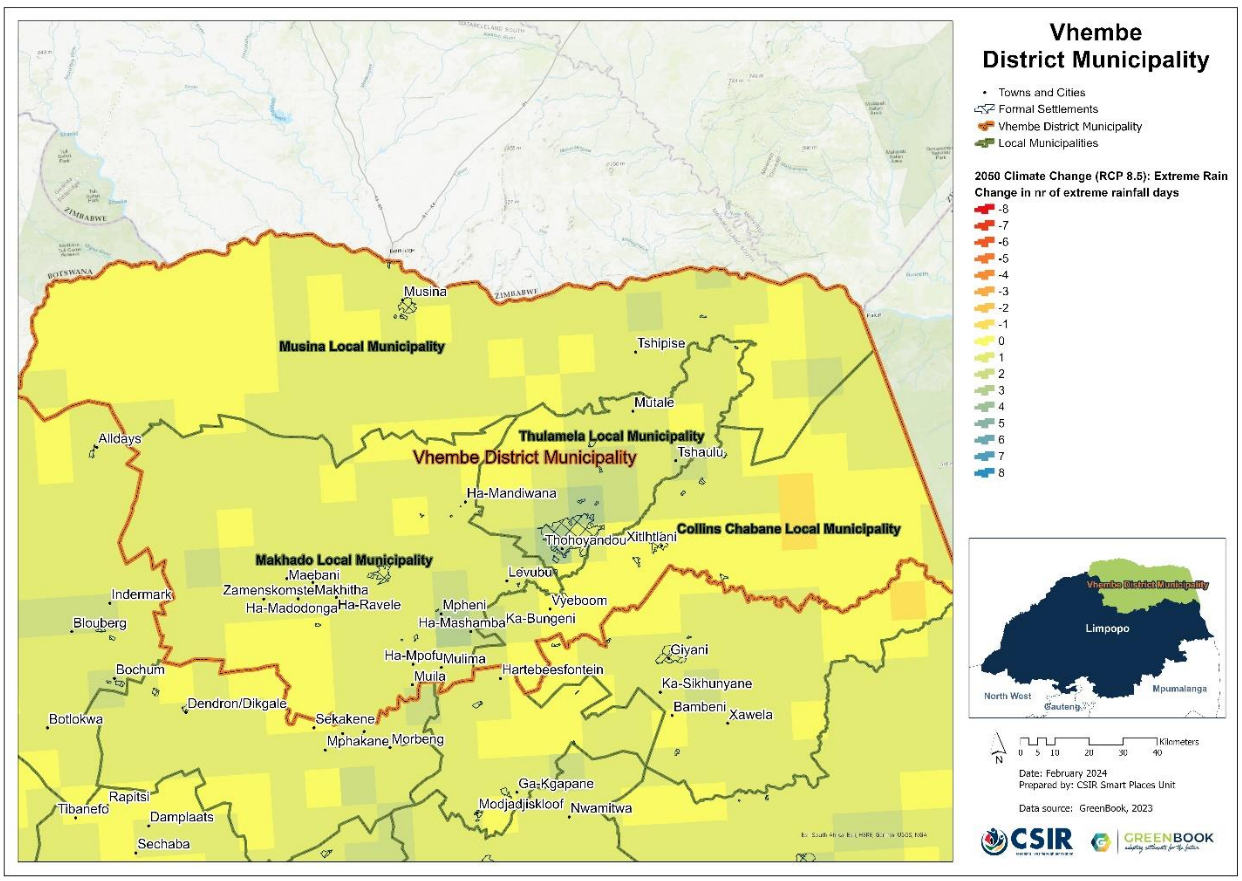

Figure 23: Projected changes into the future in extreme rainfall days across Vhembe District Municipality

Model projections of precipitation manifest uncertain due to several factors, including model sensitivity to spatial resolution at which processes are resolved. At 8 X 8 km 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 24 depicts the settlements that are at increased risk of flooding under an RCP 8.5 low mitigation (worst case of greenhouse gas emissions) scenario. The Makhado Airport / Air Force Base is the settlement facing the greatest risk to flooding into a climate-changed future However, the risk is moderate.

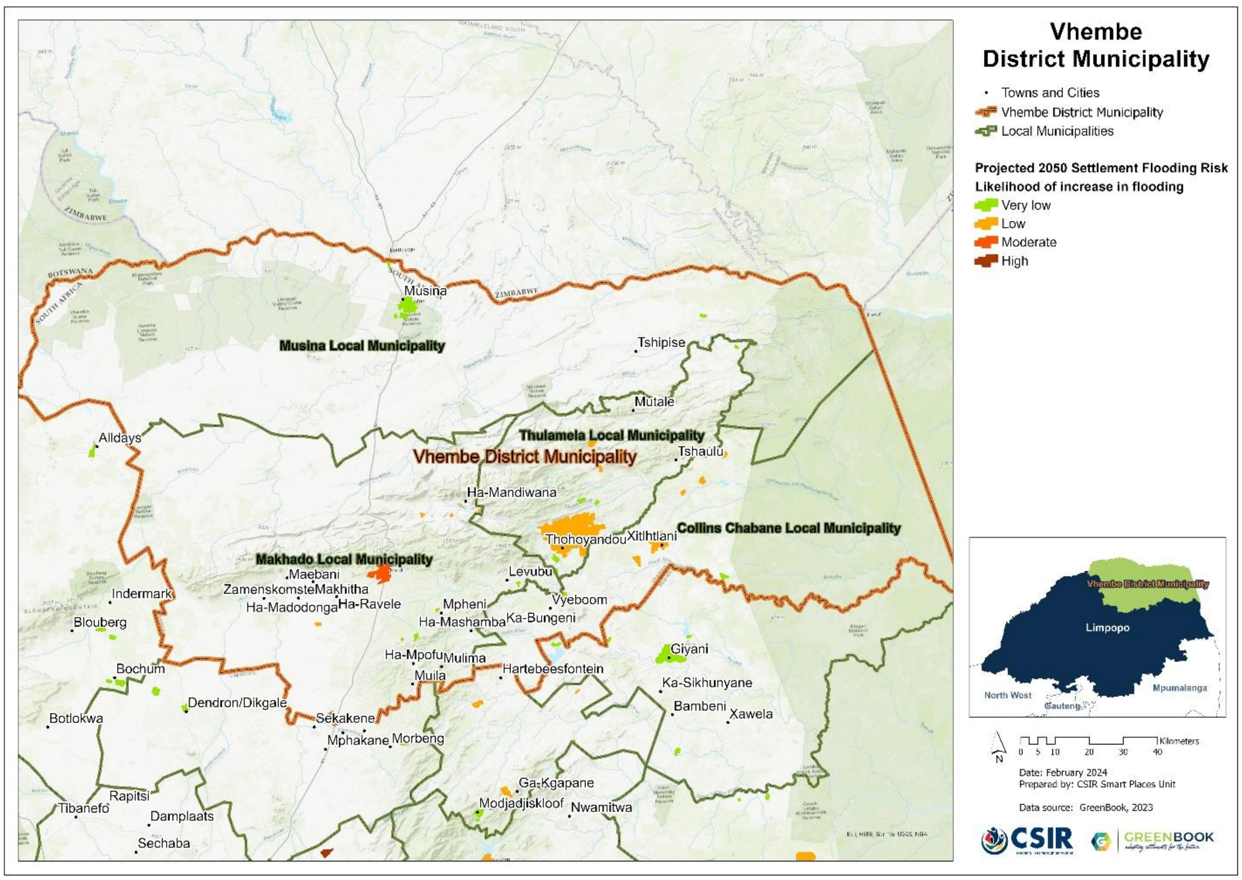

Figure 24: Flood risk into a climate change future at settlement level across Vhembe District Municipality.

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 the Vhembe District Municipality.

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 to 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 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.

Figures 25 to 28 indicates the catchment(s) related to the district. The quaternary catchments serving the district include the Olifants and Limpopo Primary Catchments.

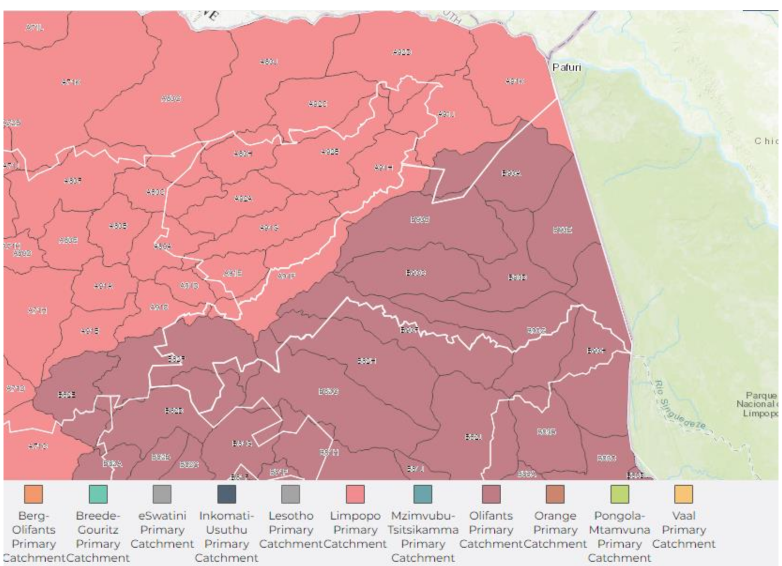

Figure 25: Quaternary catchments found in Collins Chabane Local Municipality

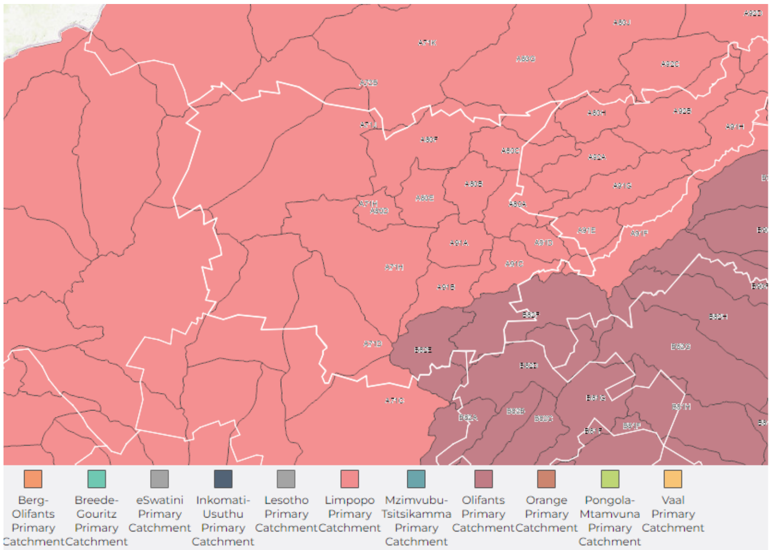

Figure 26: Quaternary catchments found in Makhado Local Municipality

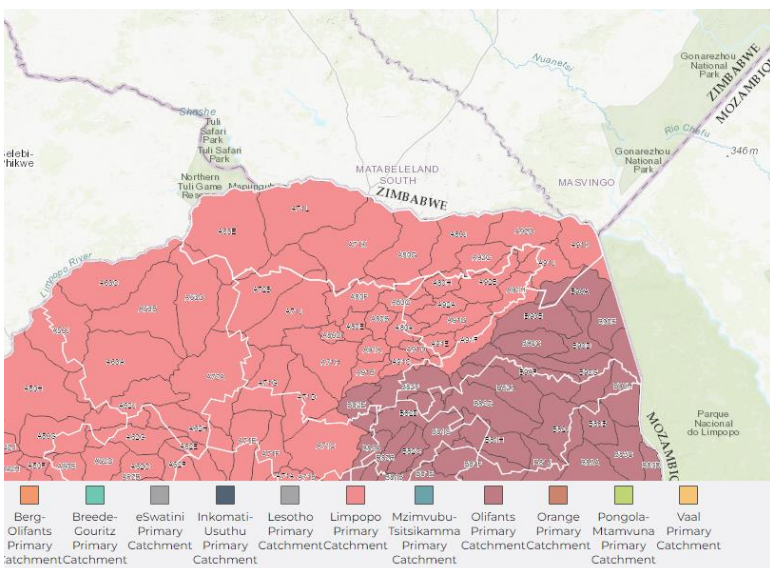

Figure 27: Quaternary catchments found in Musina Local Municipality

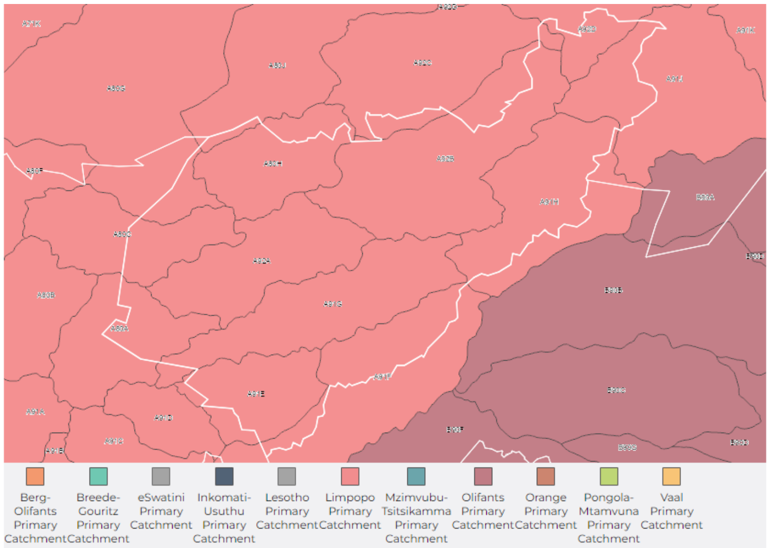

Figure 28: Quaternary catchments found in Thulamela Local Municipality

Figure 29 indicates where settlements get their main water supply from, be it groundwater, surface water or a combination of both sources. Settlements that rely on groundwater, either entirely or partially, are deemed to be groundwater dependent. In the Vhembe district, most towns are surface water dependent, with a few that use a combination of surface water and groundwater sources, i.e., the Makhado Airport / Air Force Base.

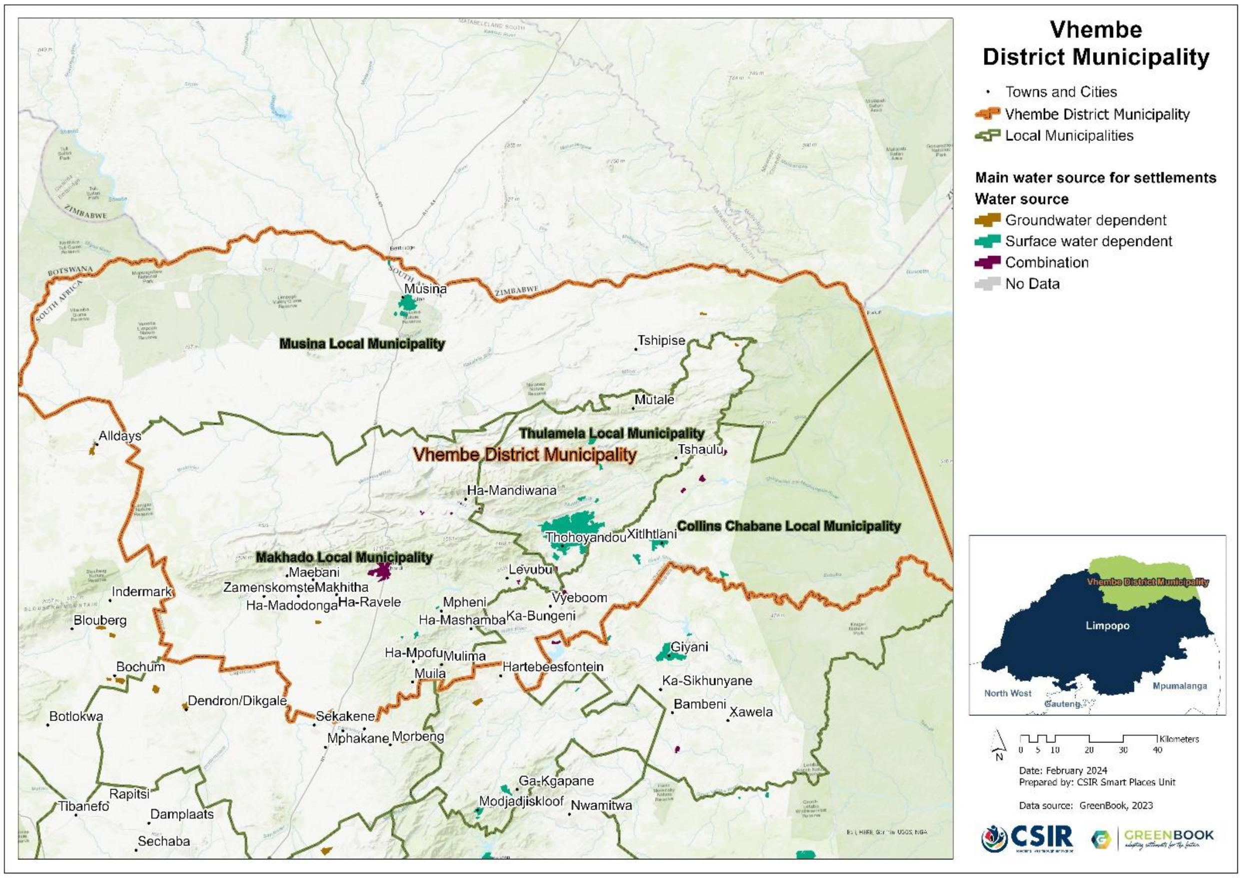

Figure 29: Main water source for settlements in the Vhembe District Municipality

Figure 30 indicates the occurrence and distribution of groundwater resources across the district municipality, showing distinctive recharge potential zones, while Figure 31 indicates the projected change in groundwater potential. Figure 32 indicates which groundwater dependent settlements that may be most at risk of groundwater depletion based on decreasing groundwater aquifer recharge potential and significant increases in population growth pressure into the future.

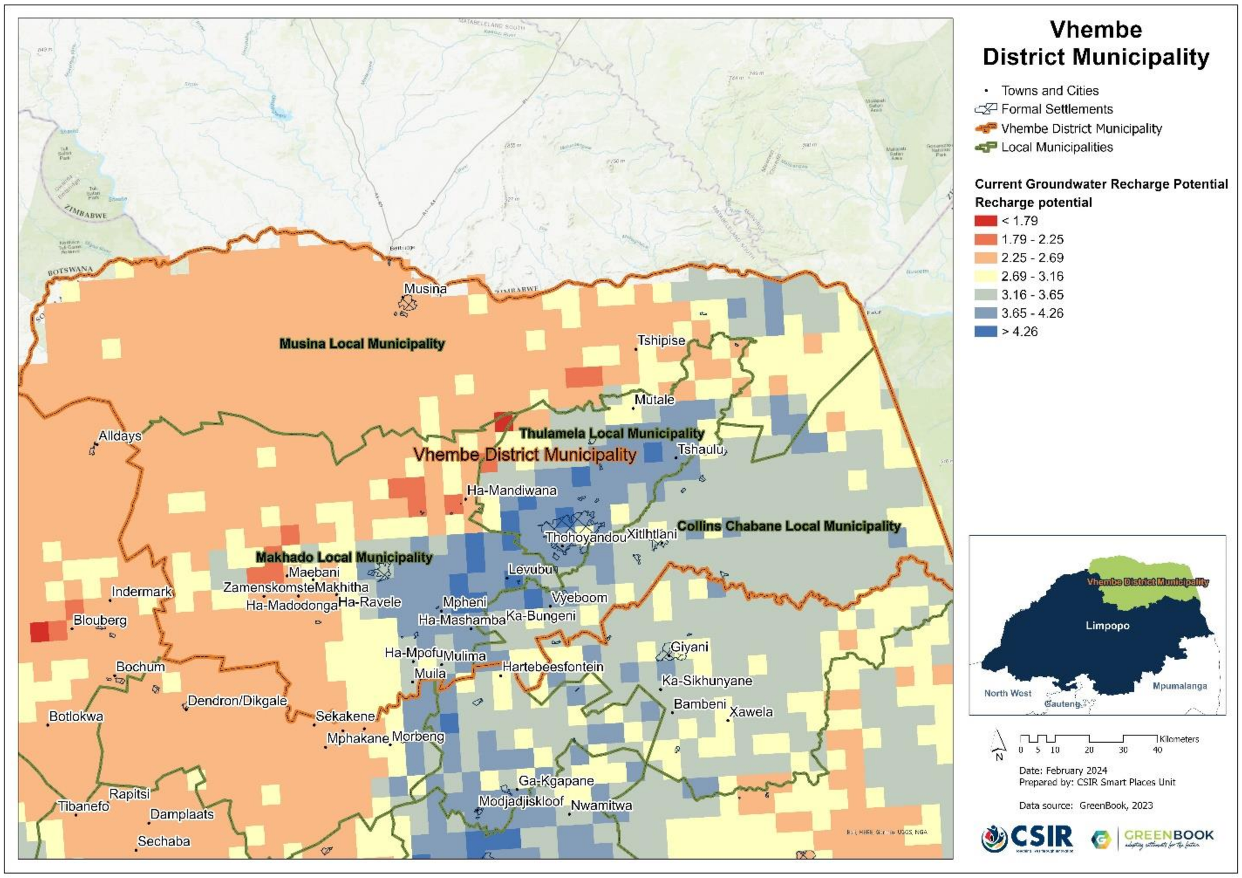

Figure 30: Groundwater recharge potential across Vhembe District Municipality, under current (baseline) climatic conditions

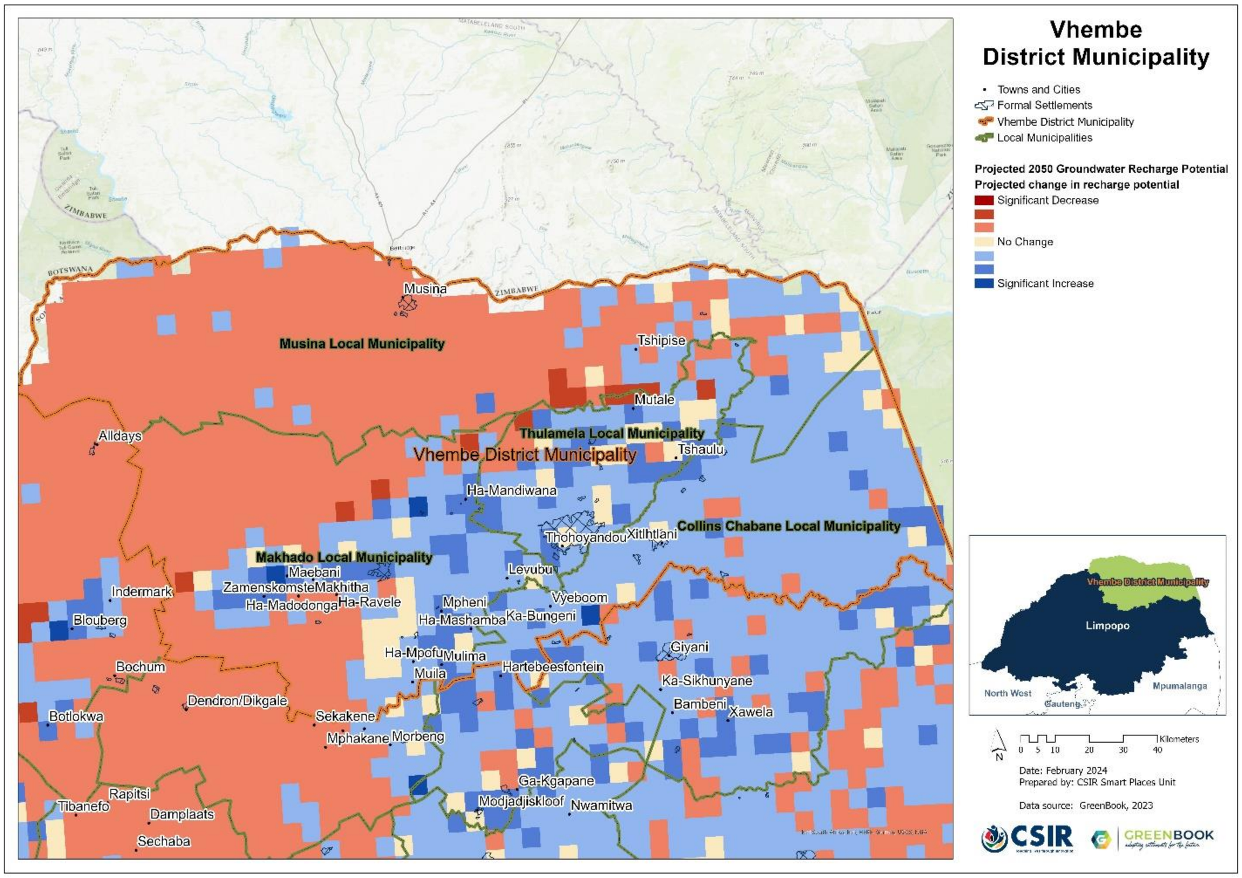

Figure 31: Projected changes in groundwater recharge potential from baseline climatic conditions to the future across Vhembe District Municipality

At the baseline, large parts of the Vhembe district, particularly the eastern parts pf Makhado LM, as well as Thulamela and Collins Chabane LMs, have high groundwater recharge potential. The local municipality of Musina has a relatively low recharge potential (Figure 30). Groundwater recharge potential is expected to increase in areas that currently have a high recharge potential (Figure 31). According to projections (Figure 32), no settlement in Vhembe faces a high risk of groundwater depletion into a climate changed future (2050).

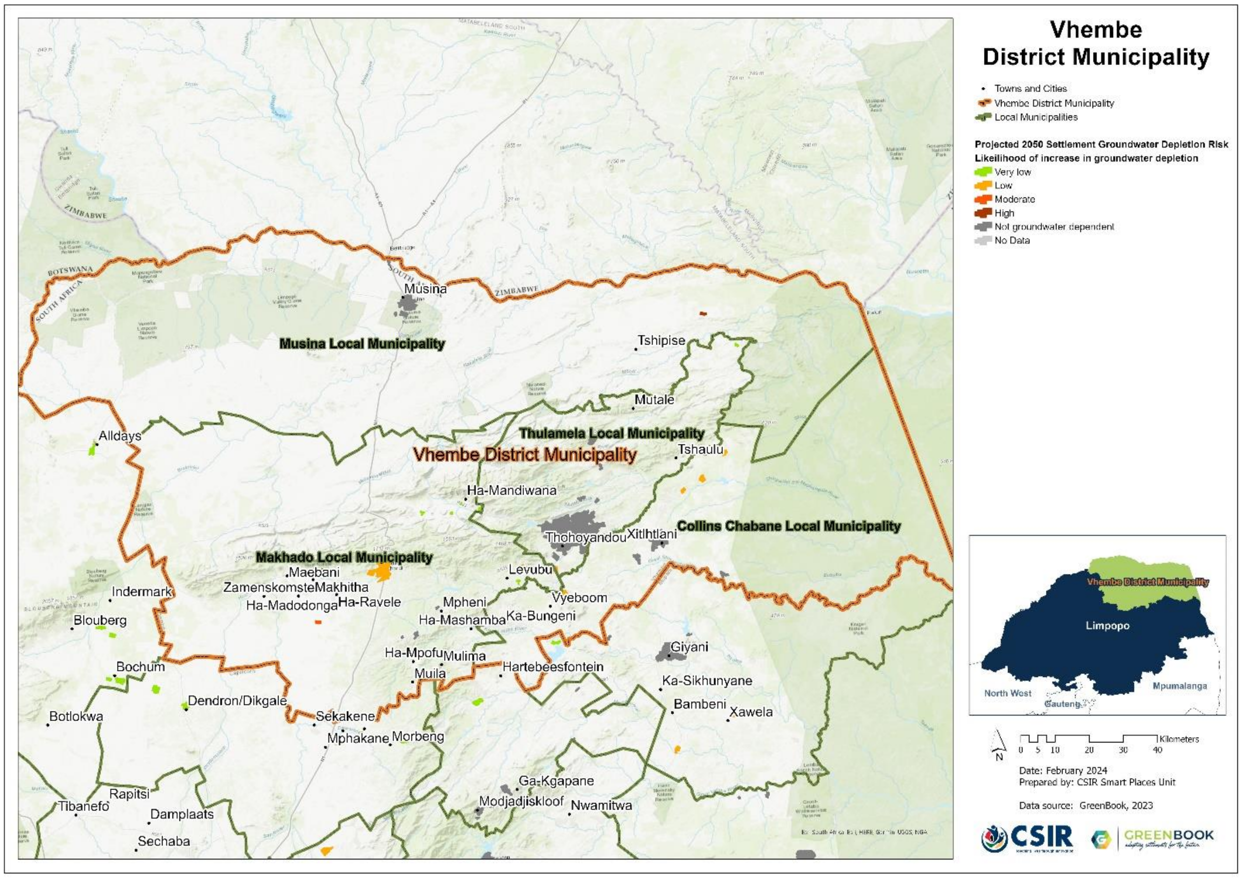

Figure 32: Groundwater depletion risk at settlement level across Vhembe District Municipality

Table 3 provides an overview of current water supply vulnerability (i.e., demand versus supply) for the local municipalities in the Vhembe district 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 3: Current water supply and vulnerability across Vhembe District Municipality

Local Municipality	Water Demand per Capita (l/p/d)	Water Supply per Capita (l/p/d)	Current Water Supply Vulnerability
Collins Chabane	No data	No data	No data
Makhado	87.49	91.83	0.95
Musina	148.71	283.21	0.53
Thulamela	163.74	205.74	0.8

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 the 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. See the GreenBook Municipal Risk Profile Tool for more information on surface water, change in precipitation, runoff, and evaporation. Water supply vulnerability per local municipality is discussed below.

Collins Chabane

Water supply vulnerability data is currently not available for the Collins Chabane LM on the GreenBook website.

Makhado

Water supply vulnerability is currently relatively low (see Table 3), but because of the projected decline in mean annual precipitation, combined with an increase in mean annual evaporation, water supply vulnerability is projected to increase into the future (at least up to 2050).

Musina

Water supply vulnerability is currently low (see Table 3), but is projected to increase into the future due to a decrease in mean annual precipitation, as well as an increase in mean annual evaporation and population growth.

Thulamela

Water supply vulnerability is low (see Table 3) but is expected to increase slightly by 2050 due to increased mean annual evaporation and population growth. However, despite the projected slight increase, the Municipality's water supply vulnerability score is projected to remain under 1, in case of a medium growth scenario.

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 with regard to the industries served, and also 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 has been 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.

The Agricultural sector contributed 3 % to the district's GVA in 2018 (CoGTA, 2020). Moreover, 28 % of small, medium and micro enterprises (SMMEs) in the district operated within this primary sector. Therefore, the potential impact of climate change and climate hazards on agriculture is notable considering the contribution this sector makes to support livelihoods of the local residents. The main commodities farmed in the district include citrus, avocado, macadamia, mango, banana, litchi, and garlic (VDM, 2023).

Below, the main agricultural commodities for each local municipality within the district is discussed in terms of what the impact of climate change might be on those commodities under an RCP 8.5 low-mitigation "business as usual" greenhouse gas emissions scenario.

Collins Chabane

In the Collins Chabane LM, the AFF sector contributes 1.78 % to the local GVA, which is a contribution of 0.12 % to the national GVA for the AFF sector. Of the total employment, 7.41 % is within the AFF sector. The main agricultural commodities are subtropical fruit, beef cattle and maize for grain. Climate projections show a hotter and drier climate, but wetter towards end of century with more extreme rainfall events. While high temperatures will result in increased evaporation and irrigation requirements for subtropical fruit, extreme temperatures will also contribute to poor tree flowering and fruit set, and ultimately lead to decreases in production. The hot and drier climate will also result in the deterioration of veld/forage quality and quantity for the beef cattle, as is commonly associated with declining rainfall. Heat stress may also result in reduced growth and reproduction performance in cattle. The decline in rainfall and increasing temperatures will also likely lead to maize yield reductions.

Makhado

In the Makhado LM, 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 agricultural commodities are also subtropical fruit, beef cattle, and maize for grain. Climate projections show a generally hotter and wetter climate with more extreme rainfall events. While hot and moist conditions will likely increase the exposure of subtropical fruit to pests and diseases, extreme temperatures can also contribute to poor tree flowering, fruit set and decreases in production. Hot and moist conditions could also result in increased spread of disease and parasites for cattle, as well as reduced growth and reproduction performance due to heat stress. However, increased water availability will improve the quality and quantity of veld/forage for cattle. More extreme rainfall events may result in potential increases in maize yield for the near future. However, towards 2050, heat stress can negatively impact on production.

Musina

In the Musina LM, 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 agricultural commodities are citrus and subtropical fruit, as well as cotton. Climate projections show a generally hotter and drier climate, but wetter towards the end of the century (2100). For citrus, the projected climate will likely result in increased evapotranspiration and irrigation requirements, at least until towards the end of the century. However, an increase in temperature will benefit a more heat-tolerant disease vector. For subtropical fruit, the projected climate will lead to increased evaporation and irrigation requirements. Moreover, extreme temperatures contribute to poor tree flowering, fruit set and decreases in production. With regard to cotton, the projected climate will likely result in increased evapotranspiration and irrigation requirements. However, cotton production remains viable subject to water availability.

Thulamela

In the Thulamela LM, the AFF sector contributes 1.19 % to the local GVA, which is a contribution of 0.19 % to the national GVA for the AFF sector. Of the total employment, 3.36 % is within the AFF sector. The main agricultural activities are beef cattle, citrus and maize for grain. Climate projections show a generally hotter and drier climate, but wetter towards end of century with more extreme rainfall events. For beef cattle, the projected climate could result in the deterioration of veld/forage quality and quantity, which is associated with declining rainfall. This will also likely lead to reduced growth and reproduction performance, due to heat stress. For citrus, the projected climate will likely result in increased evapotranspiration and irrigation requirements. However, an increase in temperature will benefit a more heat-tolerant disease vector. For maize, the projected climate will likely result in yield reductions due to the decline in rainfall and increasing temperatures.

3. Recommendations

The greatest risk faced across the Vhembe district are increasing temperatures, heat extremes and drought, with the increasing risk of wildfires threatening several settlements in the district into the future (2050). The district also has very high economic vulnerability (EcVI) and physical vulnerability (PVI) – with all local municipalities in the Vhembe district recording above national average EcVI and PVI scores. The high unemployment rate, as well as the extreme remoteness of a large number of the settlements in the district (as indicated by their high regional connectivity vulnerability), are evidence of these vulnerabilities. This means that Vhembe's economy and settlement fabric is highly susceptible to the adverse consequences of external shocks, including those induced by climate hazards; therefore, highlighting the importance of building the adaptive capacity and resilience of the district's local economy and physical make-up, including regional connectivity and settlement fabric, to the future climate. Three quarters of the district also have very high environmental vulnerability (EnVI), with three of the four LMs in the Vhembe district recording above national average EnVI scores. This is indicative of the increasing conflict between preserving Vhembe's rich and diverse natural environment (see DEA, 2018 and https://www.ramsar.org/) and accommodating growth pressures associated with urbanisation, population growth and economic development.

The rainfall in large parts of the district is expected to decline into a climate-changed future (2050), therefore threatening the DM's water security – especially considering its heavy reliance on surface water resources. It is also important to address the impact of climate change on the agricultural sector, especially considering that 28 % of SMMEs in the district operate within this primary sector (VDM, 2023).

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), heat extremes and drought tendencies will have on Vhembe district's future water supply (in addition to the projected decrease in rainfall) – developing comprehensive strategies for water resource management is crucial. As part of these strategies, the VDM and its local municipalities 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 and promote

the uptake of alternative water sources such as rainwater (harvesting), groundwater (recharge and extraction), and wastewater (reuse).

2. To protect natural resources and ecosystems: Considering the diversity and international significance of Vhembe's natural environment – it is critical to protect the natural resources and ecosystems found in the district. Protecting and restoring natural ecosystems such as wetlands and riparian areas, will maintain (and eventually enhance) Vhembe's biodiversity, support water resource management, and provide natural buffers against climate-related hazards such as wildfires and surface water flooding. Some of the actions that could be taken to realise this goal include establishing or expanding protected areas, enforcing regulations against harmful practices in such areas, and promoting the sustainable use of natural resources.

3. To reduce the exposure and vulnerability of human systems to climate change and extreme weather events: Considering the diversity and international significance of Vhembe's natural environment – it is critical to protect the natural resources and ecosystems found in the district. Protecting and restoring natural ecosystems such as wetlands and riparian areas, will maintain (and eventually enhance) Vhembe's biodiversity, support water resource management, and provide natural buffers against climate-related hazards such as wildfires and surface water flooding. Some of the actions that could be taken to realise this goal include establishing or expanding protected areas, enforcing regulations against harmful practices in such areas, and promoting the sustainable use of natural resources.

4. 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 residents: 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. Furthermore, efforts to create more inclusive economies, that also provide job opportunities at all skill levels, may involve training programmes 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). In so doing, some of the district's KPAs, i.e., KPA 2 on economic development and its associated strategic objective of 'creating an enabling environment to attract investment and generate economic growth and job creation' – can be met. Furthermore, considering the impact of the agricultural sector on SMMEs (and by extension livelihoods) in the district – it will be to the benefit of those who rely on this sector for employment, sustenance and economic development (wealth generation), to increase its resilience to the impacts of climate change. This can be done by providing

farmers with (i) access to resilient crop varieties and efficient irrigation systems; (ii) training in sustainable farming techniques; (iii) financial risk management tools; and (iv) market opportunities, i.e., to help the agricultural sector withstand shocks and stresses such as climate change impacts, market fluctuations, and pest outbreaks.

These goals should be pursued with the understanding that the district's climate risks are likely to increase due to climate change. Hence, any actions taken need to remain adaptable to the evolving risks over time. Furthermore, while these recommended goals are not exhaustive, they can be enhanced by strategies tailored to the specific needs of VDM. The key to success lies in integrating these goals and the principles behind them into all aspects of municipal decision-making and operations, as well as in actively engaging communities in these initiatives.

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