



# GREENBOOK

*adapting settlements for the future*



## Thohoyandou Node Climate Risk Profile Report

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## List of Acronyms and Abbreviations

°C	Degree Celsius
AFF	Agriculture, Forestry, and Fisheries
AR5	Fifth Assessment Report
CABLE	CSIRO Atmosphere Biosphere Land Exchange model
CBA	Critical Biodiversity Areas
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
DWS	Department of Water and Sanitation
EcVI	Economic Vulnerability Index
EnVI	Environmental Vulnerability Index
ESA	Ecological Support Areas
GCM	General circulation model
GDP	Gross Domestic Product
GRiMMS	Groundwater Drought Risk Mapping and Management System
GVA	Gross Value Added
ICT	Information and communications technology
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
SDF	Spatial Development Framework
SEVI	Socio-Economic Vulnerability Index
SPI	Standardised Precipitation Index
SPLUMA	Spatial Planning and Land Use Management Act, 2013 (Act No.16 of 2013)
THI	Temperature Humidity Index
TLM	Thulamela Local 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	<p>“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).</p>
Sensitivity	<p>“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).</p>
Vulnerability	<p>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).</p>

## 1. Introduction

This Climate Risk Profile report, as well as the accompanying Adaptation Actions Plan, were developed specifically for the Thohoyandou Node, a Priority Human Settlement and Housing Development Area (PHSHDA) located in the Thulamela Local Municipality, 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 | Adapting settlements for the future](#)).

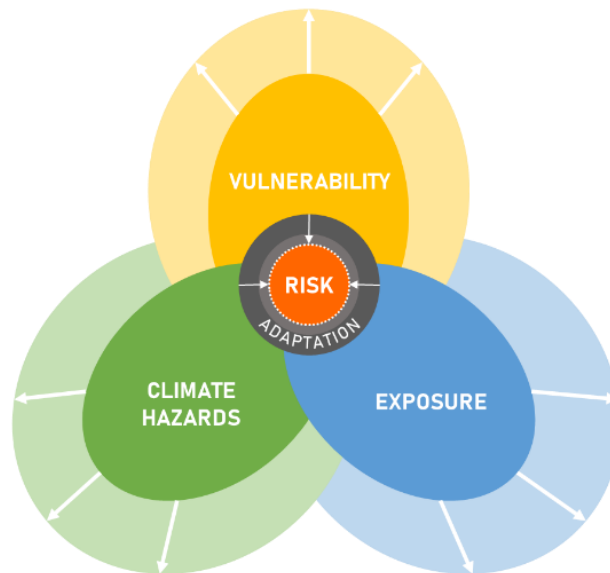
The purpose and strategic objectives of the Climate Risk Profile and the Adaptation Actions Plan are to:

- Build and further the climate change response agenda,
- Inform strategy and planning in the 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, the Thulamela Local Municipality's, and Thohoyandou Node'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 Local Municipality and PHSHDA, 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 Municipality's 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 the Local Municipality and PHSHDA, in particular. The greatest risks faced across Thohoyandou Node are increasing temperatures and wildfires, with the risk of heat extremes and drought becoming greater towards 2050.

## 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 PSHDA, as well as the Local Municipality in which the PSHDA 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 PSHDA falls within a settlement, the local municipal and settlement level

risk profile will be 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 Thohoyandou Node is located in the Thulamela Local Municipality, one of four Local Municipalities in the Vhembe District. Thulamela Local Municipality is situated in the centre of the District Municipality and is bordered by Musina Local Municipality in the north, Makhado Local Municipality in the west and southwest, as well as Collins Chabane Local Municipality in the east and southeast (TLM, 2020). Thulamela Local Municipality covers an area of approximately 2 893.94 km<sup>2</sup>, which accounts for 10.35% of the District Municipality's geographical area, thus making it the smallest Local Municipality in the Vhembe District (TLM, 2020).

Thulamela Local Municipality is home to both urban (formalised) and rural settlements/areas, with a road infrastructure network that comprises of Provincial, District and Local roads (HDA,

2022). The three main roads linking the various settlements within the Municipality, as well as connecting them to other major roads and areas outside the Municipal Area are the R523, R524 and P22/1 roads. The R524 road is the busiest, and directly links Thulamela to two other Local Municipalities in the Vhembe District, including Collins Chabane and Makhado Local Municipalities (TLM, 2020).

In 2011, about 460 333 people resided in the settlements found within Thulamela Municipal Area. This settlement-based population is expected to increase by 22.73% between 2011 and 2030. In 2016, the Local Municipality recorded a population of 497 237, about 35.67% of the total population in District, therefore making Thulamela the most populous Local Municipality in the Vhembe District, as well as the second most populous Municipality in the Province of Limpopo (TLM, 2020).

The Local Municipality's Gross Domestic Product (GDP) grew to R 19.4 billion in 2019, which is a contribution 30.57% to Vhembe District Municipality's GDP, and 5.06% to that of the Province. Major economic sectors include Wholesale and Retail Trade, as well as the informal sector, which relies on the Agricultural sector as its competitive advantage (HDA, 2020). In 2011, the Thulamela Local Municipality recorded an unemployment of 43,8% (Stats SA, 2023).

Thulamela Local Municipality is home to various ecological, cultural and heritage assets, including biodiversity areas, which comprise of Protected areas, Critical Biodiversity Areas (CBAs) and Ecological Support Areas (ESAs), as well as rivers, dams, and indigenous and sacred sites – which could be leveraged to reduce the unemployment burden, particularly through tourism. Protected areas include the Makuya, Mphaphuli, N'wanedi, and Mutavhatsindi Nature Reserves, as well as the Thohoyandou Botanical Garden. CBAs are all the areas located outside of formal protected areas, with the highest biodiversity value. The Local Municipality's ESAs, which play an important role in supporting the ecological functioning of CBAs and delivering ecosystem services, are mainly situated within the already built-up areas of Municipality, including Thohoyandou and Sibasa (HDA, 2022). These areas are also home to ecological assets that often act as natural buffers against the impacts of climate change.

Additional assets leveraged by the Tourism sector include the Local Municipality's various natural falls and springs; the Luvuvhu River and its tributaries; Nandoni, Fundudzi and other local dams; Tshatshingo potholes and neighbouring attractions; the University of Venda; Phiphidi, and Tshirovha Waterfalls; Tusk Hotel and Casino; as well as various other cultural places, business and infrastructure. The Luvuvhu catchment, which serves the Local Municipality, is the second-largest catchment in the Vhembe District, and all rivers in the District Municipality flow into Luvuvhu before joining the Limpopo River (HDA,2022).

The Local Municipality is also home to two major regional growth points, including Thohoyandou – within which the Thohoyandou Node (PHSHDA) lies – and Sibasa. Thohoyandou is located in the south-central parts of Thulamela Local Municipality and is classified in terms of the Limpopo

Spatial Development Framework (SDF) as a Provincial Growth Point. The node serves all settlements within the Thulamela Municipal Area, as well as several other Local Municipalities within the Vhembe District, plus the wider region. The area has an established and diverse economy, with a range of high order social and government services. Moreover, the area has been earmarked for government infrastructure investment (HDA, 2022).





## 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 Thulamela Local Municipal Area, and Thohoyandou Node (PHSHDA) in particular, 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 Thulamela Local Municipality and its settlements – including the settlement of Thohoyandou, parts of which lie within the PSHDA – 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 Thulamela Local Municipality 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 Thulamela Local Municipality.

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, as well as 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.

Thulamela Local Municipality is 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 Thulamela Local Municipality*

MUNICIPALITY	SEVI 1996	SEVI 2011	Trend	EcVI 1996	EcVI 2011	Trend	PVI	Trend	EnVI	Trend
Thulamela	4.93	4.89	↓	4.98	6.22	↑	6.19	N/A	6.87	N/A

As outlined in Table 1, Thulamela Local Municipality's socio-economic vulnerability (SEVI) has decreased (improved) between 1996 and 2011 and is below the national average. Therefore, when compared to the national average, the Local Municipality houses a lower amount of socio-economically 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 (6.22). The Local Municipality's high unemployment rate, which stood at 43.8% in 2011, contributed to the score. However, there are numerous opportunities for economic diversification, particularly in the sectors of Agriculture, Logistics, Knowledge-Economy, Manufacturing and Tourism – which could reduce the Municipality's economic vulnerability (HDA, 2022).

Thulamela Local Municipality also has very high physical vulnerability (PVI), as well as the second highest environmental vulnerability (EnVI) score in the Province. These allude to the structural vulnerabilities present in the Municipality and (considering the limited road network and public transport available in the Municipality), the remoteness of settlements. The high environmental vulnerability (EnVI) score indicates the large presence of ecological assets in the

area, as well as the rising conflict between the need to preserve the natural environment and accommodate 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 settlement in which the PSHDA is to be found within the Thulamela Municipal Area, i.e., Thohoyandou, with regards to six composite indicators. This enables the investigation of the relative vulnerabilities of the settlement of Thohoyandou, 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 indicators, 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.

Figure 3 illustrates the multi-dimensional vulnerabilities of the settlements found within the Thulamela Municipal Area. This is followed by a brief description of the settlement vulnerability in Thohoyandou, compared to other settlements in the Local Municipality.

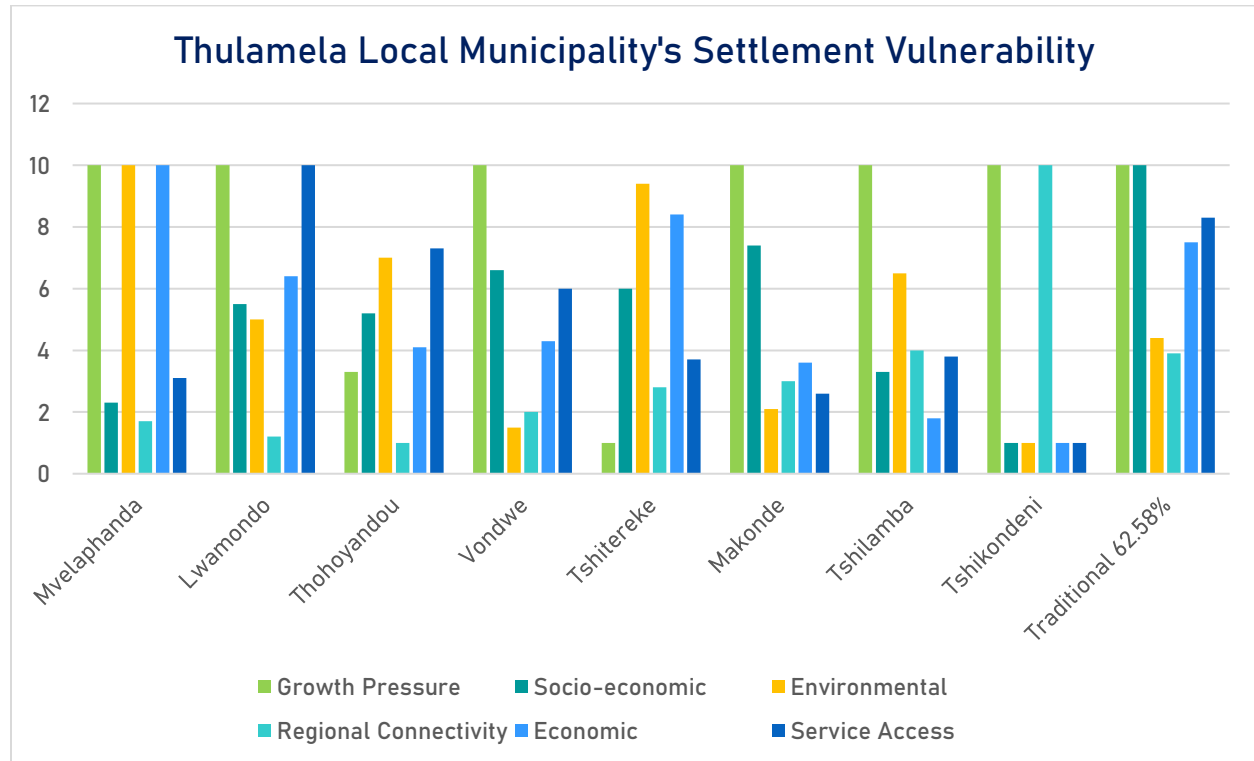


Figure 3: Thulamela Local Municipality's settlement vulnerability

The major settlements in Thulamela Local Municipality are Mvelaphanda, Lwamondo, Thohoyandou, Vondwe, Tshitereke, Makonde, Tshilamba, Tshikondeni and several traditional areas. The settlement of Thohoyandou has the lowest regional connectivity vulnerability, and when compared to all the other major settlements in the Local Municipality. Thohoyandou does not stand out in terms of the rest of the settlement vulnerability indices.

### 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 Thulamela Local Municipality

Municipal Population Growth	2011	Medium Growth Scenario	
		2030	2050
Thulamela Local Municipality	460 333	564 948	569 736

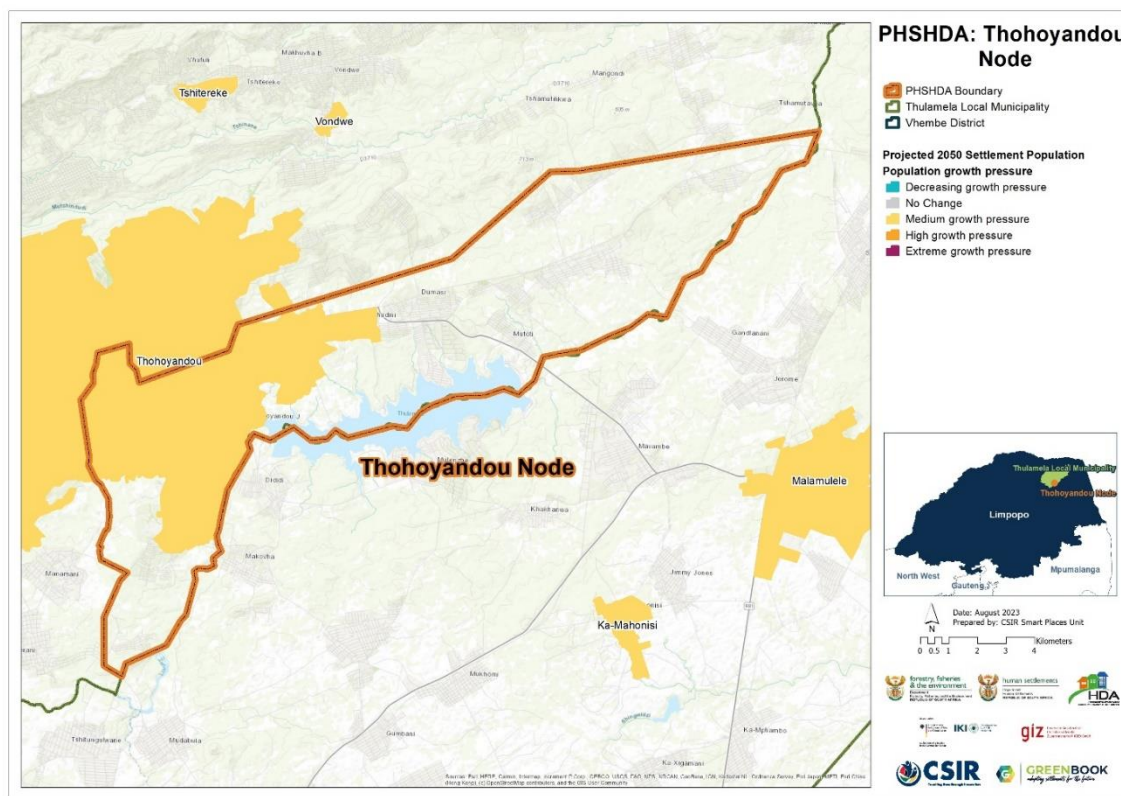


Figure 4: Settlement-level population growth pressure across Thohoyandou Node

Thulamela Local Municipality’s population is projected to increase by 23.77% between 2011 and 2050, under a medium growth scenario. Most of the growth will occur between 2011 and 2030. Figure 4 depicts the growth pressures that the settlement of Thohoyandou – parts of which lie within the Thohoyandou Node (PSHDA) – will likely experience. The map is accompanied by a

table that 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.

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

Thulamela Local Municipality				
Town	Pressure	2011	2030	2050
Mvelaphanda	Medium	4,013	5,130	5,181
Lwamondo	Medium	8,039	10,487	10,599
Thohoyandou	Medium	176,515	232,288	234,756
Vondwe	Medium	3,749	4,694	4,738
Tshitereke	Medium	7,220	8,834	8,908
Makonde	Medium	5,077	6,031	6,075
Tshilamba	Medium	8,407	10,009	10,082
Tshikondeni	No Change	97	108	108

As displayed in Figure 4 and outlined Table 3, almost all settlements across the Thulamela Local Municipality are projected to experience medium population growth pressure, under a medium growth scenario, including the settlement of Thohoyandou – parts of which lie within the PSHDA.

## 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<sub>2</sub> 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.



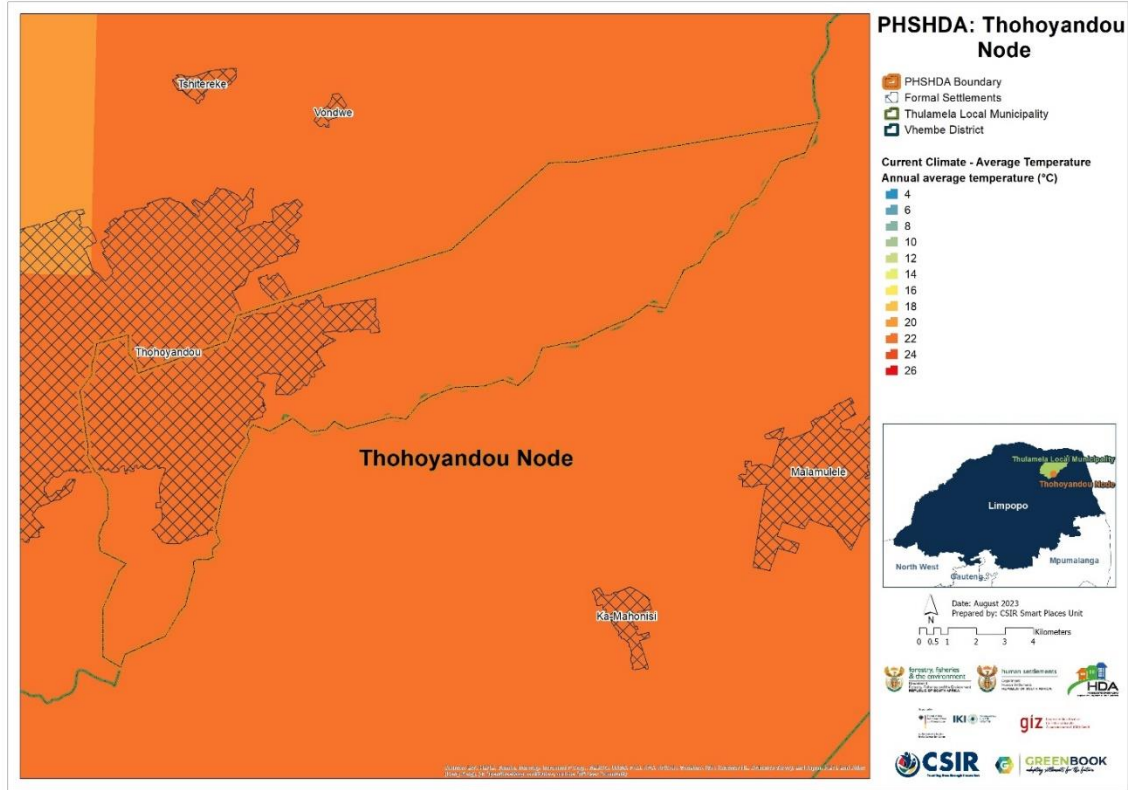


Figure 5: Average annual temperature (°C) for the baseline period 1961 – 1990 for Thohoyandou Node

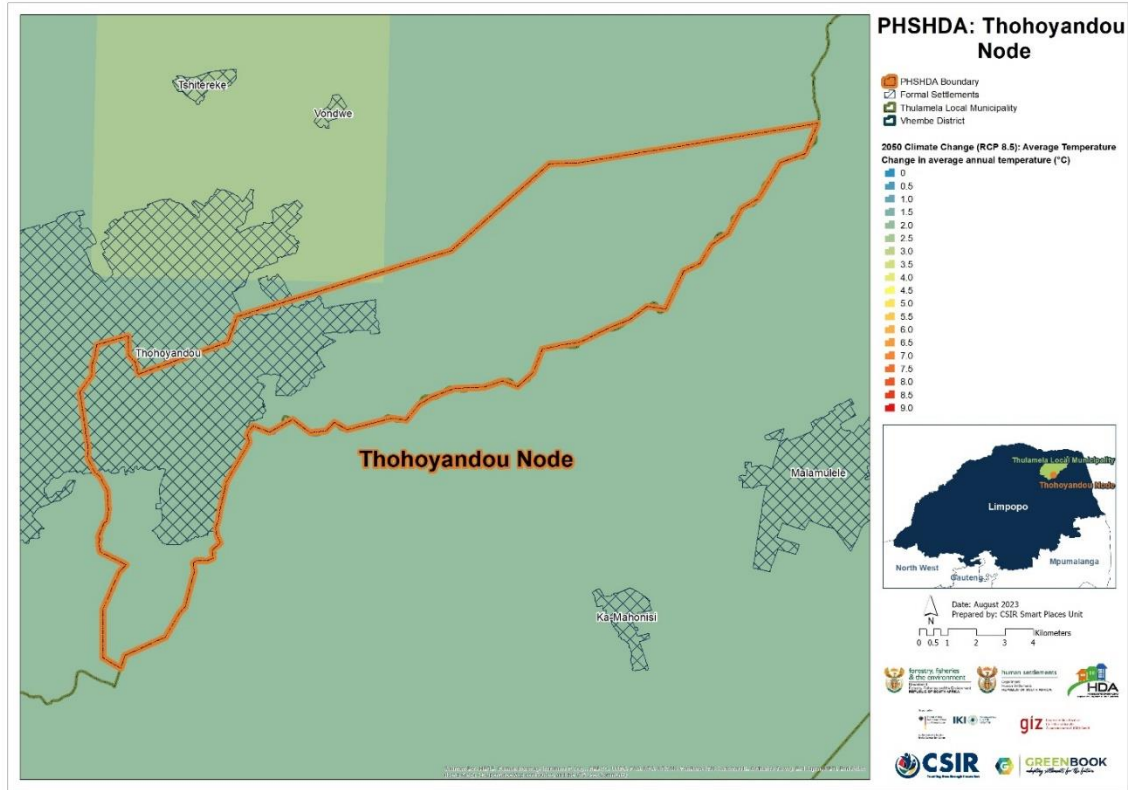


Figure 6: Projected change in average annual temperature (°C) from the baseline period to the period 2021 – 2050 for Thohoyandou Node, assuming an (RCP 8.5) emissions pathway

At the baseline (current), Thulamela Local Municipality experiences average annual temperatures of between 18 and 22 °C, with higher temperatures found in the eastern parts of the Municipality. The projections show average annual temperature increases of between 2.3 and 2.6 °C by 2050, under an RCP 8.5 “business as usual” emissions scenario. Thohoyandou Node (PHSHDA) experiences average annual temperature of 22 °C at the baseline (Figure 5); this is projected to increase by a little over 2°C, by the year 2050, assuming an RCP 8.5 low mitigation 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 10<sup>th</sup>, 50<sup>th</sup> and 90<sup>th</sup> 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.

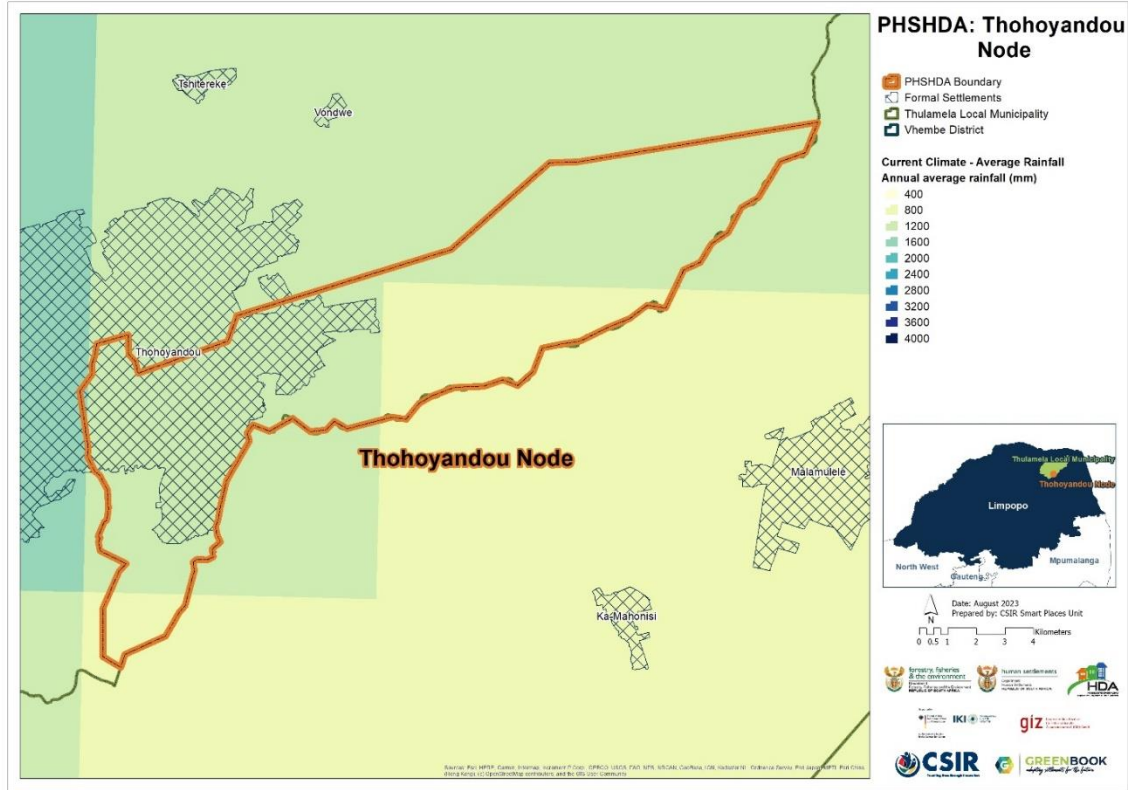


Figure 7: Average annual rainfall (mm) for the baseline period 1961 – 1990 for Thohoyandou Node

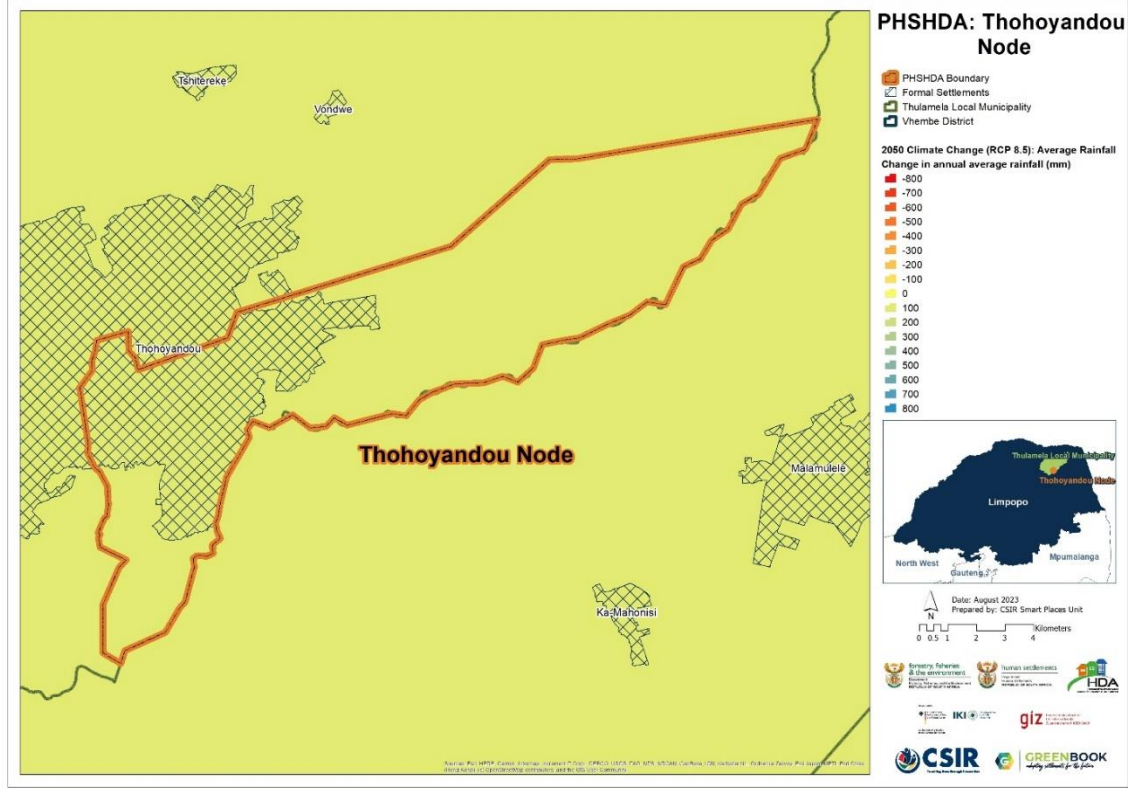


Figure 8: Projected change in average annual rainfall (mm) from the baseline period to the period 2021 – 2050 for Thohoyandou Node, assuming an (RCP 8.5) emissions pathway

Thulamela Local Municipality experiences current GCM derived average annual rainfall of between of 400 and 1 600 mm, with the southwestern parts of the Municipality receiving the most rainfall. The projections show changes in average annual rainfall of between 21 mm less and 40.48 mm more by 2050, under an RCP 8.5 “business as usual” emissions scenario. The Thohoyandou Node experiences current average annual rainfall of between 800 and 1 200 mm (Figure 7), with increases of less than 100 mm per annum projected for the area, by 2050 (Figure 8).

## 2.3. Climate Hazards

This section showcases information with regards to Thulamela Local Municipality and Thohoyandou Node’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 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 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. Figure 11 depicts the settlements that are at risk of increases in drought tendencies.



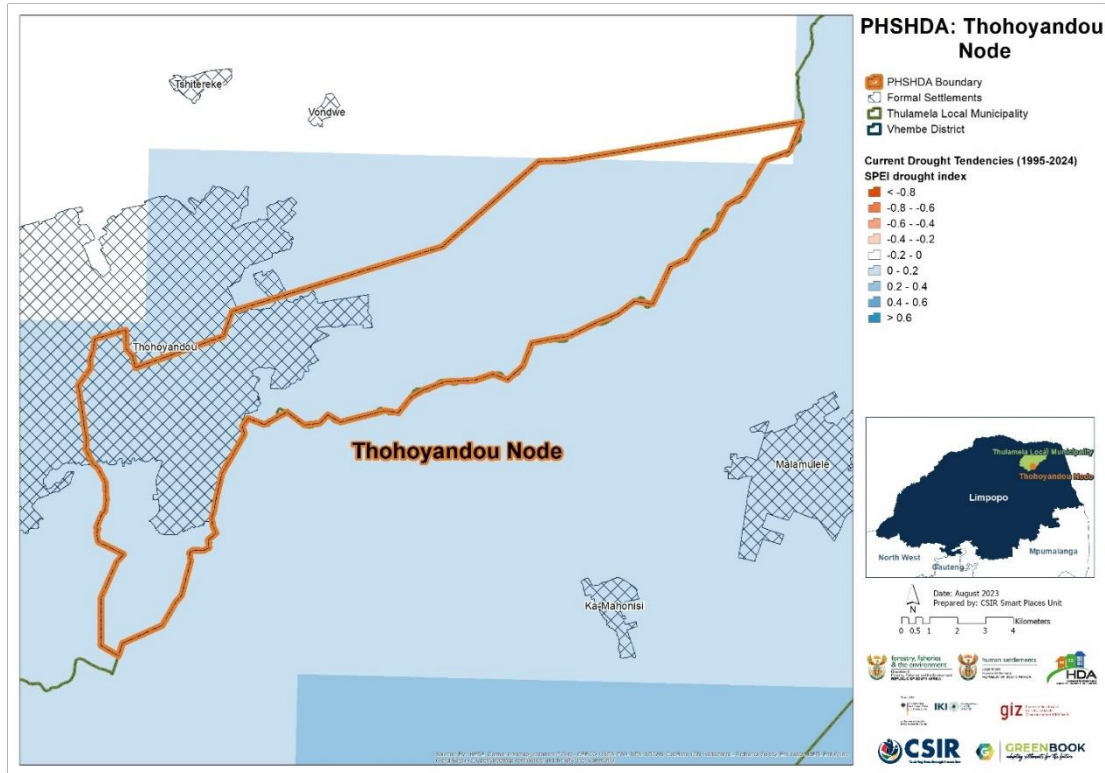


Figure 9: Projected changes in drought tendencies from the baseline period (1986 - 2005) to the current period (1995 - 2024) across Thohoyandou Node

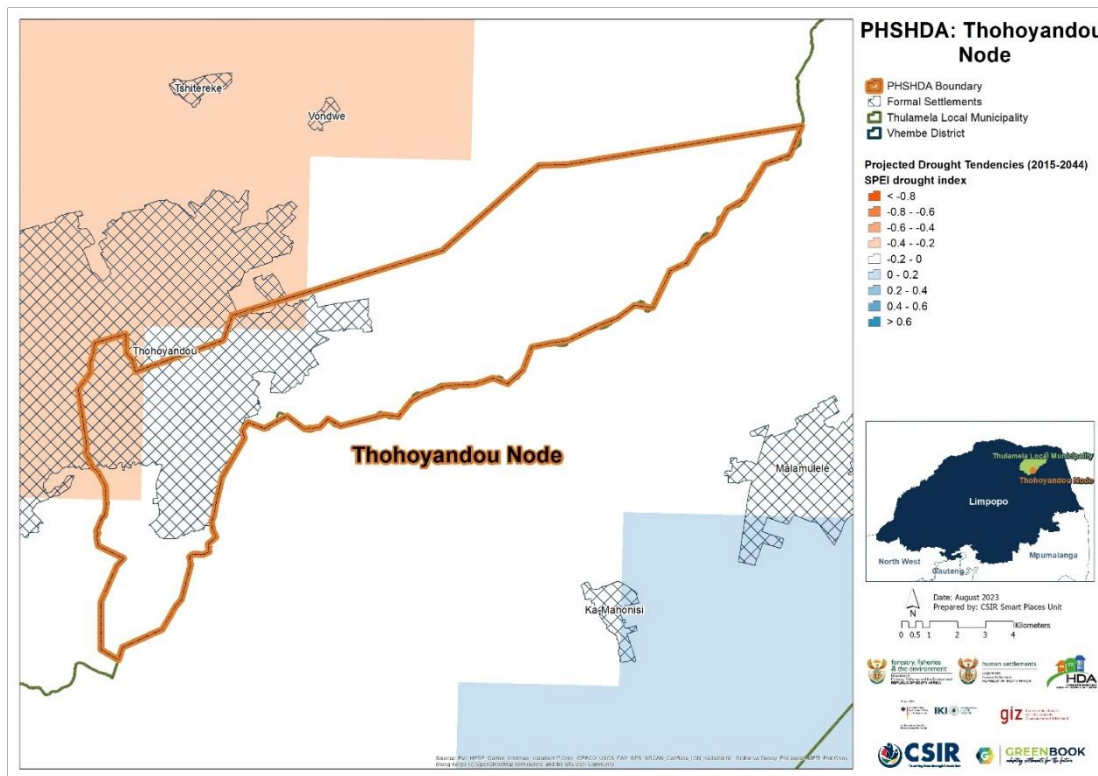


Figure 10: Projected changes in drought tendencies from the baseline period (1986 - 2005) to the future period (2015 - 2044) for Thohoyandou Node

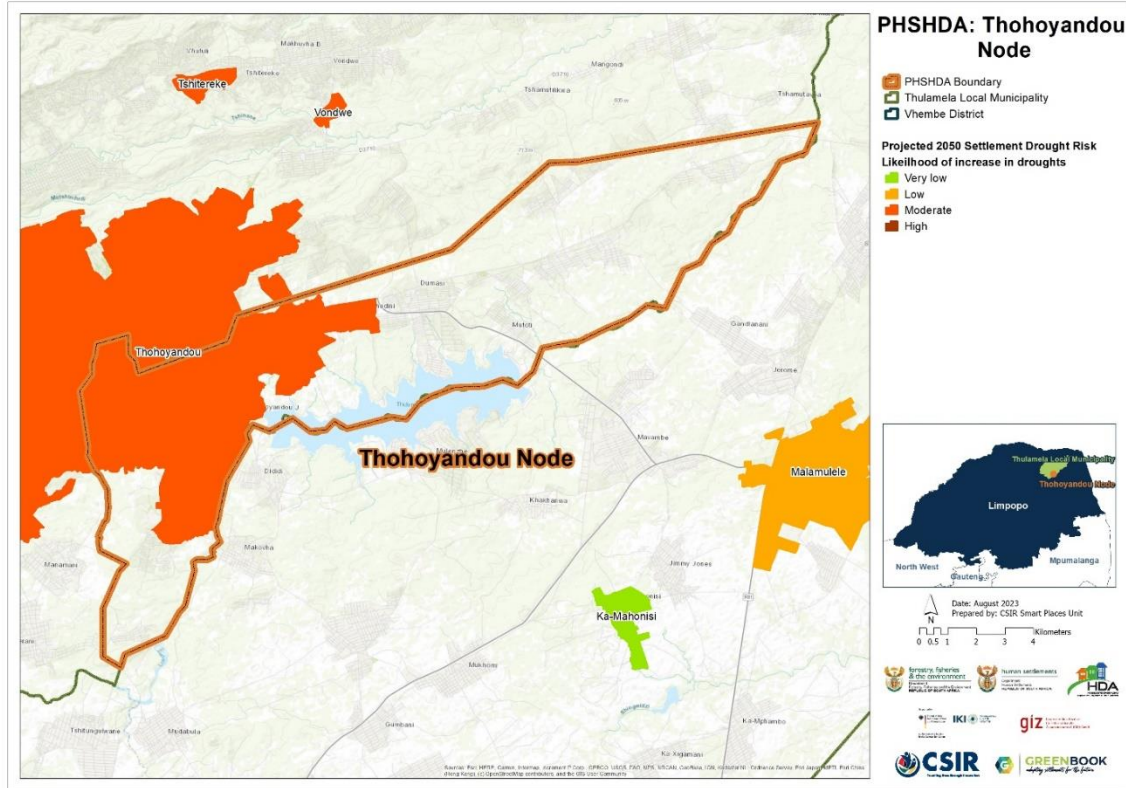


Figure 11: Settlement-level drought risk for Thohoyandou Node

At the baseline, large parts of Thulamela Local Municipality are exposed to drought tendencies, with higher tendencies found in the northern parts of the Municipality. More frequent and intense droughts are expected in the western parts of the Local Municipality by 2050. Thohoyandou Node (PHSHDA) experiences wet conditions under baseline conditions (Figure 9). These are expected to decline into a climate-changed future, at least up to 2050 (Figure 10). The settlement of Thohoyandou – parts of which fall within the PHSHDA boundary, i.e., Thohoyandou Node – faces a moderate risk of drought into the future (Figure 11).

2.3.2. Heat

The GCMs were used to simulate bias-corrected, annual average 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 12), and for the projected change for period 2021–2050 (Figure 13), assuming a “business as usual” (RCP 8.5) emissions pathway.

The annual heatwave days map under baseline conditions (Figure 14) 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 15), assuming a “business as usual” (RCP 8.5) emissions pathway, is also shown.

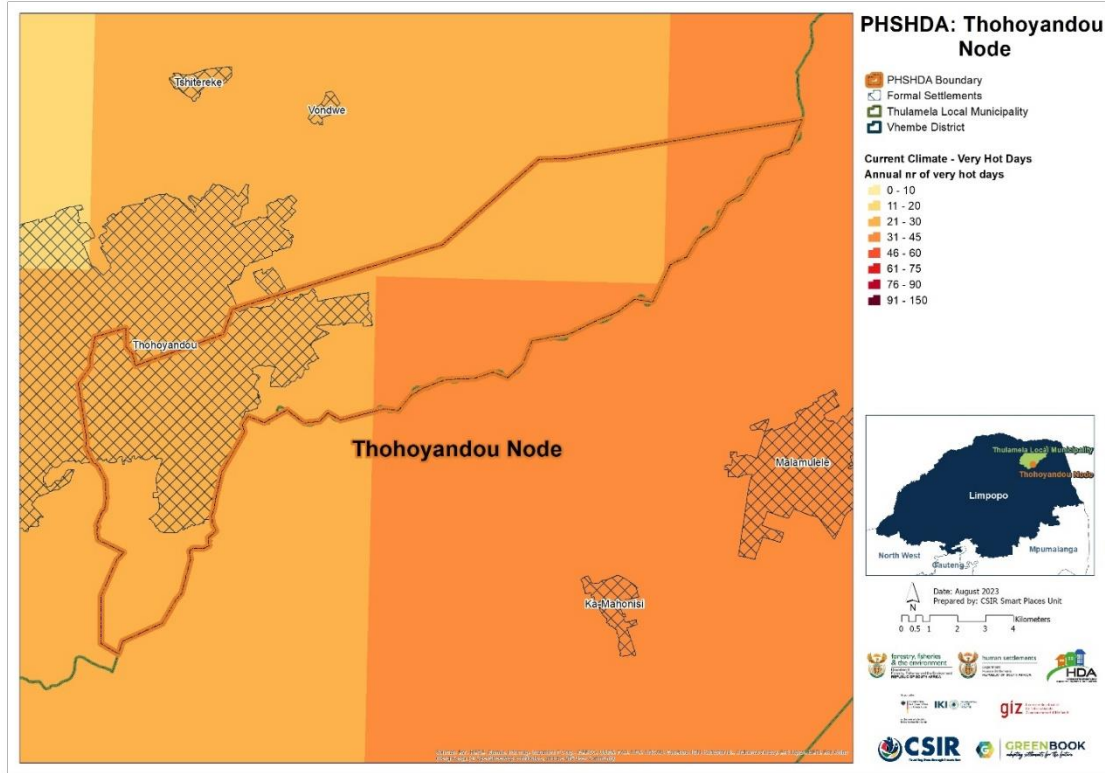


Figure 12: Annual number of very hot days under baseline climatic conditions across Thohoyandou Node with daily temperature maxima exceeding 35 °C

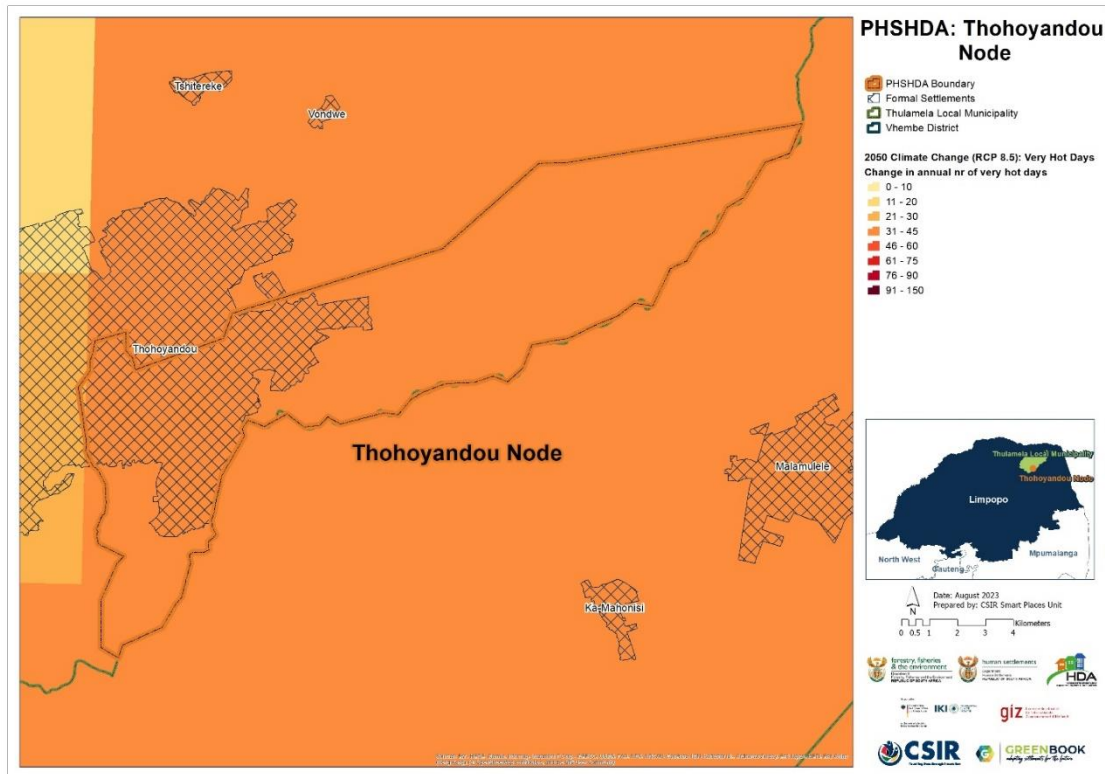


Figure 13: Projected change in annual number of very hot days across Thohoyandou Node with daily temperature maxima exceeding 35 °C, assuming an (RCP 8.5) emissions pathway



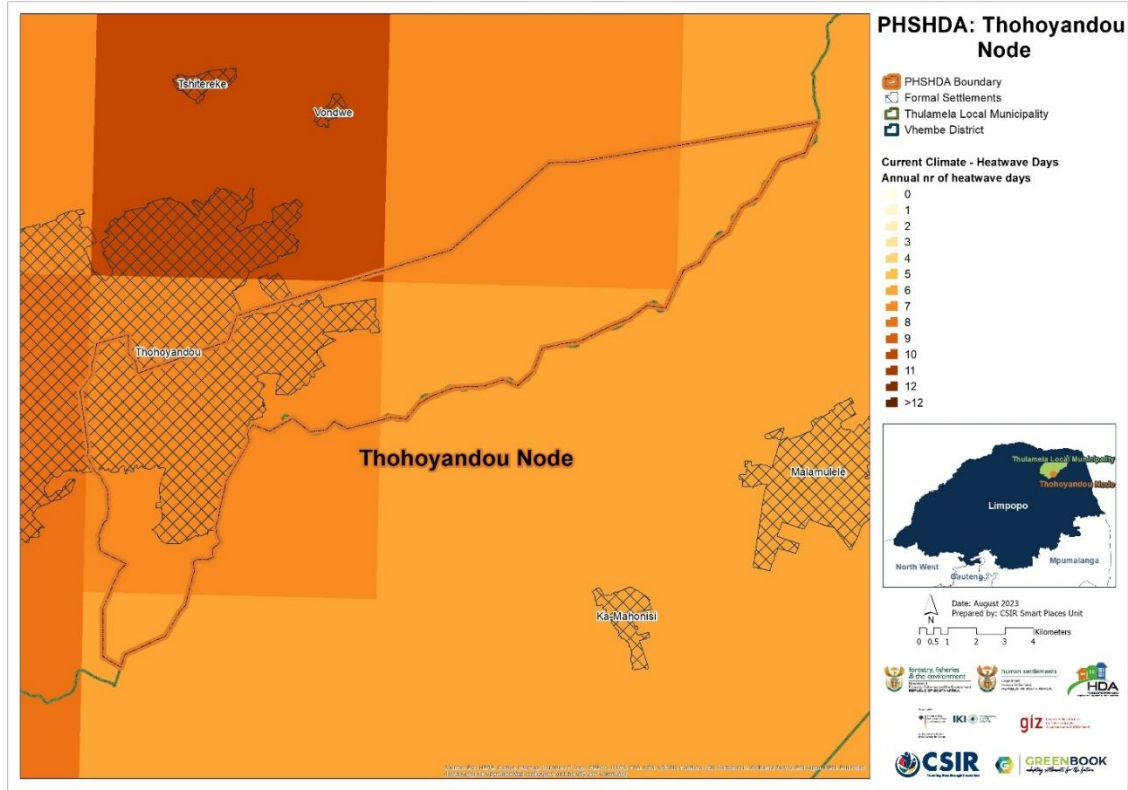


Figure 14: Annual number of heatwave days under baseline climatic conditions across Thohoyandou Node

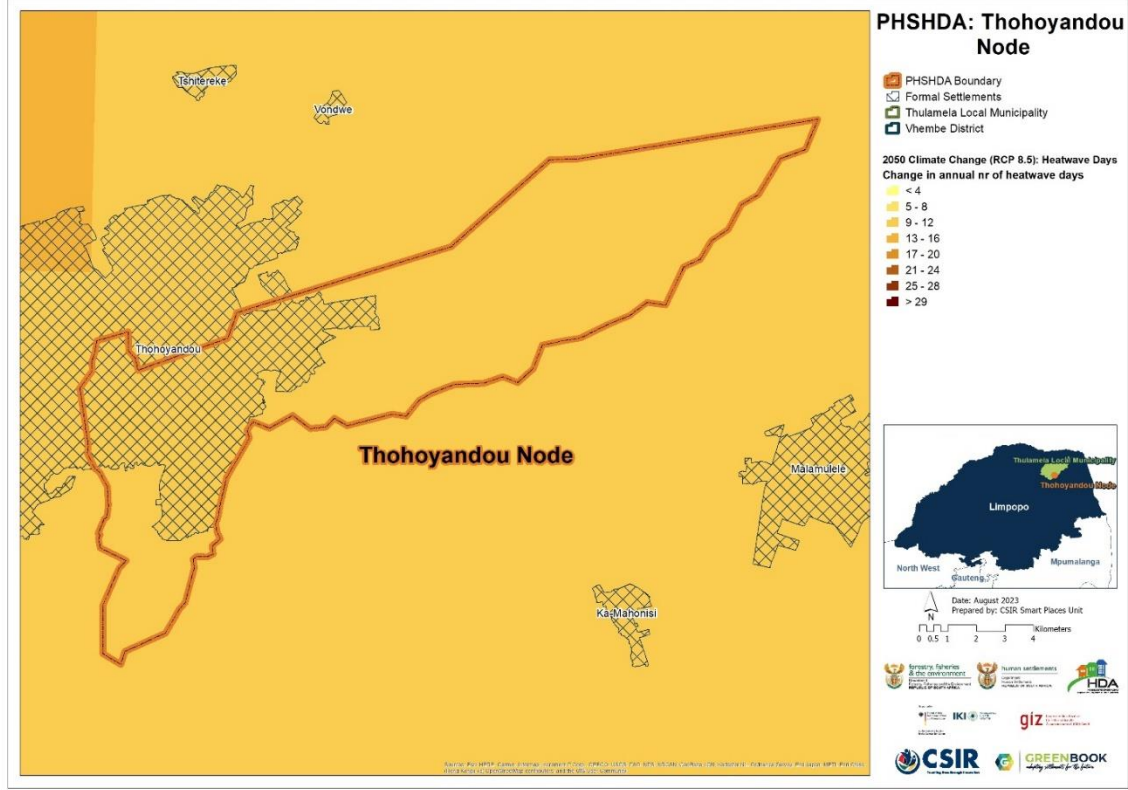


Figure 15: Projected change in annual number of heatwave days across Thohoyandou Node, assuming an (RCP 8.5) emissions pathway



Under baseline conditions, Thulamela Local Municipality experiences between 15 and 75 very hot days per year, these are expected to increase by between 10 and 44 days per annum by 2050, assuming an RCP 8.5 low mitigation scenario. Thohoyandou Node currently experiences around 21 to 45 very hot days per year (Figure 12). The annual number of very hot days is expected to increase by 31 to 45 days by 2050, under an RCP 8.5 emissions scenario (Figure 13). While the Local Municipality experiences between 5 and 10 heatwave days per year, Thohoyandou Node experiences between 5 and 9 heatwave days per annum (Figure 14). This number (for the PSHDA) is expected to increase by between 5 and 8 days per year, by 2050, under an RCP 8.5 “business as usual” emissions scenario (Figure 15).

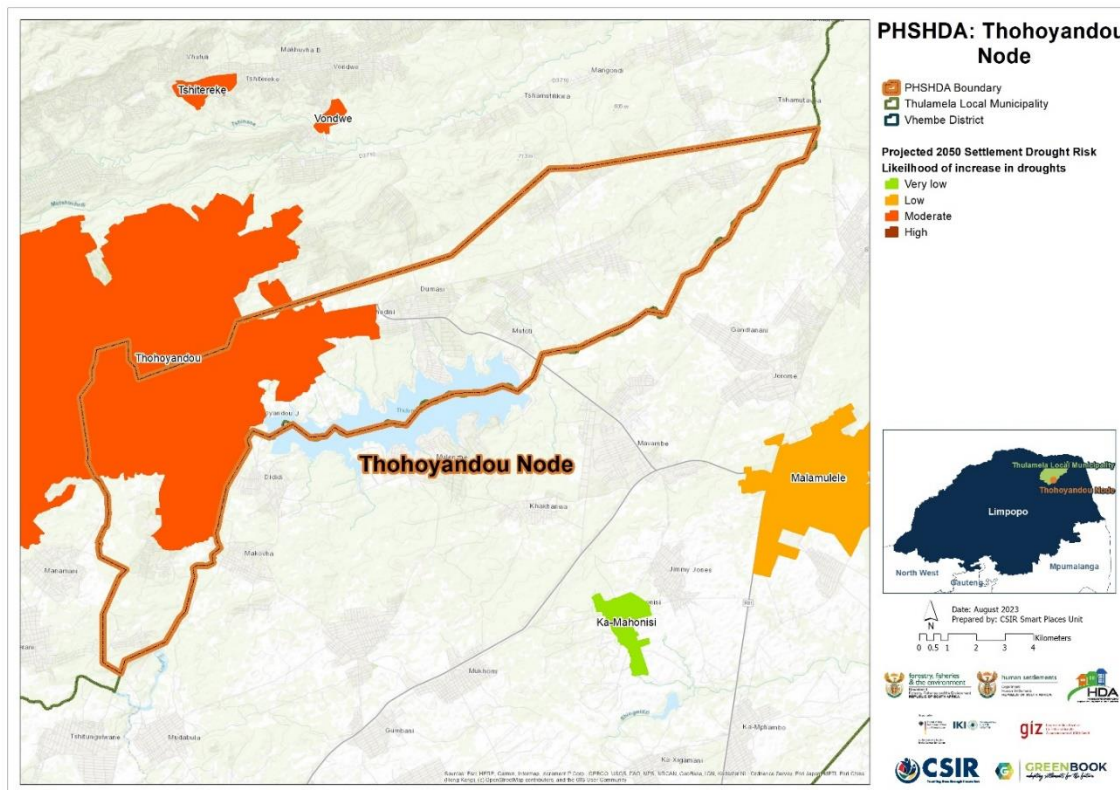


Figure 16: Settlement-level heat stress risk across Thohoyandou Node in the 2050s

Figure 16 depicts the settlements that are at risk of increases in heat risk. 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. As outlined in Figure 16, the settlement of Thohoyandou – parts of which lie within the PSHDA boundary – faces a moderate risk of heat stress into the future (2050).

### 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. Figure 17 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.

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. Figure 18 depicts the settlements that could be at risk of increases in wildfires by the year 2050.

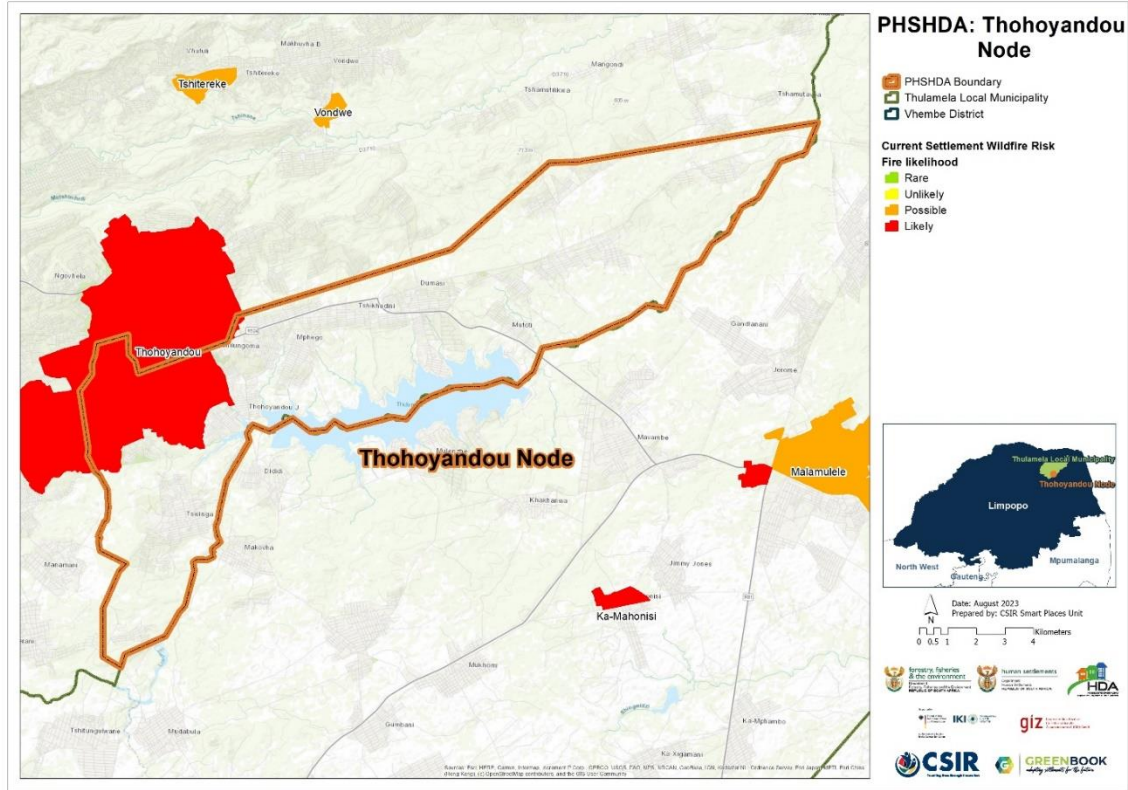


Figure 17: The likelihood of wildfires under current climatic conditions across settlements the Thohoyandou Node

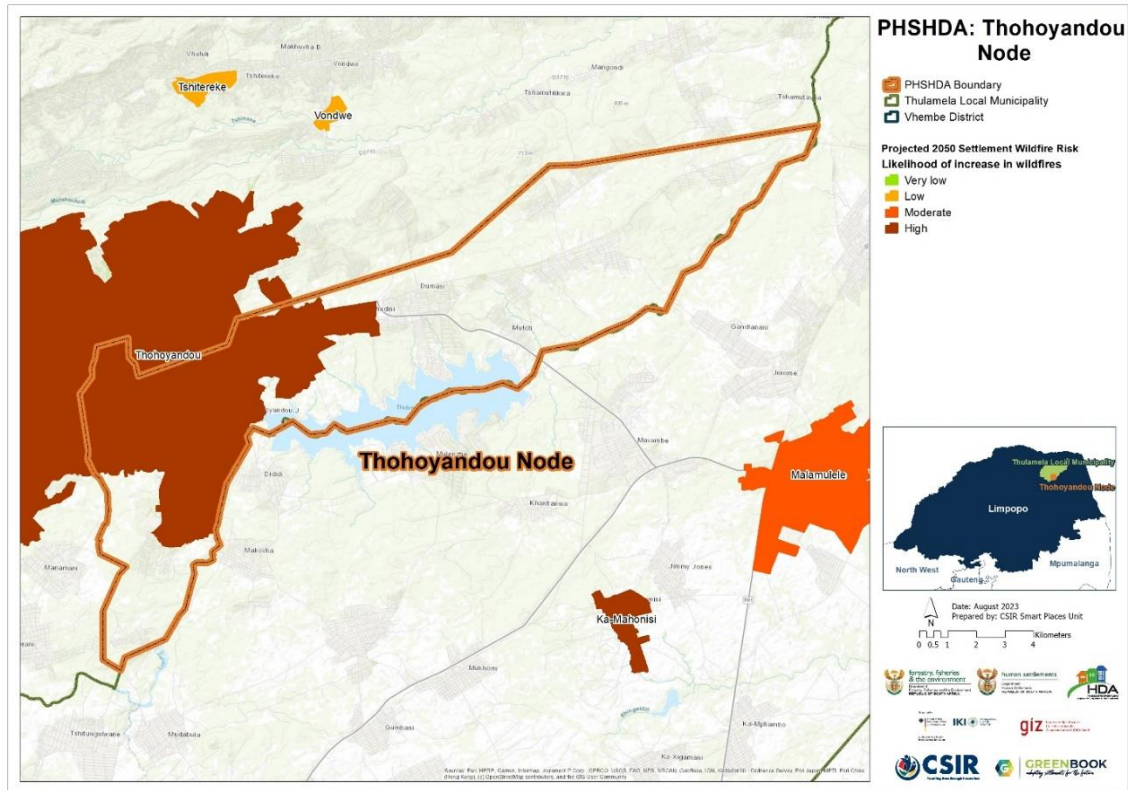


Figure 18: The likelihood of wildfires under projected climatic conditions across settlements in Thohoyandou Node

Figure 17 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, while Figure 18 depicts the settlements that could be at risk of increases in wildfires by the year 2050. Several settlements in the Thulamela Local Municipal Area – including Thohoyandou – face a high likelihood of wildfires on their wildland-urban interface, and it is projected that the same settlements face an increased risk of wildfires into a climate-changed future, at least up to 2050.

#### 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 19 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. There is significant variation of the flood hazard index across Thulamela Local Municipality. Large parts of the Municipality have a medium flood hazard index, while Thohoyandou Node has medium and medium to high flood hazard index.



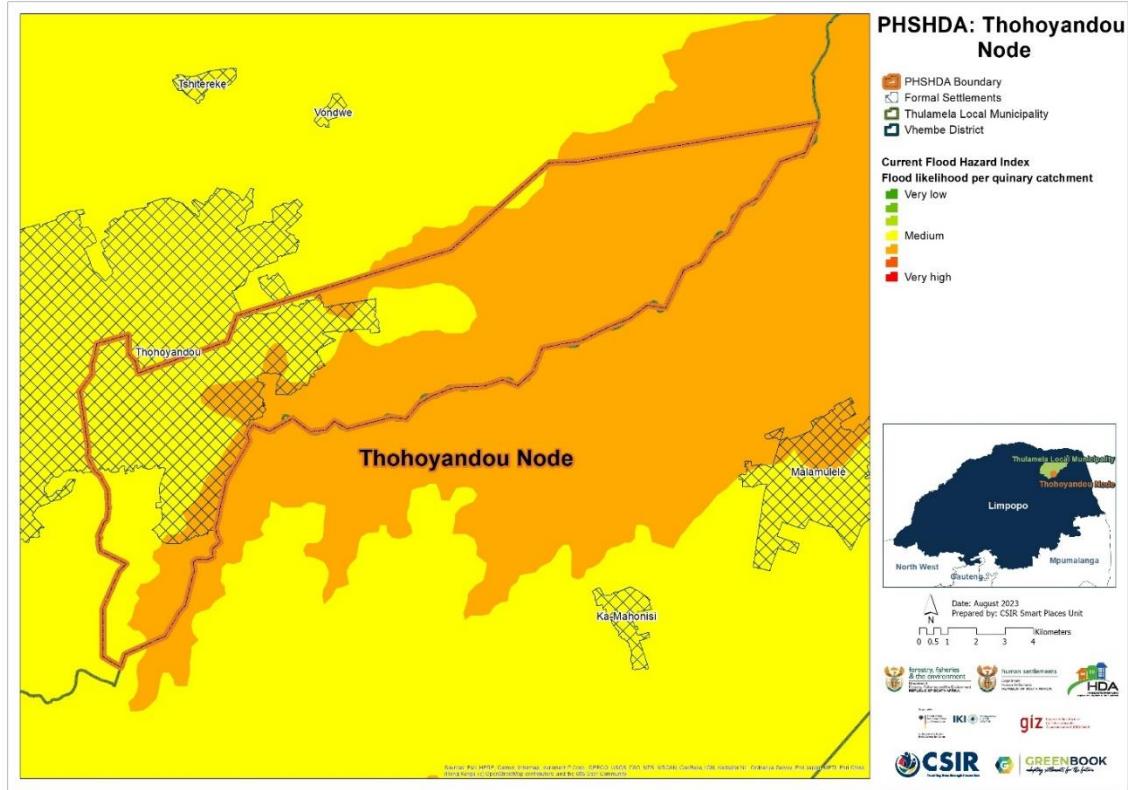


Figure 19: The flood hazard index across Thohoyandou Node under current (baseline) climatic conditions

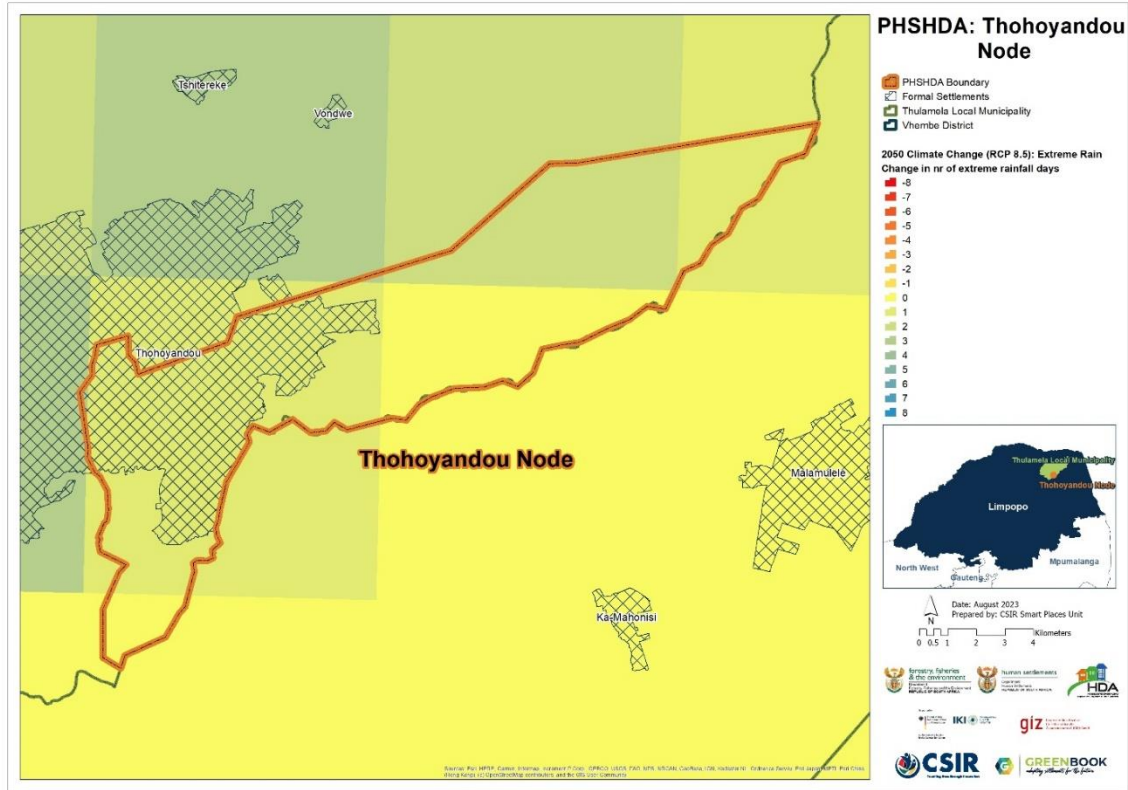


Figure 20: Projected change into the future in extreme rainfall days across the Thohoyandou Node

Figure 20 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., 95<sup>th</sup> 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. Large parts of Thulamela Local Municipality are projected to experience slight to moderate decreases in the annual number of extreme rainfall days, under an RCP 8.5 emissions scenario. The number of extreme rainfall days across Thohoyandou Node are projected to increase by between 0 and 3 days per year.

Figure 21 depicts the settlements that are at increased risk of urban flooding under an RCP 8.5 low mitigation (worst case of greenhouse gas emissions) scenario. Several settlements in the Thulamela Local Municipality face a low risk of flooding into a climate-changed future (at least up to 2050) – including the settlement of Thohoyandou.

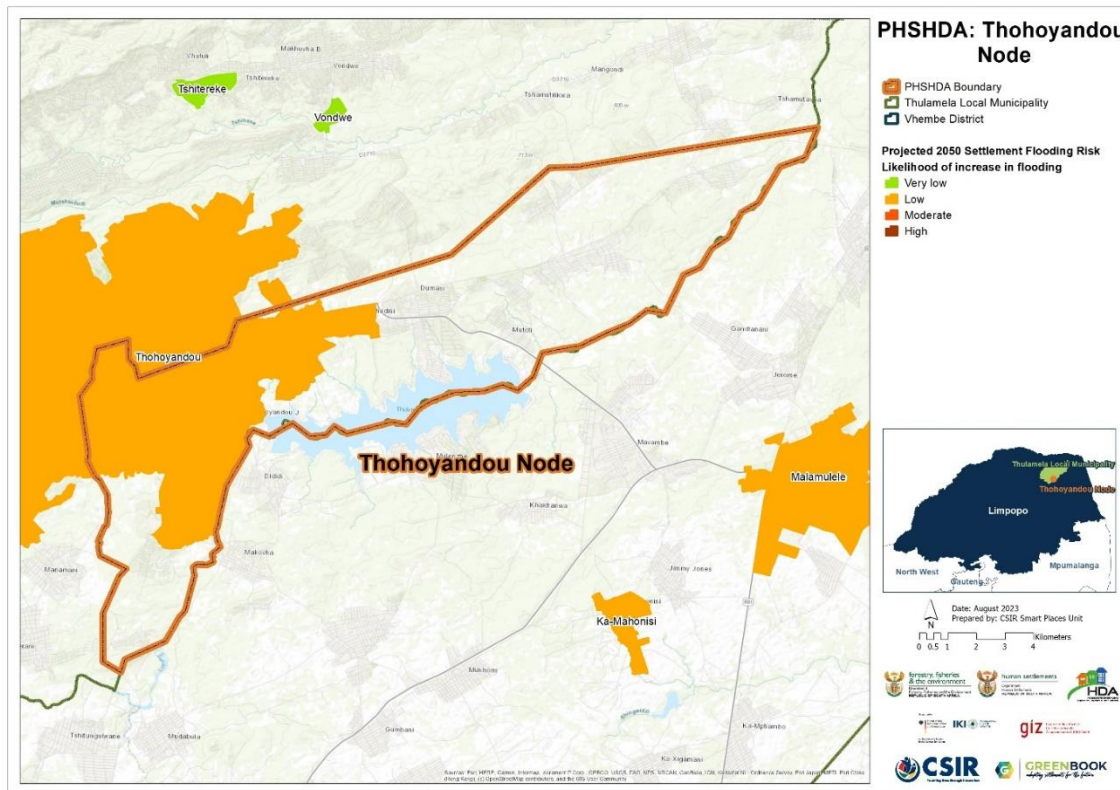


Figure 21: Flood risk into a climate change future at settlement level across the Thohoyandou Node

## 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 Thulamela Local 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 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.

Figure 22 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 groundwater dependent. The settlement of Thohoyandou – parts of which fall within the PSHDA boundary – relies solely on surface water.

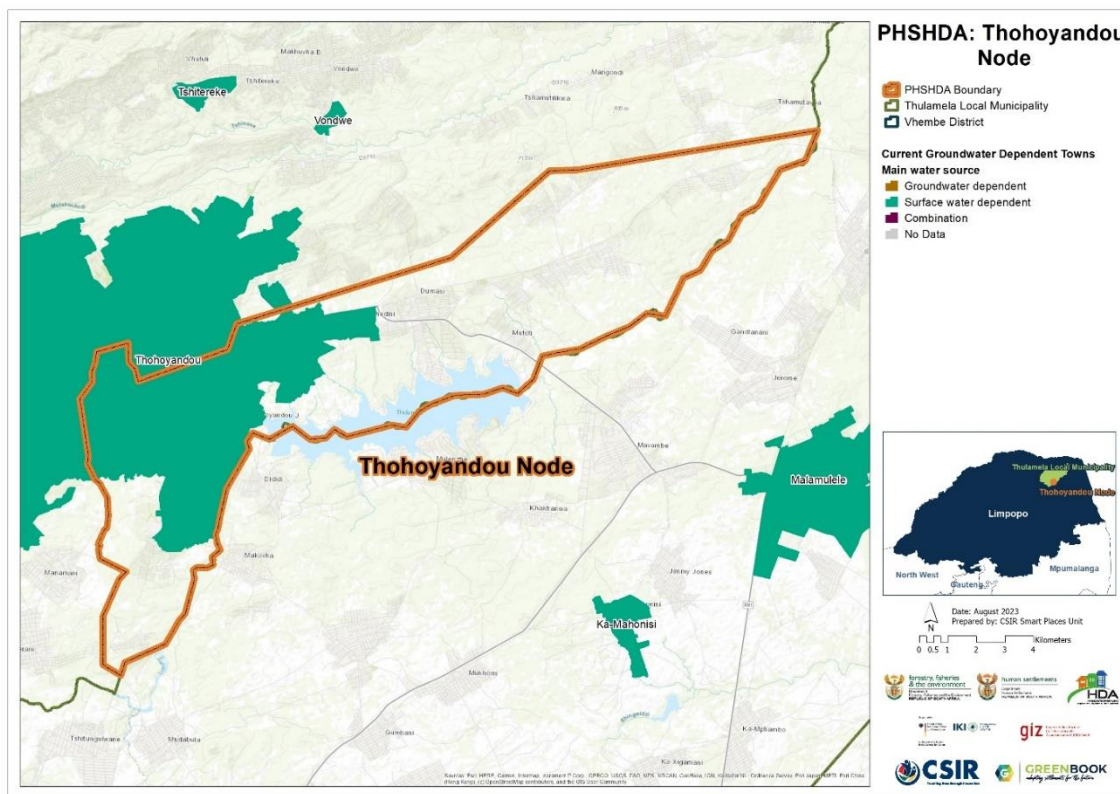


Figure 22: Main water source for settlements in Thohoyandou Node

Table 4 provides an overview of current water supply vulnerability (i.e., demand versus supply) in the Thulamela Local Municipality 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

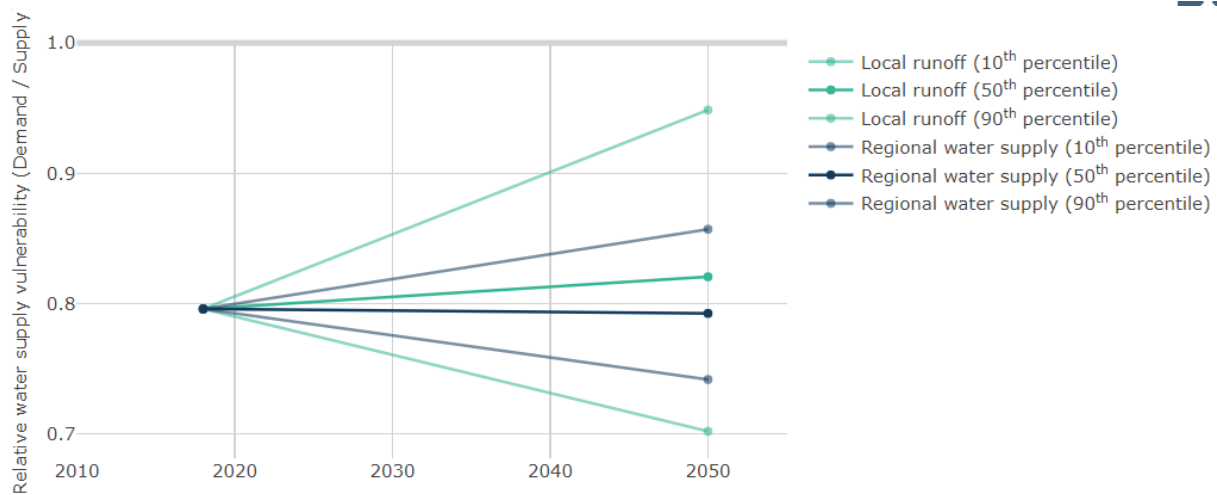


indicates that demand is more than supply, while a score below 1 indicates that supply is meeting demand.

*Table 4: Current water supply and vulnerability across Thulamela Local Municipality*











Local Municipality	Water Demand per Capita (l/p/d)	Water Supply per Capita (l/p/d)	Current Water Supply Vulnerability
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 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 Thulamela Local Municipality is discussed below. Figure 23 shows the Local Municipality's estimated current and future water supply vulnerability, under the two water supply vulnerability estimation scenarios. The factors contributing to the estimated water supply vulnerability are outlined in Table 5.



*Figure 23: Future water supply vulnerability in Thulamela Local Municipality*

Table 5: Future water supply vulnerability contributors for Thulamela Local Municipality, under a medium population growth scenario

VULNERABILITY CONTRIBUTION FACTORS		PERCENTAGE CHANGE	
	Mean annual precipitation		4.03%
	Mean annual evaporation		9.06%
	Mean annual runoff		13.18%
	Regional urban water supply		20.15%
	Population growth		3.14%

In 2011, Thulamela Local Municipality's water demand was lower than supply (Table 4). The Municipality's water supply is expected to remain low, at least up to 2050, due to the projected increase in mean annual precipitation and -runoff, as well as increased regional water supply (Table 5).

#### 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 Thulamela Local Municipality, 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 commodities are beef cattle, citrus and maize for grain. Climate projections show a generally hotter and drier climate for the Local Municipality, with wetter conditions projected into the future (towards 2100). Reduced rainfall, at least in the near future, could lead to the deterioration of veld/forage quality and quantity, thus affecting cattle feed. Increased heat stress could also reduce the growth and reproduction performance of cattle. Increasing temperatures and declining rainfall could also result in maize yield reductions. For citrus fruit, the projected climate could lead to increased evapotranspiration and irrigation requirements. An increase in temperature will also benefit a more heat-tolerant disease vector.

### 3. Recommendations

The greatest risks faced across the Thohoyandou Node (PHSHDA) are increased temperatures and wildfires, with the risk of heat extremes and drought becoming greater towards 2050. The settlement of Thohoyandou – parts of which fall within the PHSHDA boundary – also faces an increased risk of wildfires into a climate-changed future. Although the Local Municipality's water supply vulnerability is estimated to remain low, the future increase in the risk of drought, as well as the projected population growth, may result in the need to diversify portable water supply and conserve available water.

Thulamela Local Municipality also has a highly vulnerable economy (EcVI), settlement fabric (PVI) and natural environment (EnVI), which will undermine the Local Municipality's (and PHSHDA's) ability to recover from external shocks, including climate hazards, if not addressed. The Local Municipality's sluggish economy, that struggles to absorb the local labour force, is a key contributor to the Municipality's high economic vulnerability (HDA, 2022; Stats SA). It is, therefore, essential to manage these factors by diversifying the local economy. Thulamela's Agriculture, Logistics, Knowledge-Economy, Manufacturing and Tourism sectors have been identified as the sectors with the most opportunities for diversification. The Agricultural sector, in particular, (through Agro-processing) has been identified as catalytic industry with the potential to transform and grow the economy, as well as create jobs. The Local Municipality, and Thohoyandou Node, therefore, stand to benefit from adapting the sector to future climate conditions and their impacts. The provision of services and development of rural areas, 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 the Municipal Area.

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 the Local Municipality, as well as the PSHDA's future water supply – developing comprehensive strategies for water resource management is crucial. As part of these strategies, Thulamela Local Municipality, and the custodians of the Thohoyandou Node, 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 PSHDA, 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. 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 the Thulamela Local Municipality and Thohoyandou Node 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

Climate hazards and climate events can have far-reaching impacts across a range of sectors. This section summarises the impact of climate change on Thohoyandou Node's key sectors. Several development strategies have been identified for the PSHDA, including Agriculture and Rural Development, Environmental Management, Tourism Development, Industrial Development, Growth Management and Spatial Regeneration, as well as Sustainable Human Settlements Development. Each of these strategies are tied to critical sectors found in the PSHDA, including Agriculture and basic services such as Water. With the impacts of climate change on these two sectors already discussed, the remaining 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 PSHDA, the respective impacts (such as increased temperature and heat extremes, decreased rainfall, and drought) should be given special consideration.

### 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
<ul style="list-style-type: none"> <li>Increased risks of water shortages increasing demand for irrigation of gardens and agriculture.</li> <li>Increased evapotranspiration rates with rising temperatures, reducing the water available in reservoirs and water available for reliant ecosystems.</li> </ul>	<ul style="list-style-type: none"> <li>Decreased amounts of rainfall reaching ecosystems as settlements use rainwater harvesting techniques for increased household use.</li> <li>Increased reliance on irrigation and greater demand for water to maintain public open space and gardens.</li> </ul>	<ul style="list-style-type: none"> <li>Rainfall in shorter and more violent spells making recharging groundwater difficult.</li> <li>Increase in intensity of rainfall and flooding leading to increased surface runoff, resulting in increased soil erosion, soil loss and degradation.</li> <li>Increasingly saturated soils leading to more</li> </ul>

<ul style="list-style-type: none"> <li>• Increase in temperature leading to water loss via evapotranspiration resulting in decreased water quality and loss of wetlands.</li> <li>• Loss or degradation of indigenous species, including threatened species or ecosystems.</li> <li>• Increased threat from invasive species as competition for water increases.</li> <li>• Dieback or death of susceptible plants (e.g., street trees) and animals (e.g. fish).</li> <li>• Increased water temperature leading to increased growth of aquatic weeds which increases breeding of disease vectors and reduces water oxygen levels.</li> <li>• Milder winters and reduced frost increase the duration of the growing season, increasing the survival rate of insects and diseases.</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced planting and pollination leading to greater risk of erosion and soil loss.</li> <li>• 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.</li> <li>• Drought and decreased rainfall causing wetland habitat loss.</li> <li>• 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.</li> <li>• Drying up of aquatic systems, perennial systems will become seasonal and seasonal systems will die off and be replaced by terrestrial plants.</li> <li>• Increased spread of drought-adapted alien invasive plant species.</li> </ul>	<p>standing water (ponding) which can result in more insect (pest) activity and their potential to carry diseases.</p>
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### 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
<ul style="list-style-type: none"> <li>• Potential risk of undermining the temperature regime of temperature-sensitive stormwater ponds and receiving waters, resulting in a decrease in water quality.</li> <li>• Increased corrosion in stormwater drains due to a combination of higher temperatures, increased strengths, longer retention times, and stranding of solids.</li> <li>• Increased shrinking soils increasing the potential for cracking, increased infiltration and exfiltration of water mains and sewers, which in turn exacerbates treatment and groundwater or storm water contamination.</li> </ul>	<ul style="list-style-type: none"> <li>• Increased risk of flooding due to pressure on stormwater systems.</li> <li>• Increased risk of litter entering the stormwater systems.</li> <li>• Increased risk of damage and failure of stormwater systems due to overloading during floods and intense rainfall events.</li> <li>• Failure of stormwater treatment devices during high flow events leading to by-pass and / or flushing of contaminated water.</li> <li>• High wet-weather hydraulic loads and bottle-necks in stormwater and networks due to inflow and sewer infiltration, leading to local inundation and overflows of untreated wastewater.</li> <li>• Increased rainfall causes soil erosion thus damaging underground stormwater systems.</li> <li>• Increased surface and stream erosion causing deposition of sediments in receiving environments.</li> <li>• Stream morphology for undeveloped, developing and fully developed urban areas may change, hence affecting existing outfall structures and potential stormwater pond locations.</li> </ul>

## 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
<ul style="list-style-type: none"> <li>• Increased risk of combustion at open waste disposal sites and illegal dumps, and increase in explosion risk associated with methane gas.</li> <li>• Increased rate of decay of putrescible waste resulting in increased odour, breeding of flies, and attracting of vermin.</li> <li>• Increased health and safety concern regarding heat stroke to staff collecting waste.</li> <li>• 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).</li> </ul>	<ul style="list-style-type: none"> <li>• Increased risk of flooding due to pressure on stormwater and leachate management systems at landfills.</li> <li>• Increased demand for capacity to cope with large volumes of waste generated by flood events.</li> <li>• Increase in soil saturation causing decreased stability of slopes and landfills linings (if clay or soil based) at waste management facilities.</li> <li>• Inundation of waste releasing contaminants to waterways, pathways and low elevation zones.</li> <li>• Potential loss of value and degradation of paper and cardboard for recycling due to increased moisture content.</li> <li>• Increased flooding causing the risk of localised disruption of waste collection rounds.</li> <li>• Flooding in areas with untreated, dumped waste causing the risk of groundwater contamination.</li> <li>• Increased flooding causing the risk of litter entering the storm water systems.</li> </ul>

## 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
<ul style="list-style-type: none"> <li>• Increased heat waves, accompanied by dry weather, can exacerbate already stressed water supply systems leading to competition between sectors for water services; affecting sanitation.</li> <li>• Decrease in water supply for sanitation through decrease in available water to flush sewage systems adequately.</li> <li>• Declining annual rainfall threatening the viability of water-borne sanitation systems, and the capacity of surface water to dilute, attenuate and remove pollution.</li> <li>• 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.</li> <li>• Increased corrosion in sewers due to a combination of higher temperatures, increased strengths, longer retention times, and stranding of solids.</li> </ul>	<ul style="list-style-type: none"> <li>• 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.</li> <li>• Increased rainfall and heavy rainfall events increasing the washing of faecal matter into water sources due to flooding of wastewater treatment works.</li> <li>• Increased risk of flooding resulting in both infrastructure damage and contamination of surface and groundwater supplies.</li> <li>• 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).</li> <li>• 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.</li> <li>• Increased vulnerability of pit toilets (widely used in rural areas) due to flooding, causing serious environmental contamination.</li> <li>• Increase in groundwater recharge and groundwater levels causing flooding of</li> </ul>

	subsurface infrastructure such as pit toilets or septic tanks.
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**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
<ul style="list-style-type: none"> <li>• Increased heat causing expansion of overhead cables, and cable sag. Sagging below a certain amount result in a reduction in the amount of electricity transmitted.</li> <li>• Increased heat stress on electricity transmission networks (overhead cables).</li> <li>• Increase in heat island effect increasing energy demand for cooling, leading to grid stress.</li> <li>• Increased threat of wildfires causing widespread damage to infrastructure and causing disruptions to service provision.</li> </ul>	<ul style="list-style-type: none"> <li>• Increase in flooding causing damage to electricity transmission and distribution infrastructure, poles, lines and sub-stations</li> <li>• Increase in frequency and cost of maintenance of concrete structures due to frequent and intense rainfall, flooding, or sea level rise.</li> <li>• Increased repair events increasing stress put on service crews and resulting in delays to power restoration.</li> </ul>

**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
<ul style="list-style-type: none"> <li>• Increased weathering and deterioration of infrastructure resulting in increased maintenance and repair costs.</li> <li>• Heat stress causing structural damage to infrastructure.</li> <li>• Increased energy demands during heatwaves resulting in power outages which can impact on delivery of telecommunications services.</li> <li>• Increases in temperature and higher frequency, duration, and intensity of heat waves increasing the risk of overheating in data centres, exchanges, and base stations, which can result in increased failure rates of equipment.</li> <li>• Increased mean temperature increasing operating temperature of network equipment which may cause malfunctions if it surpasses design limits.</li> <li>• Decreased precipitation leading to land subsidence and heave, reducing the stability of telecommunications infrastructure above and below ground (foundations and tower structures).</li> </ul>	<ul style="list-style-type: none"> <li>• Increased risk of flooding of low-lying infrastructure, access holes and underground facilities.</li> <li>• Increases in storm frequency or intensity increasing the risk of damage to aboveground transmission infrastructure and impacting on telecommunications service delivery.</li> <li>• Increases in storm frequency leading to more lightning strikes, consequently damaging transmitters and overhead cables, causing power outages.</li> <li>• 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.</li> <li>• Road closures due to flooding thus inhibiting service and/or restoration efforts.</li> </ul>

**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
<ul style="list-style-type: none"> <li>• Increased rate of infrastructure deterioration leading to pavement failure including cracking, rutting, potholes, flushing, and stripping.</li> <li>• Increased stress on bridges, particularly expansion joints, through thermal expansion and increased movement.</li> <li>• Corrosion of steel reinforcing in concrete structures due to increase in surface salt levels in some locations.</li> <li>• Increased infrastructure maintenance cost for road repair and reconstruction work, causing traffic delays and emergency service response delays.</li> <li>• Increased frequency and intensity of wildfires leading to more road closures.</li> <li>• Increased vehicle accidents, due to low pavement adhesion, leading to higher rates of transport-related fatalities.</li> </ul>	<ul style="list-style-type: none"> <li>• Increased rate of infrastructure deterioration, especially in areas with poor infrastructure maintenance history.</li> <li>• Temporary and permanent flooding of road, rail, port and airport infrastructure.</li> <li>• Structural integrity of roads, bridges and tunnels could be compromised by higher soil moisture levels.</li> <li>• Potential destruction of bridges and culverts.</li> <li>• Erosion of embankments and road bases leading to undermining of roads or railways.</li> <li>• Increased risk of landslides, slope failures, road washouts and closures.</li> <li>• Undermining of bridge structures (scouring).</li> <li>• Closure of roadways and tunnels leading to traffic delays.</li> <li>• Transportation system disruptions, impacts to traffic signalling and low water crossings.</li> <li>• Increased weather-related accidents.</li> </ul>

### Culture and heritage

Culture refers to the dynamic totality of distinctive spiritual, material, intellectual, emotional and aesthetic features that characterise a society or social group, including its arts, but also intangible aspects such as values, worldviews, ideas and beliefs, and the expression of these in individual and social behaviour, relationships, organisational and societal forms, and in

economic, political, educational and judicial systems. The variance between these groups, known as cultural diversity, is illustrated by the many ways in which the cultures of groups and societies find expression. Within an urban context, culture may manifest itself spatially through heritage sites and resources. These areas are vulnerable to the effects of climate change and require particular management and sensitivity within planning. This heritage may include wildlife and scenic parks, sites of scientific or historic importance, national monuments, historic buildings, works of art, literature and music, oral traditions and museum collections together with their documentation. Due to the sensitive nature of culture and heritage, the physical and cultural value associated with these sites and resources is vulnerable to any aesthetic and functional changes caused by climate change. Potential physical impacts may have indirect social consequences. The table below outlines the cascading effects of selected climate change impacts on Thohoyandou’s heritage and cultural resources.

Increased temperatures and heat extremes	Drought and decreased rainfall	Increase in rainfall and inland flooding
<ul style="list-style-type: none"> <li>• Increased temperature having significant impacts on the comfort levels of built heritage resources, resulting in the building no longer being fit-for-purpose.</li> <li>• Increased demand for additional heating and cooling resulting in the installation of heating, ventilation and air-conditioning systems with potential negative consequences on the heritage value.</li> <li>• Increased heat stress potentially impacting on the materials and structural integrity of heritage resources.</li> <li>• Migration of several plant species due to changing climate patterns, posing a threat to the conservation of biodiversity hotspots,</li> </ul>	<ul style="list-style-type: none"> <li>• Decreased rainfall impacting negatively on ground moisture levels and thus the geological conditions of sensitive heritage resources. Drying out clays, for example, will shrink and potentially undermine founding conditions.</li> </ul>	<ul style="list-style-type: none"> <li>• Increased rainfall in areas with clay soils resulting in swelling which poses a threat to the structural integrity of heritage resources.</li> <li>• Increased floods and changes in precipitation resulting in increasing vulnerability of archaeological evidence buried underground due to changing stratigraphic integrity of the soils.</li> <li>• Increased threat to materials and structural integrity of heritage resources exposed to higher humidity/precipitation levels.</li> </ul>

<p>and potentially altering heritage places.</p> <ul style="list-style-type: none"><li>• Increase in veld and forest fires raising the threat of fire to all heritage resources, natural and built, as well as posing health risks to heritage resource dwellers from exposure to smoke and ash pollution.</li></ul>		
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