Development of a Climate Change Jurisdiction Vulnerability Index in South Africa

Phase II: Pilot Study Report

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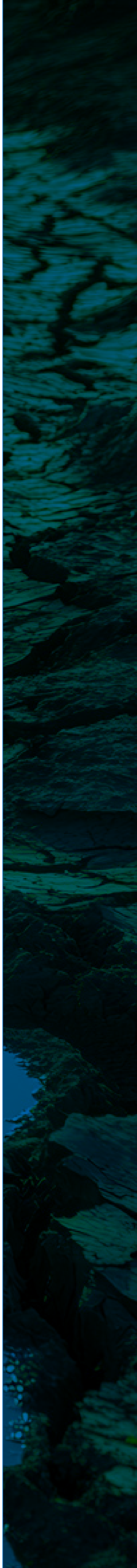

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ACRONYMS

ANOVA	Analysis of Variance
CBA	Community-Based Adaptation
CC-JVI	Climate Change Jurisdictional Vulnerability Index
DEA	Department of Environmental Affairs
DEM	Digital Elevation Model
DMA	Disaster Management Act
DMP	Disaster Management Plan
DRR	Disaster Risk Reduction
DSI	Department of Science and Innovation
EC	Eastern Cape
FGD	Focus Group Discussion
GCF	Green Climate Fund
GIS	Geographic Information System
HEA	Health Economic Assessment
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
IVA	Integrated Vulnerability Assessment
JVI	Jurisdictional Vulnerability Index
KII	Key Informant Interview
KZN	KwaZulu-Natal
LP	Limpopo
MP	Mpumalanga
NAP	National Adaptation Plan
NASA	National Aeronautics and Space Administration
NCCAS	National Climate Change Adaptation Strategy
NCCRWP	National Climate Change Response White Paper
NDP	National Development Plan
NDVI	Normalised Difference Vegetation Index
NGO	Non-Governmental Organization
PDF	Probability Density Function
SDG	Sustainable Development Goal
UNFCCC	United Nations Framework Convention on Climate Change
VAR	Variance

KEYWORDS

climate change; vulnerability index; climate adaptation; socio-economic factors; community resilience

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EXECUTIVE SUMMARY

Climate change is an escalating global crisis characterised by rising temperatures, shifting weather patterns, and increasing frequency of extreme weather events. These changes have far-reaching impacts on natural ecosystems and human societies, with significant consequences for communities worldwide. This pilot study aimed to establish a Climate Change Jurisdictional Vulnerability Index (CC-JVI) to assess community-level vulnerabilities in the face of climate change in South Africa. The research revealed significant disparities in the availability and quality of data across targeted communities, which affected accurate vulnerability assessments. The key objective of this study was to evaluate the feasibility of utilising local-level data for the CC-JVI. However, challenges emerged due to the incomplete and heterogeneous nature of data at the local level. Most critical metrics for vulnerability assessment are relatively more available at the district, provincial, and national levels. However, qualitative data collected through Focus Group Discussions (FGDs) provided rich contextual data that is critical to vulnerability assessment and, more importantly, identification of entry points for interventions to mitigate and adapt to climate change. To address these data challenges, the research adopted another secondary data collection technique, leveraging Statistics South Africa census data from 2011 and 2022, alongside NASA's online database. This data was normalised and analysed using various statistical methods, revealing significant regional variations in climate vulnerability. KwaZulu-Natal (KZN) exhibited heightened variability attributed to extreme weather events, while Mpumalanga (MP) demonstrated a stable warming trend. Vulnerability indices categorised the Eastern Cape (EC), KZN, and MP as "moderately vulnerable," while Limpopo (LP) was classified as "vulnerable", emphasising the necessity of localised assessments. Assessments for 2001 to 2022 show that temperature changes were significant across regions, particularly in KZN and MP. All provinces, including Limpopo, show significant vulnerability despite observable differences in some aspects. These findings indicated the importance of adapting vulnerability assessments to specific regional contexts and emphasised the value of integrating both qualitative and quantitative data into the CC-JVI framework. In conclusion, this study laid a foundational framework for enhancing climate resilience by developing a CC-JVI that reflected regional climatic and socio-economic disparities. Recommendations from this study include establishing a centralised data repository to improve data accessibility and quality, implementing community-based data collection programs, and fostering collaboration among stakeholders. Furthermore, integrating climate adaptation strategies into existing national policies and prioritising localised initiatives to empower communities to build resilience against climate impacts. A phased, iterative approach to index development was deemed essential in ensuring the involvement of local communities in validating the index.

INTRODUCTION

Climate change is an escalating global crisis characterised by rising temperatures, shifting weather patterns, and increasing frequency of extreme weather events. These changes have far-reaching impacts on both natural ecosystems and human societies, with significant consequences for communities worldwide. The trajectory of climate change indicates a persistent and worsening trend that could lead to catastrophic environmental and socio-economic disruptions if not effectively mitigated and adapted to (Hoegh-Guldberg et al., 2019). The urgency to address this issue is heightened by the disproportionate impact on developing countries, which often lack the resources and infrastructure necessary to effectively combat these changes (Klein & Smith, 2008).The trajectory of climate change has been marked by a steady increase in global temperatures and an increase in the frequency and severity of extreme weather events, such as heatwaves, droughts, flooding, and storms (Hoegh-Guldberg et al., 2019). This trend is projected to continue, with potentially devastating consequences for both natural ecosystems and human societies. Ecosystems are being pushed beyond their capacity to adapt, leading to the collapse of critical habitats and loss of biodiversity (Bustamante et al., 2019). For human societies, the impacts include food and water insecurity, increased health risks, and economic instability. Developing countries, particularly in the Global South, are vulnerable due to their heavy reliance on climate-sensitive sectors like agriculture and limited adaptive capacity (Seddon et al., 2019).

Despite significant advancements in climate science and technology, several challenges remain in effectively mitigating and adapting to climate change. One of the primary challenges is the lack of accurate and timely early warning systems, particularly in vulnerable regions. This deficiency hampers the ability of communities to prepare for and respond to extreme weather events, leading to higher levels of damage and loss of life (Quinn et al., 2018). Mitigation efforts are also hindered by political and economic barriers, as well as the need for large-scale systemic changes that are often met with resistance from stakeholders with vested interests in maintaining the status quo (Wu, 2016). Adaptation presents further challenges, particularly in developing countries where resources are limited. Adaptation measures often require substantial investments in infrastructure, technology, and capacity building, which many countries cannot afford without external support (Klein & Smith, 2008). Hence, the 3rd International Conference on Financing for Development (United Nations, 2015) expressed the international community's commitment to cooperate through multistakeholder partnerships in financing environmentally, socially and economically sustainable development that addresses gaps in technology and infrastructure. Furthermore, the integration of adaptation strategies into existing policy framework requires coordination across multiple sectors and levels of governance (Broberg, 2020).

This challenge is further compounded by the need to balance short-term development goals with long-term resilience building, and the need to consider human rights in climate actions. This trade-off is not always easy to manage.

Developing a Climate Change Jurisdictional Vulnerability Index (CC-JVI) for climate change is a crucial step in addressing these challenges. A CC-JVI provides a localised assessment of vulnerability, enabling policymakers to identify specific areas and communities that are most at risk (Hlalele, 2019). This targeted approach allows for the development of tailored adaptation and mitigation strategies that are more effective than one-size-fits-all solutions. Though incorporating various dimensions of vulnerability, such as socio-economic factors, environmental conditions, and institutional capacity, a CC-JVI offers a comprehensive understanding of the unique challenges faced by different jurisdictions (Schneiderbauer et al., 2020). In South Africa, the application of a CC-JVI is particularly important due to the country's diverse climatic and socio-economic conditions. Different regions face varying levels of exposure and sensitivity to climate impacts, and their adaptive capacities also differ significantly (Ford & King, 2022).

For instance, while some areas may be more prone to drought, others may experience more frequent flooding. A CC-JVI can help identify these patterns and guide the allocation of resources to areas where they are needed most, thereby enhancing the overall resilience of communities (Olsson et al., 2023).

Moreover, a CC-JVI can support the integration of climate adaptation into broader development planning and policy frameworks. By providing a clear, evidence-based assessment of vulnerability, it can inform the design of policies that not only address climate risks but also contribute to poverty reduction and sustainable development (Mechler et al., 2020). This is particularly important in the context of the Paris Agreement, which emphasises the need for integrated approaches to climate adaptation that consider the socio-economic and environmental dimensions of vulnerability (UNFCCC, 2015). The development of a Climate Change Jurisdictional Vulnerability Index (JVI) aligns closely with the United Nations Sustainable Development Goal (SDG) 13, which calls for urgent action to combat climate change and its impacts. This goal emphasises the need for resilience-building and adaptation strategies, particularly in vulnerable regions such as Africa. The JVI also supports the African Union's Agenda 2063 Aspiration 1, which envisions a prosperous Africa based on inclusive growth and sustainable development, by promoting the integration of climate adaptation into national planning. Furthermore, the JVI complements South Africa's Department of Science and Innovation (DSI) Decadal Plan, which prioritises research and innovation in addressing socio-economic challenges posed by climate change. It also aligns with the National Development Plan (NDP) 2030, which emphasises the importance of enhancing the country's adaptive capacity and resilience to environmental changes, ensuring sustainable livelihoods and economic stability for all South Africans.

BACKGROUND

Climate change poses a significant threat to global ecosystems and human societies, with impacts ranging from extreme weather events to long-term changes in climate patterns. South Africa, like many other countries in Sub-Saharan Africa, is particularly vulnerable due to a combination of socio-economic challenges and diverse environmental conditions. This vulnerability is compounded by the country's heavy dependence on climate-sensitive sectors such as agriculture and tourism, as well as its high levels of poverty and inequality (Gbetibouo et al., 2010). The impacts of climate change in South Africa affect various sectors and regions differently. For instance, increased temperatures and changing rainfall patterns have significant implications for agriculture, which is a vital sector for both employment and food security in the country. Regions such as Limpopo and the Eastern Cape, which rely heavily on rain-fed agriculture, are particularly vulnerable due to their high exposure and low adaptive capacity (Mthethwa & Zegeye, 2022). The Western Cape, known for its wine and fruit production, has experienced prolonged droughts, leading to severe water shortages and economic losses (Gbetibouo et al., 2010). In addition to environmental challenges, South Africa's socio-economic context exacerbates its vulnerability to climate change. High levels of poverty, unemployment, and inequality mean that many communities have limited resources to cope with and adapt to changing climatic conditions. Social vulnerability, which includes factors such as income, education, and access to services, varies widely across the country and is often concentrated in urban areas with large populations living in informal settlements (Apotsos, 2019). These areas are typically more susceptible to climate-related hazards such as flooding and heatwaves due to inadequate infrastructure and poor living conditions.

Despite the recognition of these vulnerabilities, implementing effective adaptation strategies remains a challenge. One major issue is the lack of coordination between different levels of government and sectors. A recent study emphasised the need for a cohesive national framework that aligns local and national efforts to assess and address climate risks more effectively (Ziervogel & Taylor, 2023).

Effective implementation of efforts to lessen the effects of climate change on the environment and societies also require strengthened regional governance and is especially critical in large and diverse countries, where the impacts of climate change vary significantly across different regions (Sheriff, 2019). Local governments and communities play a significant role in addressing the impacts of climate change and implementing adaptation strategies. Moreover, limited financial resources and inadequate data on local climate impacts hinder the ability to design targeted interventions. Social vulnerability plays a key role in determining the effectiveness of adaptation measures. Research shows that women, children, and the elderly are often more vulnerable to the impacts of climate change due to their limited access to resources and decision-making processes (Goldin et al., 2019).

Gender-sensitive approaches to vulnerability assessment are therefore essential for ensuring that adaptation strategies are inclusive and equitable. While recent studies have made significant strides in identifying vulnerable regions and populations, much work must be done to translate these findings into effective evidence-informed policies and actions. Strengthening local adaptive capacities, improving coordination across governance levels, and ensuring that adaptation strategies are inclusive will be critical for enhancing South Africa's resilience to climate change. There is a growing need for detailed vulnerability assessment to address these challenges that can inform effective adaptation planning.

OBJECTIVES OF THE PILOT STUDY

1. To determine the feasibility of utilising local-level data for developing a comprehensive and context-specific vulnerability index that captures multiple dimensions of community vulnerability.

2. To assess the challenges and opportunities associated with data collection, management, and integration from various sources at the community level.

3. To construct a Climate Change Jurisdictional Vulnerability Index using a combination of existing data and community-specific indicators, ensuring relevance and applicability to targeted study area.

4. To explore mechanisms for enhancing climate change resilience at national and sub-national levels, particularly in communities vulnerable to climate change hazards.

RATIONALE FOR A PILOT STUDY

Several reasons support the need for a pilot study on vulnerability measurement at the local level. These include, but are not limited to, addressing context-specific challenges for local populations, enhancing data appropriateness and relevance, testing and refining methodological approaches to data collection, building local capacity and engagement, informing policy and practice, and appraising interventions for potential scaling-up to similar contexts.

Vulnerability to climate change varies significantly across regions, particularly in the Global South, where socio-economic and environmental conditions differ markedly from those in the Global North. South Africa and other parts of Africa face unique challenges, such as high poverty levels, inequality, and reliance on climate-sensitive livelihoods. A pilot study is essential to develop and test vulnerability measurement tools tailored to these specific contexts (Ford & King, 2022) and can shape specific jurisdiction's climate adaptation plans (Le, 2020). Without such adaptation, existing frameworks may fail to capture the nuanced realities of these communities, leading to ineffective policy and intervention strategies.

In many parts of South Africa, there is a significant gap in the availability of high-quality, locally relevant data on climate vulnerability (Tschakert & Tuana, 2022). A pilot study would allow researchers to refine data collection methodologies, ensuring they accurately reflect the local context. This includes identifying appropriate vulnerability indicators, such as socio-economic status, local livelihood practices, cultural factors, community resilience strategies, and institutional and governance capacity. By piloting these tools, researchers can improve the reliability and validity of the data, providing a stronger foundation for broader studies and policy development. Vulnerability measurement often involves complex methodologies that integrate various socio-economic, environmental, and political factors (Klenk & Meehan, 2023). Conducting a pilot study allows researchers to test and refine these approaches in a real-world setting. For example, in South Africa, integrating social vulnerability indices with Geographic Information Systems (GIS) or participatory approaches can be tested to ensure they work effectively in diverse and resource-constrained environments. This process helps identify potential methodological weaknesses or logistical challenges, enabling researchers to adjust their approach before scaling up to a full study.

Pilot studies are crucial for building local capacity and engaging communities in research. In the Global South, where research infrastructure may be less developed, a pilot study can help establish partnerships with local stakeholders, including community leaders, NGOs, and government agencies (Rodriguez-Cordero et al., 2022). This engagement ensures that the study is grounded in local realities and fosters trust and collaboration, which are essential for the successful implementation of vulnerability assessments and subsequent participation of communities in interventions when they perceive processes as transparent and inclusive. Furthermore, it provides an opportunity to train local researchers and practitioners in vulnerability measurement techniques, contributing to long-term capacity building necessary for implementing climate justice approaches.

Policymakers in South Africa and other parts of the Global South require accurate, context-specific information to design effective climate adaptation strategies. According to Ziervogel and Parnell (2022), a pilot study on vulnerability measurement can provide preliminary findings that inform immediate policy decisions while also laying the groundwork for more comprehensive research. Identifying key areas of vulnerability and testing potential intervention strategies on a smaller scale, the pilot study can offer actionable insights that can be quickly implemented to mitigate the impacts of climate change on the most vulnerable communities.

Finally, a pilot study is a critical step in scaling up interventions. It allows researchers to test the feasibility and impact of various vulnerability reduction strategies on a small scale before implementing them more broadly. This approach minimises risks and ensures that resources are allocated efficiently, targeting the most vulnerable populations with interventions that have been proven to work (Olsson et al., 2023). In the context of South Africa and the broader Global South, where resources are often limited, this careful, phased approach to vulnerability reduction is particularly important.

Thus, a pilot study on vulnerability measurement in communities is not just a preliminary research exercise; it is a necessary step to ensure that subsequent research and interventions are relevant, effective, and grounded in the realities of the communities most at risk. By addressing context-specific challenges, enhancing data quality, testing methodologies, building local capacity, informing policy, and ensuring scalable interventions, such a study can significantly contribute to the global effort to mitigate and adapt to the impacts of climate change.

STUDY AREA DESCRIPTION

The study area is described in two parts: a) selected villages and Limpopo in general, and b) the rest of the selected provinces for the provincial vulnerability assessment.

Profiles of Selected Villages

i. Muyexe

Topography

Muyexe is located in the Mopani District of Limpopo Province, with predominantly flat terrain that limits natural water retention and affects agricultural potential. The area experiences moderate to severe soil erosion due to its sparse vegetation and dry conditions (Makhubele et al., 2016)

Livelihood

Residents rely on subsistence agriculture, including rain-fed maize and livestock farming. Limited access to markets and infrastructure, coupled with climate variability, constrains agricultural productivity and economic development. Dependency on government grants is widespread due to limited livelihood diversification (Rankoana, 2023).

Climate

Muyexe experiences a semi-arid climate characterised by irregular rainfall patterns, long dry seasons, and rising temperatures. These conditions exacerbate water scarcity and soil degradation, further impacting agricultural activities (Paumgarten et al., 2020).

ii. Nkowankowa

Topography

Nkowankowa features flat to gently undulating terrain with occasional river systems, which provide irrigation opportunities. However, low-lying areas are susceptible to flooding during intense rainfall events (Munyai et al., 2021).

Livelihood

Nkowankowa's economy is more diversified, with small-scale farming of vegetables and fruits like tomatoes contributing significantly to household incomes. Informal trade and other small businesses also play an important role in livelihood strategies (Makhubele et al., 2016).

Climate

Nkowankowa experiences similar semi-arid conditions with rising temperatures and decreasing rainfall. Seasonal variability in rainfall has led to challenges in water availability for irrigation, affecting both subsistence and commercial agriculture (Paumgarten et al., 2020).

iii. Limpopo Provincial Profile

Rainfall patterns

Rainfall in Limpopo exhibits significant variability, ranging from 160 mm to 1,109 mm annually. The prevailing climate in this region is undergoing significant transformation, characterised by rising temperatures and a decrease in precipitation frequency. Consequently, this shift has led to persistent droughts and associated water scarcity issues (Mosase & Ahiablame, 2018; Shikwambana et al., 2021). In KwaZulu-Natal, the frequency and severity of droughts have increased, with particularly arid conditions observed during the years 1992 and 2014/15. Although relatively infrequent, periods of abundant rainfall in this region are often linked to cyclonic activity (Ndlovu & Demlie, 2020; Ndlovu et al., 2021). The Eastern Cape has been experiencing significant droughts since 2015, which have profoundly affected its water resources and agricultural sector.

Specifically, there has been a marked reduction in spring rainfall, leading to decreased water availability during critical crop growth periods (Mahlalela et al., 2020). Rainfall patterns in Mpumalanga are characterised by erratic behaviour, displaying a tendency toward extreme conditions. This region is susceptible to both periods of drought and excessive precipitation, with global climate phenomena such as El Niño exacerbating these fluctuations (Masingi & Maposa, 2021).

Topography

The Limpopo Province exhibits a heterogeneous topography, comprising both the low-lying Limpopo River Basin and its mountainous regions. This variation in elevation significantly influences local climatic conditions and water availability, as noted by Mosase and Ahiablame (2018). Similarly, the landscape of KwaZulu-Natal is characterised by diversity, incorporating coastal regions, the Drakensberg mountains, and the midlands. This varied topography plays a crucial role in shaping local weather patterns, resulting in fluctuations in rainfall and temperature, as observed by Blamey and Reason (2009). In the Eastern Cape, the terrain ranges from coastal zones to mountainous areas, which in turn affects local climatic and weather patterns. The region's multifaceted landscapes contribute to intricate meteorological dynamics, further elucidated by Blamey and Reason (2009). Likewise, Mpumalanga's geography, which encompasses the highveld, lowveld, and escarpment areas, exerts a significant influence on its climate. The disparities in elevation across these regions give rise to diverse rainfall and temperature patterns (Blamey & Reason, 2009).

Livelihood

In Limpopo, agriculture plays a key role in sustaining livelihoods, particularly for smallholder farmers who are disproportionately affected by climate change. The reduction in rainfall has led to diminished crop yields and water scarcity, thereby posing significant challenges to the implementation of sustainable agricultural practices (Shikwambana et al., 2021; Mpandeli, 2014). In KwaZulu-Natal, agriculture is similarly a dominant sector, with farmers adopting various strategies to adapt to changing rainfall patterns. However, the intensification of drought conditions threatens both agricultural sustainability and the availability of water resources (Thomas et al., 2007). In the Eastern Cape, many individuals' livelihoods depend on agriculture, which is severely impacted by persistent droughts affecting both rural and urban populations. The decline in rainfall necessitates the adoption of adaptive strategies to mitigate water shortages and address the existing agricultural challenges (Mahlalela et al., 2020). Likewise, agriculture is of great significance in Mpumalanga, where farmers are actively adjusting to the fluctuating patterns of rainfall and temperature, as these variables significantly influence agricultural productivity and the availability of water resources (Thomas et al., 2007).

Climate

Limpopo's semi-arid climate displays significant variability and frequent occurrences of extreme weather events, which render the region particularly susceptible to the effects of climate change. These effects encompass rising temperatures and diminishing precipitation (Mosase & Ahiablame, 2018; Shikwambana et al., 2021). In contrast, KwaZulu-Natal's climate, shaped by its proximity to the Indian Ocean, experiences alternating wet and dry periods, with a notable trend towards rising temperatures and increasingly erratic rainfall patterns over time (Ndlovu et al., 2021; Jury, 2022). The climate of the Eastern Cape is marked by considerable fluctuations, influenced by both midlatitude and tropical systems, and is characterised by decreasing rainfall and a higher frequency of drought occurrences (Mahlalela et al., 2020). Similarly, Mpumalanga faces comparable climate-related challenges, characterised by significant variability and trends of increasing temperatures and shifting precipitation patterns, substantially influenced by both local and global climatic factors (Masingi & Maposa, 2021). Figure 1 shows the map of the study areas for this study.

Figure 1: Map of South Africa showing the provincial study areas

Source: https://d-maps.com/m/africa/southafrica/afrdusud/afrdusud21.gif

LITERATURE REVIEW

Jurisdictional approaches to climate change adaptation

Climate change presents a significant global challenge, influencing both natural ecosystems and human societies. Addressing its consequences requires coordinated efforts across multiple levels of governance. International frameworks are key in shaping measures, institutional arrangements, policies, processes, and strategies for climate change adaptation. The United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement serve as foundational elements of international initiatives, facilitating global cooperation. These agreements emphasise the importance of enhancing adaptive capacity, building resilience, and reducing vulnerability to climate change (Broberg, 2020). International organisations, such as the Intergovernmental Panel on Climate Change (IPCC), contribute by providing scientific assessments that guide policy decisions. The IPCC's reports highlight the urgency of implementing adaptation measures and the necessity for evidence-based strategies (Mechler et al., 2020). Furthermore, international financial mechanisms, such as the Green Climate Fund (GCF), assist developing nations in executing adaptation projects (Omukuti et al., 2022).

National governments play a fundamental role in climate change adaptation by establishing policies and regulations that direct action. Numerous countries have formulated National Adaptation Plans (NAPs) to detail their strategies for confronting climate risks. These plans frequently integrate risk assessments, identify priority sectors for adaptation, and devise strategies for capacity building (Adejonwo-Osho, 2019). Building governance capacity at various levels is critical to any country's climate action. The responsibilities of national governments also encompass legislative measures that support adaptation initiatives. For instance, laws and regulations regarding land use, building codes, and disaster risk management are vital for reducing vulnerability (Rimmer, 2019).

Furthermore, national policies often include measures to protect critical infrastructure, such as water supply systems, transportation networks, and energy grids (Asadnabizadeh, 2019).

Regional and sub-national authorities, encompassing states, provinces, and municipalities, are increasingly acknowledged as essential agents in climate adaptation. These entities typically implement national policies while tailoring them to local mandates and contexts (Mingaleva, 2020). Regional cooperation can enhance adaptation efforts by addressing cross-jurisdictional challenges, such as watershed management and ecosystem conservation (Brauch et al., 2019). In many instances, regional and sub-national authorities have developed their own adaptation strategies. For example, cities and municipalities are at the forefront of urban adaptation, concentrating on initiatives such as green infrastructure, heat action plans, and flood risk management (Pietrapertosa et al., 2021). The role of regional governance is especially critical in large and diverse countries, where the impacts of climate change vary significantly across different regions (Sheriff, 2019). Local governments and communities play a significant role in addressing the impacts of climate change and implementing adaptation strategies. Community-based adaptation (CBA) emphasises transdisciplinary approaches and the involvement of local stakeholders in identifying risks and developing effective responses. This approach acknowledges the importance of local knowledge and experience in designing adaptation measures that are effective (Mechler et al., 2020). Local governments frequently collaborate with non-governmental organisations (NGOs), community groups, and the private sector to execute adaptation projects. These projects may encompass initiatives such as coastal protection, water resource management, and enhancing agricultural resilience (Roppongi, 2020). Local initiatives are critical for addressing specific vulnerabilities and ensuring that adaptation strategies are culturally appropriate and socially inclusive (Stephenson et al., 2019). Jurisdictional approaches to climate change adaptation encounter several challenges, including the need for coordination among different levels of government, limited resources, and varying capacities. To maximise effectiveness, it is essential to integrate adaptation into broader policy frameworks, such as development planning and disaster risk reduction (Roppongi, 2020). Enhancing data sharing and collaboration between international, national, and local levels presents opportunities for improving jurisdictional approaches (Forster et al., 2023). Capacity building and technical assistance can also strengthen the adaptive capacity of lower levels of government (Brauch et al., 2019). Moreover, innovative financing mechanisms, such as public-private partnerships and climate bonds, can support adaptation initiatives (Omukuti et al., 2022).

Integration of socio-economic and environmental data in vulnerability assessments

The process of integrating socio-economic and environmental data into vulnerability assessments is a key component in understanding the factors that contribute to a community's susceptibility to climate change. Through combining various datasets, this integration allows for the identification and prioritisation of areas that require immediate intervention. Socio-economic factors encompass demographic attributes, including age, gender, income, educational attainment, and access to essential services. These factors significantly influence a population's ability to cope with and adapt to climate impacts. For example, communities with lower incomes may lack the financial resources necessary for post-disaster reconstruction, while communities with limited educational opportunities may not have access to vital climate risk information and adaptation strategies (Sherbinin et al., 2019). Furthermore, health indicators, such as the prevalence of chronic illnesses, can indicate populations that are more susceptible to heat stress or vector-borne diseases (Birkmann et al., 2021). Environmental data consists of information on physical and ecological conditions, such as land usage, vegetation coverage, water resources, and climatic patterns. This data aids in understanding the exposure to climate-related hazards like floods, droughts, and heatwaves. Regions with inadequate drainage infrastructure are prone to flooding, while areas with limited vegetation coverage are more vulnerable to soil erosion and desertification (Zhang et al., 2019). Integrating data on flood-prone areas with information on low-income neighborhoods enables the identification of communities at a higher risk of displacement and economic hardship (Li et al., 2019).

This approach facilitates targeted interventions, such as the improvement of infrastructure in vulnerable areas, the enhancement of early warning systems, and the promotion of public awareness and education regarding climate adaptation strategies (Mafi-Gholami et al., 2021).

Historical and current climate trends in South Africa

South Africa has experienced an increase in average temperatures throughout the past century. Historical records indicate that the country has warmed up by approximately 1.5°C since the early 20th century. This warming trend has gained momentum in recent decades, resulting in a higher frequency of hot days and heatwaves. The rising temperatures have significant implications for a range of sectors, including agriculture, health, and water resources. Specifically, they lead to increased rates of evaporation, heat stress, and alterations in growing seasons (Jury, 2018). South Africa's national parks in particular have experienced a substantial surge in extreme high temperature events, particularly in arid areas (van Wilgen et al., 2016). Furthermore, the temperature trends observed in various regions of KwaZulu-Natal align with global patterns, exhibiting positive increases in both maximum and minimum temperatures (Ndlovu et al., 2021).

Rainfall patterns in South Africa are highly variable, with certain areas becoming more arid while others face an increase in precipitation. The Western Cape, for instance, has observed a trend towards drier conditions, contributing to the severity of recent droughts (Mahlalela et al., 2018). Conversely, the eastern and northern regions have experienced more intense rainfall events, heightening the risk of flooding. Studies on the Olifants River Catchment have revealed an overall decline in rainfall, although no significant changes have been detected in the distribution of rainfall over time (Adeola et al., 2022). Moreover, in Limpopo Province, diminishing rainfall has exacerbated challenges related to water scarcity, impacting smallholder agriculture and rendering farmers more vulnerable to the effects of climate change (Shikwambana et al., 2021). These alterations in precipitation patterns are influenced by global climate phenomena, such as El Niño and La Niña, which can exacerbate droughts and floods. The severe drought experienced in the Western Cape between 2015 and 2017 can be attributed, at least in part, to these climatic drivers (Mahlalela et al., 2018).

Impact of climate change on key sectors in South Africa

The impacts of climate change are extensive, affecting multiple sectors that are crucial to South Africa's economy and society. Key sectors, including agriculture, water resources, health, and infrastructure, are particularly vulnerable, with potential consequences for food security, public health, and economic stability (Bonetti et al., 2022). For instance, studies indicate that climate change is likely to reduce freshwater availability, which, in turn, affects sectoral production and the welfare of households, especially in impoverished communities (Juana et al., 2012). Agriculture is a pivotal sector in South Africa, providing livelihoods for a significant portion of the population and contributing to food security. However, the sector is highly susceptible to climate variability and change. Increasing temperatures, altered rainfall patterns, and extreme weather events result in decreased crop yields and livestock productivity. Droughts lead to water shortages for irrigation, while elevated temperatures stress crops and livestock, diminishing their resilience. Changes in growing seasons also necessitate adjustments in crop selection and farming practices, posing challenges for farmers (Calzadilla et al., 2014). Furthermore, climate projections indicate substantial impacts on the water and agricultural sectors, endangering food security and economic stability (Nhemachena et al., 2020).

Another pressing issue in South Africa is water scarcity, which is exacerbated by climate change. Changes in precipitation patterns and increased evaporation due to higher temperatures contribute to diminishing water availability. This situation jeopardises domestic water supply, agricultural irrigation, and industrial usage. The water crisis in Cape Town, colloquially known as "Day Zero", demonstrated the vulnerability of urban areas to water shortages and highlighted the need for effective water management strategies (Shikwambana et al., 2021).

Moreover, water scarcity can intensify conflicts over resources and heighten competition among different sectors and regions (Kusangaya et al., 2014). Climate change has direct and indirect impacts on public health. Rising temperatures and heatwaves can result in heat-related illnesses and exacerbate pre-existing health conditions, such as cardiovascular and respiratory diseases. Changes in climate patterns can also influence the distribution of vector-borne diseases like malaria and dengue fever. Warmer temperatures can expand the range of mosquitoes, increasing the risk of outbreaks in previously unaffected areas. Extreme weather events lead to injuries, displacement, and mental health issues, further burdening healthcare systems (Chersich et al., 2018). Furthermore, changes in climate can compound water and food insecurity, indirectly affecting health through malnutrition and increased poverty (Mukwada et al., 2021).

Conceptualisation of climate change vulnerability

Dimensions of vulnerability

Vulnerability assessment in disaster risk management and climate change adaptation involves two key components: core factors such as susceptibility, sensitivity, fragility, and coping or adaptive capacities, which indicate societal response capabilities to adverse environmental conditions, and thematic dimensions like social, environmental, economic, and institutional vulnerability. The term "vulnerability" is preferred as it highlights deficiencies determining the likelihood of severe harm and loss from adverse events, whereas "sensitivity" is more neutral, potentially indicating positive or negative movements. Exposure, defined as the geographic extent of hazard events affecting communities or systems, is another factor considered in vulnerability assessments. While exposure denotes the presence of people, assets, or infrastructure in hazard-prone areas, susceptibility refers to the predisposition to suffer harm. Despite exposure, susceptibility, and sensitivity, vulnerable groups have shown adaptive capacities over time, emphasising the importance of considering coping and adaptation mechanisms in vulnerability assessments. The social dimension of vulnerability deals with aspects of societal organisation as well as individual strength (Adger & Kelly, 1999; Adger, 2006; Birkmann, 2006a, 2006b, 2006c). The social dimension of vulnerability includes issues such as poverty, social marginalisation and powerlessness, social networks, education, and health (Cutter et al., 2003), as well as migration and displacement (Dwyer et al., 2004). Furthermore, social vulnerability might also deal with the influence of institutions and rule systems that might make people more susceptible to suffer harm and loss due to natural hazards and climate change impacts (Wisner et al., 2004; Birkmann et al., 2011b). While past disasters such as the Indian Ocean tsunami, which hit Indonesia and Sri Lanka hardest, revealed that young and elderly, as well as female persons, were among the most vulnerable demographic groups, the heat wave in 2003 in Europe showed that elderly people particularly were more vulnerable compared to other age groups due to a variety of factors, such as health conditions, social isolation, family composition and mobility, all of which are social determinants of vulnerability (IPCC, 2012a). Consequently, vulnerability patterns are not universal but often depend on specific context conditions and development processes in the respective country or region and on the respective hazard focus.

Additionally, social vulnerability criteria may indicate complex issues, such as the social isolation of the elderly. Research reveals that factors like gender are not inherent vulnerabilities but are shaped by societal structures, such as norms leading women to be more susceptible to coastal hazards due to limited engagement in survival training. Other characteristics like socio-economic class, gender, age, race, ethnicity, and housing tenure, along with access to financial resources post-disaster, influence susceptibility and exposure to hazards. Economic vulnerability encompasses both household livelihood patterns and the capacity of economic systems to absorb and address damage and losses. Some assess economic vulnerability through occupational diversity, assuming communities reliant on single occupations, like fishing or agriculture, face greater challenges recovering from disasters.

Macro-economic vulnerability considers GDP, consumption, fiscal position, and issues like low income and high indebtedness at the national level. Institutional vulnerability, particularly in failed or fragile states, affects the provision of basic human security and post-disaster recovery capacity, as seen in events like the Somalia drought and Haiti earthquake recovery. The World Risk Index approach by Welle et al. (2005) illustrates national-level institutional vulnerability assessment.

In recent years, there has been a growing emphasis on environmental vulnerability, recognising the environment as both the source of natural hazards and a crucial resource for many exposed populations. This approach highlights the role of ecosystem services in shaping human vulnerability and the vulnerability of social-ecological systems. Environmental vulnerability refers to the risk of harm and disruption to livelihoods and societal processes due to environmental degradation, such as land and coastal degradation impacting exposure, susceptibility, and adaptive capacities. Coastal ecosystems like mangrove swamps and reefs offer significant benefits to coastal communities, serving as natural defenses against hazards like coastal erosion and waves. Assessing environmental vulnerability involves identifying the susceptibility and fragility of ecosystem services that communities rely on, such as water filtration and fisheries.

The institutional dimension of vulnerability pertains to governance modes, rules, and capacities of organisations to manage risks and adaptation challenges. Mismatches between governmental and non-governmental adaptation strategies, as seen in flood protection measures and resettlement efforts, can exacerbate vulnerability by overlooking local dependencies on environmental services. Understanding vulnerability to hazards and climate change remains challenging due to changing hazard patterns and dynamic social, economic, and institutional conditions. For instance, increased drought risk in regions like Maharashtra, India, underscores the need to assess community vulnerability to determine potential disaster impacts. Addressing underlying vulnerabilities, including structural inequalities and poverty, is crucial for sustainability in the face of climate change. Both incremental measures and transformative changes are necessary to reduce risks from climate extremes and enhance adaptive capacity.

MEASUREMENT FRAMEWORKS FOR CLIMATE CHANGE VULNERABILITY ASSESSMENTS

There are several frameworks for assessing climate change vulnerability. Most recent frameworks involve a multidisciplinary approach incorporating biophysical and socio-economic factors. These frameworks often focus on understanding how different systems (e.g., ecosystems, human communities) are exposed to climate-related hazards, their sensitivity to these hazards, and their adaptive capacity. The four listed below are some examples of these frameworks which recognise that all measures for addressing climate change and its potential impact should incorporate the human dimensions.

IPCC Vulnerability Assessment Framework

The Intergovernmental Panel on Climate Change (IPCC) has developed a widely-recognised framework that considers vulnerability as a function of exposure, sensitivity, and adaptive capacity. The IPCC framework emphasises the importance of socio-economic factors and has been applied extensively in recent vulnerability assessments (IPCC, 2022).

Social Vulnerability Index (SoVI)

The SoVI tool is used to measure the social vulnerability of communities to environmental hazards. It integrates various socio-economic indicators to assess the potential impact of climate change on different populations (Cutter et al., 2023).

Climate Vulnerability Index (CVI)

CVI is a composite index combining biophysical vulnerability with socio-economic factors to comprehensively assess climate vulnerability. It has been used in various studies to assess the vulnerability of specific sectors or regions (Sullivan, & Meigh, 2023).

Integrated Vulnerability Assessment (IVA)

IVA integrates multiple dimensions of vulnerability, including environmental, economic, and social aspects. It often involves participatory approaches to capture local knowledge and stakeholder input (Hinkel et al., 2022).

These frameworks provide a solid foundation for understanding the complexity of climate change vulnerability and are essential for informing all measures, including institutional arrangements, investments, adaptation strategies, coherent policy development, and all processes that ensure achieving development that is underpinned by climate justice (Aizawa, 2016).

EMPIRICAL WORK ON VULNERABILITY MEASUREMENT

Empirical studies focusing on vulnerability measurement in vulnerable communities in Africa, including South Africa, often highlight how socio-economic, environmental, and political factors intersect to exacerbate climate vulnerability. Some recent examples include the following:

Table 1: Examples of empirical work on vulnerability measurement

Empirical work	Source
Vulnerability to climate change in coastal communities of Ghana This study assessed the vulnerability of coastal communities in Ghana to climate change, using a combination of household surveys and environmental data. The research focused on how socio-economic factors such as income, education, and access to resources influenced the communities' adaptive capacity and overall vulnerability.	Mensah, A. S. & Amponsah, O. (2023)
Social vulnerability in South African townships This research examined the social vulnerability of communities in South African townships, focusing on how historical legacies of apartheid, poverty, and inequality have shaped their vulnerability to climate-related hazards. The study used the Social Vulnerability Index (SoVI) to quantify vulnerability levels across different townships.	Le Roux, A. & Pauw, K. (2022)
Drought vulnerability in rural Ethiopia This empirical study analysed the vulnerability of rural households in Ethiopia to drought, a common climate hazard in the region. The researchers used a mixed methods approach, combining household surveys with GIS-based analysis to assess the spatial distribution of vulnerability and the role of livelihood diversification in enhancing resilience.	Tessema, Y. A. et al. (2023)
Flood vulnerability in informal settlements in Kenya This study focused on the vulnerability of informal settlements in Nairobi, Kenya, to flooding. The researchers conducted participatory vulnerability assessments, involving local residents in identifying key vulnerability factors such as poor infrastructure, lack of drainage systems, and limited access to emergency services.	Otieno, P. O. & Odhiambo, M. O. (2022)
Vulnerability of agricultural communities in South Africa This study examined the vulnerability of smallholder farmers in the Eastern Cape Province of South Africa to climate change. It looked at how factors like land tenure, access to water, and government support influenced the farmers' ability to adapt to changing climatic conditions.	Moyo, B. & Abegunde, V. O. (2022)

These studies provide insights into the specific challenges faced by vulnerable communities in sub-Saharan Africa and South Africa, illustrating the importance of context-specific vulnerability assessments for effective climate adaptation planning.

Alternative risk assessment approach

In assessing the Jurisdictional Vulnerability Index of the Limpopo Province, a thorough examination of the critical components/drivers of hazards using long-term datasets (2010 to 2022) was conducted. These components were selected to reflect the unique challenges faced within the province, particularly concerning environmental risk and community well-being. The key factors included an analysis of environmental degradation, the prevalence of droughts, occurrences of floods, instances of fires, and the prevalence of diseases. These issues within both rural and urban areas are important risk factors across diverse communities within the province. The study focused on geospatial indicators, which can be used as warning indices to help governments and municipalities in their readiness to handle and support communities within an actionable time. The vulnerability assessment focused on a provincial level and scaling down to a district level wherein Vhembe, Mopani, Waterberg, Greater Sekhukhune, and Capricorn districts were evaluated.

METHODOLOGY

Overall, the study used a mixed methods approach with quantitative and qualitative approaches in both sub-components. The CC-JVI pilot component comprised of 1) a document review to extract existing secondary data and describe the context, and 2) focus group discussions (FGDs), field observations, and key informant interviews (KIIs). The provincial-level analysis relied entirely on secondary data analyses based on existing databases. These are described in turn after the description of the underlying research paradigm.

Research paradigm

Pragmatism as a research paradigm offers a flexible and practical approach that integrates both qualitative and quantitative methods to address research questions. It is grounded in the philosophy that the value of research lies in its applicability and utility in real-world situations (Creswell & Creswell, 2017). This paradigm allows researchers to select the methods that best address the research problem, making it particularly useful in studies like the development of a Climate Change Jurisdictional Vulnerability Index (CC-JVI). Pragmatism emphasises the importance of actionable knowledge that can directly influence policy and practice, providing a balanced approach between theory and practical application (Biesta & Burbules, 2003). Another significant merit of pragmatism is its focus on the real-world impact of research findings. It moves beyond traditional dichotomies of qualitative versus quantitative research by advocating for methodological pluralism, where the research question dictates the choice of methods (Morgan, 2014).

In the CC-JVI study, pragmatism facilitated the integration of diverse data sources, such as environmental data and community-level qualitative insights, into a coherent framework that is aimed at informing targeted adaptation strategies for different jurisdictions. Furthermore, pragmatism's emphasis on practical problem-solving aligns well with the goals of applied research, where the objective is to understand a phenomenon and offer solutions (Maxcy, 2003). This paradigm is particularly useful in climate change adaptation studies, where research findings need to be quickly translated into policy and practice to mitigate immediate risks. Pragmatism ensures that research remains relevant and responsive to the needs of the communities it aims to serve (Johnson & Onwuegbuzie, 2004).

Research approach and design

As indicated earlier, a mixed methods approach was employed to generate data for the construction of the CC-JVI. The concurrent research design enabled the simultaneous collection of quantitative data through data mining and qualitative data through FGDs and KIIs. This integration was essential in capturing vulnerability, encompassing measurable environmental and socio-economic factors, community perceptions, and lived experiences. The concurrent mixed methods design allowed for data triangulation, enhancing the findings' validity and reliability (Creswell, 2014). This study's quantitative data on community vulnerability indices were complemented by qualitative data on local adaptation strategies and challenges, thus enriching the overall analysis.

Document review

This was conducted to collect relevant quantitative data and textual material that describes the context and contributes to the calculations of vulnerability to climate change. The documents reviewed included policies, laws and regulations, national and subnational reports, and existing studies related to climate change vulnerability assessments.

Village-Level Vulnerability Assessment

Site population and sampling techniques

The study focused on two villages in Limpopo Province, South Africa: Muyexe and Nkowankowa. Muyexe has a population of 3,228, while Nkowankowa has a much larger population of 390,095. These villages were selected due to their varying levels of exposure to climate change impacts, making them ideal case studies for assessing climate vulnerability and adaptation strategies at the community level.

The convenience sampling method was chosen because it allows for quick and efficient data collection, especially in communities where access to participants may be limited or where time and resources are constrained. In this study, a total of 20 participants were selected from the two villages.

Data collection techniques

Focus group discussions (FGDs) and key informant interviews (KIIs)

FGDs were conducted to capture community-level perceptions, experiences, and local knowledge regarding climate change impacts and adaptation strategies. These discussions are effective for exploring collective views and social dynamics, as they allow participants to build on each other's responses, providing deeper insights into community vulnerabilities and coping mechanisms.

In Muyexe, five (5) FGDs and eight (8) KIIs were conducted, while in Nkowankowa, three (3) focus groups and seven (7) KIIs were conducted. These interviews lasted 30 to 80 minutes, averaging 40 minutes. Each focus group consisted of 8 to 20 participants. Open-ended questions allowed participants to share diverse perspectives, with interviewers intervening only to clarify or deepen discussions, or, in the case of the focus groups, seeking translations, as the primary language for community members is Xitshonga, for both sites. KIIs were typically conducted with a single respondent in their office or the community recreational centre, audio-recorded with permission and transcribed for analysis. In Nkowankowa, one (1) focus group was conducted at a local school and two (2) at the community centre. All of the FGDs in Muyexe were conducted at their local community centre with permission from the chief. Eight (8) FGDs were conducted with 160 participants and 15 KIIs with representatives from various community structures, governmental departments, and civil organisations.

It is important to note that KIIs were carried out with selected individuals who possess specialised knowledge about the community and the effects of climate change, such as local leaders, government officials, and experts.

Provincial-level vulnerability assessment

The study focused on four provinces: Limpopo, KwaZulu-Natal, Mpumalanga, and Eastern Cape. This level of analysis was prompted by the need to address the data availability challenges at the local level. Data tends to be available at municipality, district, provincial, and national levels.

Provincial vulnerability assessment relied on secondary data, which was extracted from various databases. Extracted data included meteorological data from weather stations, satellite images and national databases. The data inputs and their sources are indicated below.

Input and complementary data sources

- Rainfall (Time series) Weather stations' locations South African Weather Services and the Agricultural Research Council Stations
- Wetness index (Time series) Landsat 8-Normalised Difference Water Index (NDWI) Mzansi Amanzi https://www.water-southafrica.co.za/
- Drought index (Time series) Groundwater database ARC-NRE https://www.arc.agric.za/arc%20newsletters/forms/allitems.aspx
- National Groundwater Archive https://www.dws.gov.za/NGANet
- Fire index (Time series) Fire-fighting stations, Roads ARC-NRE https://www.arc.agric.za/arc%20newsletters/forms/allitems.aspx
- Disease database (Statistics) Hospitals' locations Department of health
- Flash floods Evacuation sites' locations USGS https://earthexplorer.usgs.gov/
- Hydrological (Time Series) Portable water sources National Groundwater Archive https://www.dws.gov.za/NGANet
- Districts Shape files Municipal Demarcation Board https://www.demarcation.org.za/
- Population https://census.statssa.gov.za/#/

Fire hazard vulnerability assessment

A vulnerability assessment was conducted to analyse the fire hazard susceptibility in Limpopo. The assessment employed a remote sensing methodology, utilising a sequence of MODIS data ranging from 2010 to 2022 (https://lpdaac.usgs.gov/; Maake et al., 2023). A total of 36 fire index products were generated annually through this process. These products were then integrated by stacking all layers and evaluated based on the frequency of fire occurrences within the region over the assessment period.

In addition to the remote sensing data, information regarding the locations of fire stations was obtained from the South African census database of 2022. Furthermore, a shape file containing road networks was incorporated into the assessment. Employing a GIS-based route-analysis modelling technique, the assessment aimed to ascertain the most efficient routes from fire stations to areas prone to fires, as indicated by the series of fire indices (Papinski & Scott, 2011).

Areas deemed vulnerable were identified based on their distance from fire stations and the quality of road infrastructure. Those situated farther away from fire stations and characterised by poor road conditions were classified as particularly susceptible to fire hazards. This comprehensive approach allowed for a thorough understanding of the spatial distribution of fire vulnerability within the Limpopo Province, enabling proactive measures to mitigate potential risks.

Vulnerability was determined using the raster equation given as:

$$V=(1-R)\times D \qquad (1)$$

Wherein R is the raster layer representing road quality (1 for good quality roads, 0 for poor quality roads). D is the raster layer representing distance from fire stations, with values indicating distance, where higher values denote greater distance. V is the raster layer representing vulnerability, where 1 indicates vulnerability and 0 indicates no vulnerability (Chandra & Olivia, 2014).

Drought vulnerability analysis

To assess the susceptibility to drought within the Limpopo region, a comprehensive vulnerability assessment was conducted. This assessment relied on an integral analysis of annual rainfall data ranging from 2010 to 2022, obtained through interpolation from weather stations operated by both the Agricultural Research Council and the South African Weather Services (Moeletsi et al., 2022).

The first step involved assessing rainfall trends over the assessment period. This was achieved by examining the annual rainfall data to portray any discernible patterns or shifts in precipitation levels. Concurrently, layers depicting surface wetness and Normalised Difference Vegetation Index (NDVI) were incorporated into the analysis. These layers served as supplementary indicators to provide a holistic understanding of environmental conditions that influence drought vulnerability.

The vulnerability assessment showed that areas exhibiting low vulnerability to drought typically recorded higher annual rainfall figures, signifying a greater resilience to drought conditions. Conversely, regions characterised by high vulnerability to drought manifested lower annual rainfall levels, indicating a high risk of succumbing to water scarcity and associated impacts.

To standardise the annual rainfall data for comparative analysis, a normalisation process was undertaken. The annual rainfall composite for the years 2010 to 2022 was transformed to a normalised scale ranging from 0 to 1. In this normalisation, a score of 0 represented instances of minimal rainfall, while a score of 1 denoted instances of abundant rainfall. This standardised approach facilitated a uniform comparison across the entire dataset, enabling a clearer delineation of areas exhibiting varying degrees of vulnerability to drought based on their respective annual rainfall levels.

$$V=(1-R)+S+N \qquad (2)$$

Where R is the normalised annual rainfall raster layer, in this formula, the vulnerability index (VI) is derived by subtracting the normalised rainfall values from 1. This approach ensures that areas with higher rainfall (closer to 1) will have lower vulnerability scores, while areas with lower rainfall (closer to 0) will have higher vulnerability scores. S is a raster layer representing surface wetness (with values ranging from 0 to 1, where 0 is dry and 1 is wet), while N is a raster layer representing NDVI, with values ranging from 0 to 1, where 0 indicates low vegetation density and 1 indicates high vegetation density).

$(1-R)$ component gives more weight to areas with low annual rainfall, as low rainfall is a significant indicator of drought vulnerability. By subtracting R from 1, we effectively prioritise areas with low rainfall in the vulnerability assessment. Surface wetness is a crucial factor in determining drought vulnerability. Higher surface wetness values indicate better soil moisture retention and thus lower vulnerability to drought. NDVI represents vegetation density, which is closely related to drought resilience. Higher NDVI values indicate denser vegetation cover, which can mitigate the impacts of drought by reducing soil erosion and enhancing water retention.

Flash floods

To conduct a vulnerability assessment of flash floods in Limpopo from 2010 to 2022, several raster layers capturing various environmental and socio-economic factors were considered. These layers aided in understanding the susceptibility of different areas to flash floods and assessing the potential impact on the region. The following layers were used:

Digital elevation model (DEM)

The role of DEM data was to provide information about the terrain elevation. The data aimed to identify low-lying areas prone to flooding and areas with steep slopes that may exacerbate flash flood risks. DEM-30 was acquired from the USGS portal and used for this purpose.

Land use/land cover (LULC)

The LULC data was acquired from the Department of Forestry, Fisheries, and the Environment data portal to categorise the land surface into different classes such as urban, agricultural, forested, or water bodies. The LULC aided in identifying land cover types that contribute to increased runoff and potential flash flood risks, such as urban areas with impervious surfaces. The LULC layers used covered the 2014 LULC, 2018 and 2021.This information is available at https://egis.environment.gov.za/gis_data_downloads.

Soil type

The soil type raster layer provided information about soil characteristics such as infiltration rate, permeability, and susceptibility to erosion. This aided in assessing how the different soil types influence water infiltration and runoff, which are critical factors in flash flood occurrence. The soil types layer was obtained from the Agricultural Research Council-Natural Resources and Engineering campus (ARC-NRE).

Precipitation data

Time series raster layers of precipitation data covering the period from 2010 to 2022 were used (Moeletsi et al., 2022). These layers provided information on rainfall intensity and patterns, which are primary drivers of flash floods.

Flow accumulation

The flow accumulation raster layer indicated the accumulation of water flow across the landscape. This aided in identifying drainage patterns and areas where runoff converges, indicating potential flood pathways during heavy rainfall events. This was generated using Arc Hydro tools, which is a plug-in on ArcMap.

Slope

The slope raster layer was used to depict the steepness of terrain. Generally, steep slopes can accelerate surface runoff and increase the likelihood of flash flooding; as a result, the slope layer was used to determine the terrain’s steepness.

Stream networks

The stream network raster layers were used to delineate the natural watercourses and river channels. This assisted in identifying areas prone to flash flooding along riverbanks and low-lying floodplains.

Population density and infrastructure

The population density data and infrastructure data layers were obtained from the Census 2021 database, providing information on human settlement patterns, critical infrastructure, and vulnerable communities.

Vulnerability assessment global model

The Jurisdictional Vulnerability Index included all the variables (drought, fire, disease, and floods) in one model.

Vulnerability is important because an efficient index seeks to go beyond vulnerability alleviation in the present by also examining vulnerability prevention in the future. A vulnerability reduction strategy that ignores the transient nature of vulnerability misses districts that have a high probability of being vulnerable in future and may instead devote scarce resources to communities that are only transiently vulnerable and would have found a way out of risk without government assistance.

The expected benefit is that the overall risk index tells us about the risk and the identified risk-determining factors of communities. This allows us to:

- Compare different communities across a country, to identify, and target communities with high disaster risks
- Recognise the determining factors for each community behind the existing risk: that is, whether the risk stems from the hazard itself (hazard), is due to high vulnerability levels (vulnerability), or comes from a lack of capacity
- Reveal deficits in risk management capacities

Rank-based approach

For jurisdictions with a unit of analysis count of <10, we applied a rank-based method to calculate vulnerability scores. We ranked each unit of analysis based on the observed values of core vulnerability measures and calculated vulnerability scores as the summed rankings of each of the core variables.

Diseases

Rabies was one of the major diseases occurring across the whole province. Data regarding rabies cases was obtained from the Agricultural Research Council-Onderstepoort Veterinary Research (ARC-OVR), while spatial data was obtained from the Agricultural Research Council-Soil Climate and Water Institute (Mogano et al., 2024). Only the data for 2010-2022 was used in this study. Healthcare facilities for animals and people were assessed to identify the proximity of the facilities to rural areas.

Reliability and validity

Reliability refers to the consistency or repeatability of a research study or measurement tool. It indicates the extent to which a method, instrument, or procedure yields the same results under consistent conditions (Creswell & Plano Clark, 2018). The study ensured reliability and validity through several strategies. Reliability was maintained by using multiple data sources and methods, which allowed for cross-validation of the findings. Triangulation of data from FGDs, KIIs, and index computation helped minimise biases and increased the consistency of the results.

Validity refers to the accuracy or truthfulness of a research study or measurement tool. It indicates the extent to which the instrument measures what it is intended to measure. A valid measure accurately reflects the concept it is supposed to capture (Babbie, 2016: Polit & Beck, 2017). This was addressed through face and content validity checks. Face validity was ensured by involving team members with expertise in climate change and vulnerability assessments to review the data collection tools and processes. This helped confirm that the methods and measures used were appropriate and relevant to the research questions. Content validity was achieved by including a range of indicators in the index computation and by thoroughly covering all relevant aspects of climate vulnerability in the qualitative data collection.

Team members with expertise in various disciplines reviewed the indicators and qualitative data to ensure that they adequately represented the concept of vulnerability.

All the information collected above was then used in computing and interpreting the CC-JVI. Index computation is a quantitative research method used to create a composite measure that aggregates multiple indicators (variables) into a single index score. This process involves selecting relevant (proxy) variables, standardising them, and combining them using a specific formula to produce an overall score that reflects a broader concept, such as vulnerability in this current pilot study (Field, 2013). The process followed is described in the succeeding section.

Data analysis

Village-level analysis

Data analysis involved both thematic analysis and index development to assess the vulnerability of the study area to climate change. Thematic analysis was used to interpret qualitative data collected through FGDs and KIIs. The development of the CC-JVI involved the analysis and evaluation of various indicators, such as on exposure, sensitivity and adaptive capacity, of vulnerability.

Thematic analysis began with the familiarisation stage, where researchers thoroughly reviewed and transcribed data to gain an in-depth understanding of the content. This step was key for identifying themes related to community experiences and perceptions of climate change impacts. Next, the data was systematically coded by highlighting relevant text segments and assigning labels representing the key ideas expressed by participants. These codes were then grouped into broader categories that encapsulated recurring patterns. Following the coding process, the development of themes involved a more refined analysis where related codes were collated into cohesive themes that captured the essence of the data. Each theme was reviewed to ensure it was distinct, internally consistent, and well-supported by the data.

The data collection process, as shown by the tool in **Appendix A**, initially focused on obtaining responses from key informants and secondary sources about the villages of **Muyexe** and **Nkowankowa** in Limpopo Province. The objective was to collect data related to various dimensions of climate change vulnerability, exposure, sensitivity, and adaptive capacity. However, the response rate from these communities was significantly lower than anticipated, leading to considerable gaps in the dataset. Many variables key to the development of climate vulnerability were left unanswered, making it challenging to construct a full picture of the current conditions in these villages. This limited response was a significant constraint, as the study aimed to use this data to pilot the development of a CC-JVI tailored to local contexts. Given the low response rate and the resulting data insufficiencies, the available information was carefully categorised into the key dimensions of vulnerability, as shown in **Appendix B**. The responses obtained were mapped against sensitivity, exposure, and adaptive capacity.

Despite these efforts, the analysis revealed that the data collected from Muyexe and Nkowankowa was inadequate for a meaningful computation of the CC-JVI. This implied that vulnerability could not be quantified from this dataset, thus limiting the reliability and validity of any index derived from this initial dataset. This meant that there was a critical need for a broader and more inclusive data collection strategy to support the development of a robust vulnerability index.

Provincial- and district-level analyses

Having recognised the limitations posed by the inadequate data from these two villages, the research team decided to extend the data collection efforts beyond Muyexe and Nkowankowa. To fill in the gaps, data collection was expanded to include local municipalities encompassing these villages, as well as other regions across four provinces: Limpopo, Eastern Cape, Mpumalanga, and KwaZulu-Natal.

This expansion aimed to gather a more representative and detailed set of data, capturing the diverse climatic and socio-economic conditions across these regions. The inclusion of local municipalities allowed for a more detailed comparison and ensured that the CC-JVI would be reflective of a wider array of environmental and socio-economic contexts. By broadening the scope of the study, the research team was able to collect data from reliable sources such as Statistics South Africa Census 2011 and 2022 at local municipalities, then rolled over to provincial level, that encompassed a broader spectrum of vulnerability indicators, making the subsequent analysis more applicable to said villages and multiple jurisdictions. With this dataset at local municipalities, the computation of the CC-JVI became feasible. The data collected from the municipalities provided a more complete picture of the various dimensions of climate vulnerability, such as differing levels of exposure to climate hazards, variations in socio-economic sensitivity, and the adaptive capacities of communities across the four provinces (Limpopo, Mpumalanga, KwaZulu-Natal and Eastern Cape). This broader dataset enabled the research team to develop a more comprehensive and accurate index, highlighting the specific vulnerabilities of each jurisdiction. The expanded CC-JVI thus offered a better understanding of climate change impacts, providing valuable information for policymakers to prioritise and tailor adaptation strategies based on the specific needs of each region.

The initial CC-JVI for **Muyexe** and **Nkowankowa** was planned to be computed from the following equations.

$$(CC - JVI)_{kj} = [E_{KJ} + S_{KJ}] - A_{kj} \qquad (CC - JVI)_{kj} = [E_{KJ} + S_{KJ}] - A_{kj} \quad \text{.......... (3)}$$

Where:

E_{kj} E_{kj} = Exposure function of the jurisdiction *j* with respect to economic sector *k*
S_{kj} S_{kj} = Sensitivity function of the jurisdiction *j* with respect to economic sector *k*
A_{kj} A_{kj} = Adaptive capacity of the jurisdiction *j* with respect to economic sector *k*

For CC-JVI, protocols have been developed for the determination of the function E_{kj}, S_{kj}, and A_{kj} for operations of equation (1). The maximum vulnerability is the case where there is no Adaptation Capacity, i.e., $\boldsymbol{A_{kj}} = 0$. Each climate change jurisdictional vulnerability component comprises several parameters that, combined with the assigned coefficient, determine its magnitude. The parameters involved depend on the area and economic sector of concern. The equation is given by:

$$C_x = \Sigma_n^n = 1 \; a_i \, x_i \; C_x = \Sigma_n^n = 1 \; a_i \, x_i \quad \text{.......... (4)}$$

Where:

C_x = the magnitude of that component which could be E_{kj} or S_{kj} or A_{kj}
n = the number of parameters that are significant to the component with respect to climate change and the type of vulnerability (socio-economic) sector concerned
a_i = the score coefficient of the raw score of the parameters determined from charts
x_i = the raw score of the parameters taken from the provided charts

The coefficients $\boldsymbol{a_i}$ and $\boldsymbol{x_i}$ derive from analyses of the effects of climate change on natural systems, infrastructure, and social systems. The coefficients have magnitudes that are fractions up to a maximum of 1.0 while raw scores are configured to range from 0 to 10. Exposure, *E* is herein, defined as the size of the area affected and the intensity of the stressor (primary or secondary) modified by the intensity of the stressor. The size of the area affected can be determined from climate change zonation maps based on projected temperatures, sea level rise, and hydrometeorology (e.g. rainfall). The relevant equation is presented as equation (4).

$$E_x = \Sigma_n^n = 1 \; f_{ei} \cdot e_i \; E_{kj} = \Sigma_n^n = 1 \; f_{ei} \cdot e_i \quad \text{.......... (5)}$$

Where:

$\boldsymbol{E_{kj}}$ = Exposure function of the jurisdiction j with respect to economic sector k

$\boldsymbol{n}$ = the number of component stressors selected to define the exposure of the socio-economic sector concerned

$\boldsymbol{e_i}$ = the raw score on component i

$\boldsymbol{f_{ei}}$ = the exposure frequency which is the ratio of the area exposed to the climate change derived stressor concerned, relative to the area of the jurisdiction considered.

Sensitivity focuses on the attributes of the jurisdiction that particularly make it vulnerable to exposure level/stresses imposed by global climate change. In this CC-JVI methodology, sensitivity, S, is formulated as equation (6).

$$S_{kj} = \Sigma_n^n = 1 \ f_{si} \ s_i \ s_{kj} = \Sigma_n^n = 1 \ f_{si} \ s_i \quad \ldots\ldots(6)$$

Where:

$\boldsymbol{S_{kj}}$ = the sensitivity of jurisdiction j to the vulnerability parameter i which is computed as the summation of the product of the sensitivity coefficient f_{si} and the sensitivity raw score s_i of the parameter for that jurisdiction.

$\boldsymbol{f_{si}}$ = is assumed to have a magnitude of 1.0 which assumes that all parameters have equal weight except that their magnitudes within specified ranges determine their raw scores $\boldsymbol{s_i}$

$\boldsymbol{A_{kj}}$ is the adaptation score of the jurisdiction j computed as the summation of the products of the adaptation effectiveness coefficient, $\boldsymbol{f_{ai}}$ and adaptation raw score a_i of the specific measures which can range in number from a single measure to n number of measures. It should be noted that a specific adaptation measure can have a different level of implementation effectiveness in addressing a particular climate change (exposure and sensitivity).

$$A_{kj} = \Sigma_n^n = 1 \ f_{ai} \ a_i \ A_{kj} = \Sigma_n^n = 1 \ f_{ai} \ a_i \quad \ldots\ldots(7)$$

After establishing that the planned CC-JVI computation was not feasible with existing village-level data, a new set of proxy variables was collected from NASA online database and Statistics South Africa Census 2011 and 2022 as shown in Tables 2 and 3. Proxy variables are indicators or measures that stand in for or represent a concept or phenomenon, which might be difficult to measure directly. In the context of the current climate change vulnerability computation, proxy variables are used to assess aspects such as sensitivity, exposure, and adaptive capacity, which together determine a region's overall vulnerability to climate change impacts (Birkmann et al., 2021). These variables are chosen because they are quantifiable and have a known or presumed relationship with the concept they represent. The functional relationship describes how changes in the proxy variables influence the level of vulnerability to climate change (Halkos et al., 2020). This relationship can be positive or negative, indicating whether an increase in the proxy variable leads to an increase or decrease in vulnerability (Sang & Hamann, 2022). For example, higher temperature can increase the vulnerability of ecosystems in certain regions (Zhu et al., 2020). Table 2 shows the selected proxy variables with both functional relations and descriptions respectively.

Table 2: Proxy variables and their functional relations with climate change vulnerability

Dimension/Proxy variable	Variable description on climate vulnerability	Functional relation with vulnerability
Sensitivity	Measures the degree to which a system is affected by climate variability and change	
Young children (0-14 years)	More susceptible to health issues and climate impacts	Increase (+)
Elderly (65+ years)	Higher vulnerability to climate-related health issues	Increase (+)
Dependency ratio	Higher dependency ratio can indicate a greater burden on the working-age population, affecting overall community resilience	Increase (+)
No schooling (20+ years)	Lack of education can limit awareness and adaptive capacity, increasing vulnerability	Increase (+)
Sex ratio	Imbalanced sex ratios can affect social dynamics and resilience	Increase (+)
Long-term precipitation average	Changes in long-term precipitation patterns can significantly impact water availability, agriculture, and ecosystem health	Increase (+)
Maximum temperature	High temperatures can lead to heat stress, health issues, and reduced agricultural yields, making regions more sensitive to temperature extremes	Increase (+)
Exposure	Refers to the presence of people, livelihoods, species, ecosystems, or assets in places that could be adversely affected	
Total population	Larger populations may face greater challenges in managing climate impacts	Increase (+)
Number of households	More households can mean more people potentially exposed to climate risks	Increase (+)
Average household size	Larger households might have more people at risk, but also more resources for mutual support	Increase (+)
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	
Working age population (15-64 years)	Represents the economically active segment that can drive adaptive measures	Increase (+)
Higher education (20+ years)	Higher education levels generally correlate with better awareness and capacity to implement adaptive strategies	Increase (+)
Flush toilets connected to sewerage	Indicates better sanitation infrastructure, which is crucial for health resilience	Increase (+)
Weekly refuse disposal service	Regular waste management reduces health risks and supports community resilience	Increase (+)
Access to piped water in the dwelling	Essential for health, sanitation, and overall well-being, supporting adaptive capacity	Increase (+)
Electricity for lighting	Access to electricity is critical for modern living, enabling communication, education, and other adaptive measures	Increase (+)

Table 3: Proxy variables

Dimension/Proxy variable	Variable description on climate vulnerability
Sensitivity	Measures the degree to which a system is affected by climate variability and change
Young children (0-14 years)	More susceptible to health issues and climate impacts
Elderly (65+ years)	Higher vulnerability to climate-related health issues
Dependency ratio	Higher dependency ratio can indicate a greater burden on the working-age population, affecting overall community resilience
No schooling (20+ years)	Lack of education can limit awareness and adaptive capacity, increasing vulnerability
Sex ratio	Imbalanced sex ratios can affect social dynamics and resilience
Long-term precipitation average	Changes in long-term precipitation patterns can significantly impact water availability, agriculture, and ecosystem health
Maximum temperature	High temperatures can lead to heat stress, health issues, and reduced agricultural yields, making regions more sensitive to temperature extremes
Exposure	Refers to the presence of people, livelihoods, species, ecosystems, or assets in places that could be adversely affected
Total population	Larger populations may face greater challenges in managing climate impacts
Number of households	More households can mean more people potentially exposed to climate risks
Average household size	Larger households might have more people at risk, but also more resources for mutual support
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
Working age population (15-64 years)	Represents the economically active segment that can drive adaptive measures
Higher education (20+ years)	Higher education levels generally correlate with better awareness and capacity to implement adaptive strategies
Flush toilets connected to sewerage	Indicates better sanitation infrastructure, which is crucial for health resilience
Weekly refuse disposal service	Regular waste management reduces health risks and supports community resilience
Access to piped water in the dwelling	Essential for health, sanitation, and overall well-being, supporting adaptive capacity
Electricity for lighting	Access to electricity is critical for modern living, enabling communication, education, and other adaptive measures

Source: Statistics South Africa, 2022; The National Aeronautics and Space Administration (NASA), 2024

Normalisation of variables in vulnerability assessments is important when dealing with variables that have different units. This process converts variables to a common scale, making it easier to compare and combine them without the bias of differing magnitudes or units. Normalisation ensures that each variable contributes equally to the assessment, preventing any single variable with larger numerical ranges from dominating the results (Moreira et al., 2021). It allows for the comparison of variables that are measured in different units (e.g., temperature in degrees, rainfall in millimetres, and population density in people per square kilometres) by converting them to a common scale (Sbai et al., 2021). Normalised variables can be more easily aggregated into a composite index, which simplifies the overall vulnerability assessment process.

This is particularly useful when dealing with complicated systems that require the integration of multiple indicators (Halkos et al., 2020). It helps in performing sensitivity analysis to understand the impact of each variable on the overall assessment. It ensures that the analysis is not skewed by the scale of the variables but reflects their true influence on vulnerability (Wang et al., 2020). Equations 8 and 9 were used in the normalisation of the proxy variables depicted in tables 3 and 4 with increasing and decreasing functional relationships respectively.

$$X' = \frac{X - Xmin}{Xmax - Xmin} \quad X' = \frac{X - Xmin}{Xmax - Xmin} \quad \ldots\ldots (8)$$

$$X' = \frac{Xmax - X}{Xmax - Xmin} \quad X' = \frac{Xmax - X}{Xmax - Xmin} \quad \ldots\ldots (9)$$

Where:

- X is the original value with or without units of the proxy variable.
- X_{min} is the minimum value of the proxy variable.
- X_{max} is the maximum value of the proxy variable.
- X' is the normalised value of the proxy variable.

Once all variables were normalised, they were averaged per dimension, exposure, sensitivity, and adaptive capacity. The formula for the proposed Climate Change Jurisdictional Index (CC-JVI) is given by **JVI (E, S, AC) = [Exposure + Sensitivity] – [Adaptive Capacity]**. This calculation ensures that the final index reflects the combined effect of each dimension, highlighting the overall vulnerability based on these key indicators (Schneiderbauer et al., 2020). Averaging the normalised variables within each dimension, this methodology accounts for the various influences that exposure, sensitivity, and adaptive capacity have on the system being studied. This approach provides a complete view of vulnerability, allowing for more accurate comparisons and assessments. The normalised values range between 0 and 1, and tend to follow a Beta probability distribution function with the probability density function (PDF, expected mean E(X), and variance (VAR (X)), respectively.

$$PDF = \frac{X^{a-1}(1-x^{ß-1})}{B(a,ß)} \ldots\ldots (10)$$

$$\text{Where, } B(a,ß) = \frac{\tau(a)\tau(ß)}{\tau(a,ß)}$$

$$B(a,ß) = \int_0^1 X^{a-1}(1-x)^{ß-1}dx \ldots\ldots (11)$$

$$E(X) = \frac{a}{(a+ß)} \ldots\ldots (12)$$

$$VAR(X) = \frac{aß}{(a+ß)^2(a+ß+1)} \ldots\ldots (13)$$

This distribution provides a suitable model for the normalised data, capturing the variability and patterns within the dataset. The beta distribution is particularly useful in this context because it is defined on a finite interval [0, 1], matching the range of the normalised values. Given this distribution, specific fractals are utilised to interpret the vulnerability indices, offering a good understanding of the data and aiding in the identification of critical areas requiring attention.

These fractals help in breaking down the indices into interpretable ranges thus enhancing the ability to pinpoint and address high-risk areas effectively (Hlalele, 2019). Table 4 provides fractal stages of vulnerability and how they were interpreted in the current study.

Table 4: Fractal stages of vulnerability

Description	Stage/range
Less vulnerable	0.0 < VI < 0.2
Moderately vulnerable	0.2 < VI < 0.4
Vulnerable	0.4 < VI < 0.6
Highly vulnerable	0.6 < VI < 0.8
Very highly vulnerable	0.8 < VI < 1.0

Source: Hlalele, 2019

In this study, several statistical tests were utilised to analyse vulnerability levels across different provinces. The Independent Samples t-Test, specifically the Mann-Whitney U test, was employed to compare vulnerability levels between provinces that were not related to one another. The Mann-Whitney U test is a non-parametric test used when comparing two independent groups, particularly when the data do not meet the assumptions (i.e. normal distribution) required for a parametric test like the independent samples t-test. It assesses whether there is a statistically significant difference between the medians of two groups (Happ et al., 2019). The Paired samples t-Test, on the other hand, was used to assess vulnerability levels within the same province. This parametric test compares the means of two related groups to determine if there is a statistically significant difference between their means. It is typically used when comparing two measurements from the same individuals or groups at different points in time or under different conditions (Afifah et al., 2022). The Kruskal-Wallis test was employed to assess differences in vulnerability levels across provinces. This non-parametric test is used to compare the median ranks of more than two independent groups. It is an extension of the Mann-Whitney U test and is used when comparing more than two groups or conditions that do not meet the assumptions for parametric analysis of variance (ANOVA) (Jamil & Khanam, 2024). Descriptive statistics, including means, were used to summarise and compare vulnerability ratings among provinces. Descriptive statistics involve numerical and graphical techniques to provide insight into the distribution and characteristics of the data being studied (Mishra et al., 2019). In this case, means were used to represent the average vulnerability level in each province, helping to provide a clear and concise summary of the data for comparison and interpretation.

RESULTS AND DISCUSSION

The results are presented in three main categories: a) documents review, b) community pilot results, and c) provincial-level results

Policy and legal context

The national disaster management documents highlight that South Africa's tools for addressing climate change and extreme events in disaster risk reduction (DRR) are backed by legal mandates for disaster management, as outlined in the South African Constitution. Specifically, the Constitution requires South African municipalities to develop and implement disaster management plans (DMPs). Key legislative instruments include the Disaster Management Act 57 of 2002, the Disaster Management Amendment Act 16 of 2015 (DMAA), and, at the local level, the Municipal Systems Act 32 of 2000.

Currently, there is no legal requirement for local governments to have separate climate change adaptation (CCA) strategies or plans. However, the Climate Change Act 22 of 2024, the National Climate Change Response White Paper (NCCRWP), and the National Climate Change Adaptation Strategy (NCCAS) encourage the integration of CCA into Integrated Development Plans (IDPs). While many better-resourced district municipalities have developed separate CCA strategies or plans, local municipalities have paid less attention to this.

According to the Department of Environmental Affairs (DEA), the NCCAS provides a framework for a unified CCA strategy that promotes the harmonisation of adaptation efforts across all levels of government—national, provincial, and local—while also fostering collaboration between different sectors.

Village level: qualitative results

Tables 5 and 6 below show the profile of respondents who participated in the FGDs and KIIs in the selected villages.

Table 5: Profiles of FGD participants

	Muyexe village	Number (n)
Gender	Male	20
	Female	60
Age group	18-35 years	24
	36-45 years	13
	45-59 years	17
	>60 years	26
	Nkowankowa village	**Number (n)**
Gender	Male	3
	Female	40
Age group	18-35 years	24
	36-45 years	5
	45-59 years	8
	>60 years	1
Totals		**241**

Table 6: Profiles of KII participants

Gender	Age group	Interview location	Number of key informant interviews
Male	35-60 years	Greater Giyani Municipality/ Muyexe Village	4
Female	40-60 years	Greater Giyani Municipality/ Muyexe Village	4
Male	35-49 years	Greater Tzaneen Municipality/ Nkowankowa	4
Female	24-37 years	Greater Tzaneen Municipality/ Nkowankowa	3
Totals			**15**

General knowledge and awareness

In Muyexe and Nkowankowa, climate change is generally acknowledged by participants, though their views differ. Demographic and development factors like high population density, poverty, and unemployment have increased the communities' vulnerability to drought and flood hazards. These factors highlight the different levels of vulnerability within these areas. Participants from Muyexe reported experiencing more frequent and intense climate extremes, especially drought, which they directly attribute to climate change based on their everyday observations. During FGDs, participants shared personal stories and historical timelines related to climate events. One participant recalled taking her children to school in 2021 when the roads were flooded, a situation worsened by the failure of disaster warnings.

In Nkowankowa, participants identified flooding as a major risk, particularly urban flooding, which they linked to city-related issues such as riverbed encroachment and deforestation. These problems are driven by the demand for land, housing, and fuelwood. Additionally, there is widespread non-compliance with urban bylaws, and municipal officials fail to enforce regulations effectively.

In Nkowankowa, certain areas have been declared "unliveable" due to frequent flooding, which has affected numerous homes, shops, and churches located in flood-prone zones. Participants noted that government agencies are not fully aware of the threats faced by these vulnerable communities. The impacts of such hazards have not been comprehensively studied, primarily because local officials are still in the early stages of disaster risk data collection. As one Nkowankowa resident remarked,

"All these things are being done in a piecemeal manner ...
data acquisition and awareness programmes are at initial stages,
and climate risk factors are yet to be incorporated into infrastructure planning and design."

While climate change is widely recognised, its impacts and the necessary responses are still not sufficiently addressed by government and municipal officials. Flooding affects everyone. When the main road floods, it becomes eroded, making it difficult for both learners to get to school and adults to commute to work. This challenge affects everyone, regardless of whether they use public or private transportation. No one—young or old—is immune to the difficulties brought by climate change and floods, as these events disrupt daily life for the entire community.

Key messages emerging from the FGD

The key messages emerging during the FGDs include the following:

- Local engagement was insufficient despite the need for effective communication of central warnings to local communities.
- Information is often shared through trusted networks, making it essential to strengthen these channels and address any gaps within the community.
- There was a lack of cross-governance collaboration, as government departments, local authorities, and village chiefs failed to coordinate efforts to deliver consistent messages.
- Local observers and practitioners residing in Nkowankowa are often the first to notice emerging issues and can suggest effective adaptation strategies when hazards disrupt the community.

Participants observed that government agencies are not fully attuned to the threats faced by vulnerable communities. The impacts of hazards have not been thoroughly studied, partly because local officials are still in the early stages of disaster risk data collection. As one Nkowankowa resident remarked,

There was consensus among participants, both male and female, that community members living by the riverside or near sloping landscapes should be prioritised for disaster risk reduction interventions. If this is not possible, they need to be relocated to safer areas to reduce their risk of disasters. For instance, unemployed or semi-skilled farmers residing in disaster-prone environments would benefit from moving to locations that not only minimise their disaster risk but also enhance their opportunities for self-employment. Essentially, relocating communities from high-risk areas can be seen as a key strategy in disaster risk reduction.

Regarding access to resources and motivation for adaptation, participants in both the Muyexe and Nkowankowa communities primarily viewed resources in terms of financial, technological, and human capacities, rather than natural or physical assets. The absence of these resources was perceived as a major barrier to effective adaptation. Key insights included comments such as, "resources are a major constraint" and "financial support is neither forthcoming nor provided at the right time."

Many participants also emphasised a shortage of human resources, particularly during the implementation phase when infrastructure needs rebuilding, resulting in slow progress. Agriculture is a crucial livelihood in the area, with many people depending on crop cultivation. One participant remarked, "You can see we have a nursery here. This area is underwater during the rainy season, and during drought periods, communities suffer a lot." Flooding disrupts access to resources and daily necessities, while drought devastates livelihoods, often forcing people to migrate to larger cities in Gauteng Province.

A key informant added,

*"I have 2 or 3 people employed on a full-time basis,
now I'm thinking of sacrificing one of them because of income
exacerbated by flooding we experienced recently."* – KII woman, aged 46

A bricklayer leader in Muyexe mentioned that no groups assist the community during disasters. However, a member of the chief's community committee noted that the government does intervene by vaccinating people, including children, against diseases like malaria and diarrhoea. While the disaster management department visits the village after a disaster, they do not regularly update the community on weather conditions or climate change.

When people are not compensated due to disasters, they become more vulnerable to the impacts of climate change, which can push them into or further into poverty. This underscores the severe economic impact of climate disasters on those who depend on monthly income or stipends to sustain their livelihoods.

The current "work-to-get-paid" system is inadequate during such disasters and arguably needs policy reform to ensure workers continue to receive payment, even during extreme events like flooding.

Flooding and property damage directly affect livelihoods, as homes provide essential shelter and security for families. Repairing or rebuilding damaged homes can be costly, particularly for households that were unprepared for such events. Therefore, providing disaster income for employed individuals and establishing a compensation fund for the unemployed could greatly assist in mitigating the impact of property damage caused by disasters.

Poor communities face a greater risk of displacement and slower recovery after disasters. In Muyexe, approximately 59% of the population is unemployed, with similar rates for both men and women. However, unemployment tends to decrease significantly with age and higher expenditure levels. In Nkowankowa, flooding affects everyone—men, women, the elderly, and young people. Floods create significant disruptions, forcing participants to take alternative routes to work or school, while some are forced to stay home. For instance, if a school bus cannot reach a household due to flooding, children are unlikely to be picked up. Similarly, if adults cannot get to work, they are financially penalised, despite the circumstances being beyond their control.

During disasters, traditional leaders, government officials, and religious figures provide leadership. However, participants pointed out that not everyone receives assistance during crises. As one participant explained,

*"Where I am from, we never experienced such help;
they only assist with water if there is a funeral, otherwise you don't see them."*

The same respondent added that they had been suffering from drought for over two years, which had prevented them from growing food and had left them without access to wild food. Most participants agreed that they had not received meaningful support. A ward councillor in her mid-forties mentioned an organisation called "Vatsekela", which educates communities about climate change and disasters, including in Muyexe. Another respondent noted that political organisations provide food parcels and alternative accommodation, especially during election periods. Additionally, royal councils often request disaster management to provide aid during emergencies, while home-based care helps with health, environmental, pollution, and cleaning issues.

Flooding also causes severe erosion, especially on main roads, making travel to schools and workplaces difficult, regardless of whether people rely on public or private transportation. Participants in the FGDs highlighted that no one, regardless of age or gender, is immune to the challenges posed by climate change and flooding.

Below are some of the quotations shared during the FGDs:

*"Using public transport doesn't change the situation. For those with
their own vehicles, they still can't leave their homes,
just like public transport users."* – KII woman, aged 44

*"The roads are flooded, and the drainage systems are
inadequate, indicating a lack of expertise in addressing this problem."* – KII man, aged 53

*"Public transport can't follow its usual routes, forcing people
to walk longer distances to reach main roads for taxis or buses.
This greatly affects schoolchildren, as many rely on
transport that picks them up at their homes."* – KII woman, aged 34

"The areas affected include those along the roads I mentioned and the flat regions near the river. In Nkowankowa, flooding occurs from the river that borders the eastern side. The landscape here slopes down towards the river." – KII man, aged 56

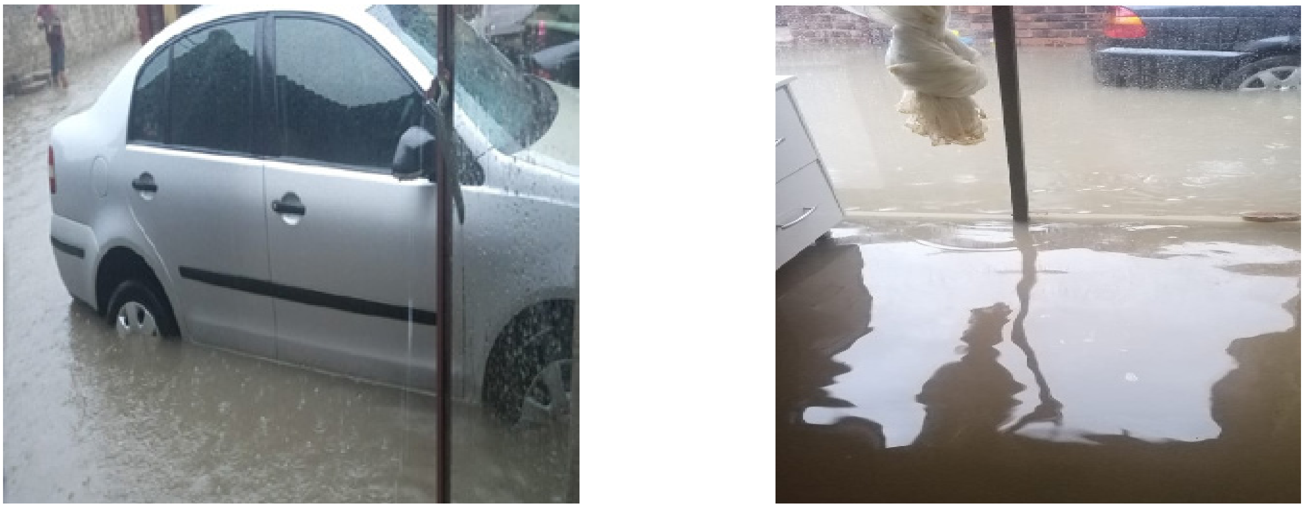


Figure 2: Flooding of roads and houses in Nkowankowa

Source: Researcher's archives

Participants emphasised that communities living near rivers or on sloping terrains should be prioritised for disaster risk reduction interventions. If this is not feasible, relocation to safer areas is necessary to minimise risks. For instance, unemployed or semi-skilled farmers in disaster-prone regions should be moved to environments that enhance self-employment opportunities. Relocating high-risk communities is crucial.

Participants also pointed out a lack of direct training to help them cope with climate change impacts. Although some have sought information online, one participant noted receiving training but could not specify its details, making it hard to evaluate its relevance. Thus, training programs must be tailored to the specific vulnerabilities and needs of the community to be effective. Additionally, participants mentioned difficulties in pre-planning for disasters due to their unpredictability. Generally, their primary coping strategy is to stay indoors, based on the advice they receive.

Below are excerpts from key informants who agree that knowledge and skills transfer is crucial for addressing climate challenges:

"To be honest, there's no skills and knowledge to cope with disasters because it's, it's not, planned. At the same time, you won't know what kind of disaster can reach you" – KII man, aged 26

"I normally check the UN page, the United Nations page, and because they've learned a lot of things about it, about disaster or how to cope with disaster" – KII man, aged 42

"When disasters happen, be it flooding, storms or whatever, we're normally advised to stay indoors and also how to defend ourselves during the flooding —because you never know what can happen" – KII woman, aged 43

"We receive training, particularly events or sessions organised by the Office of the Premier and CoGTA. Recent, they were doing it in liaison with the University of Kwa-Zulu Natal" – KII woman, aged 28

Participants believed that training on hazards and health risks could help prevent households from settling in hazardous areas. Educating communities about global warming and disaster prevention could protect livelihoods. In both Muyexe and Nkowankowa, participants felt that even if individuals choose to remain in disaster-prone areas, they should receive guidance on coping and adapting during disasters to build resilience against floods and droughts.

Raising awareness and providing knowledge can empower communities to take proactive steps in disaster risk reduction. Shared strategies can significantly minimise property damage and health risks, such as injuries. Moreover, if locals are equipped with adaptation strategies, fewer people will be affected by disasters. These strategies enable communities to plan ahead and be better prepared for future events. Effective planning and coping strategies are essential for mitigating climate risks and should be prioritised at the local level.

"We need to be capacitated on global warming because it is presenting a lot of challenges, people need to be taught that these are the challenges we are facing. People living in flood-prone areas aren't taught on evacuation. We are actually reactional than proactive" – FGD woman, aged 56

"Just the training on mitigation strategies in terms of planning. Particularly planning of the infrastructure and human settlements" – FGD woman, aged 47

Participants in Muyexe reported that droughts significantly impacted the physical and emotional health of vulnerable households and subsistence farmers. The uncertainty and trauma associated with drought left many farmers anxious about the survival of their crops. A 67-year-old female participant shared,

"We lost a lot of maize during the drought, and now that we've replanted, I'm unsure how it will turn out. As farmers, we face such uncertainty and trauma."

Farmers expressed profound despair during droughts. In previous dry periods, some received rain only in the last two days, leading them to nearly give up hope. Similar sentiments were echoed during severe droughts, with communities describing themselves as "losing hope" and "just waiting for the drought to pass." A 47-year-old male participant remarked,

"We start praying for rain and leave everything up to the Almighty. We also conduct prayer rituals, hoping it will rain soon."

The cascading effects of drought were linked to broader life challenges in Muyexe. Farmers feared that lost income could affect their children's education, resulting in long-term consequences. FGDs revealed difficulties in "sending their children to school" due to additional expenses, such as books, bags, and shoes. These challenges could create "spiraling and intergenerational effects," ultimately undermining future livelihoods.

Participants generally agreed that disasters offer little benefit, except for those who exploit the situation, such as thieves. However, some noted that certain individuals do profit during disasters. For instance, borehole owners sell water to the community, donkey cart owners charge for water transport, some engage in gardening, and royal leaders retain portions of the donations.

Figure 3: Community gardens in Nkowankowa

Source: Researcher's archives

Participants expressed mixed views on the involvement of government and community leaders during disasters. Some criticised the lack of visible and proactive support, noting that assistance typically arrives only when the situation becomes dire. Others acknowledged that government officials do provide resources such as tents, blankets, and food parcels during floods, but this aid is often selective and not uniformly distributed.

Issues with aid distribution were highlighted, with participants noting bias that favours certain groups or areas over others. For instance, one participant pointed out that water is provided to Muyexe B, but not to Muyexe A. Moreover, some mentioned that aid, like water, is only given during funerals and not during other times of need.

The distribution of food parcels was also criticised by participants claiming that food was often allocated to friends and families of those in charge rather than those in need and most affected disasters. During drought, participants reported receiving COVID-19 relief parcels instead of drought-related aid.

Despite these challenges, some participants recognised that certain government services, particularly those from the Department of Social Development, remain functional. They mentioned receiving agricultural assistance, including seeds, tractors, and fodder for livestock, although not all needs were met due to limited resources.

In summary, while some individuals and groups benefit during disasters, most participants expressed dissatisfaction with the uneven distribution of aid and the inconsistent support from leaders and government agencies.

Drought and flood vulnerability reduction, adaptation strategies and actions

The study found that floods have caused severe damages in the study sites. Households were severely affected as some of the houses were flooded and overflowed, and certain roads were cut off or made impassable. The FGDs, KIIs, and field observations were the main instruments employed to identify flood and drought vulnerability adaptation strategies or actions in these areas. Inadequate drought adaptation measures further marginalise vulnerable communities, and subsistence farmers and ultimately increase their vulnerability to drought risks and loss and damage (L&D). Households and key informants (district, municipality, government officials) were also asked to rank all identified coping strategies according to their preference and effectiveness.

The study revealed that community adaptation strategies were widely implemented across the study sites. A common preference among respondents was the construction of a "le-guba," a raised porch that surrounds the house.

Figure 4: The "le-guba" surrounding many houses across Nkowankowa

Source: Researcher's archives

The "le-guba" strategy emerged as a popular long-term adaptation mechanism among respondents in the FGDs across the communities visited. The use of sandbags, made from materials such as sturdy substances filled with sand or soil, was also a common practice. In severe flooding cases, temporary relocation was an option, as noted in Nkowankowa.

However, fewer respondents chose more permanent solutions, such as building protective walls around homes or terraces in fields. The least favoured strategies included constructing houses with stone and mortar or creating personal drainage systems. Key informants, particularly from the municipality and government, advised that with a growing population, better drainage systems and stronger housing are necessary to mitigate further damage.

Unfortunately, municipalities often lack the resources to develop and implement disaster risk preparedness measures, early warning systems, and disaster management plans (DMPs). This is concerning, especially since the Disaster Management Act (DMA) requires South African municipalities to create and coordinate these plans. Our findings reveal widespread non-compliance with this legal mandate, which is particularly alarming given the 2015 amendments to the DMA that emphasised local municipal DMPs. Furthermore, the absence of a legal requirement for Climate Change Adaptation (CCA) strategies at the local level has left rural municipalities without the motivation, resources, or capacity to develop such plans, unlike metropolitan areas that have greater capabilities.

In Muyexe and Nkowankowa, Limpopo Province, there is a clear need for increased effort at the local municipal level to integrate climate change adaptation (CCA) and disaster risk reduction (DRR) strategies, particularly in addressing social vulnerabilities. While infrastructure development has been prioritised, the underlying social vulnerabilities have received little attention. Participants in focus groups reported that disaster risk reduction interventions often overlook communities in hazardous areas, including unemployed or semi-skilled farmers who lack support and training to cope with climate change impacts.

Although economic development, capacity building, collaboration, participation, and awareness-raising campaigns were highlighted during discussions, these initiatives are not being implemented effectively at the local level. This gap underscores the importance of assessing the role of active organisations in building social, economic, and political capital both before and after disasters, which is essential for fostering equitable resilience.

As flood and drought risks intensify, improving decision support systems for effective early warning systems is critical. Accurate weather forecasts, especially for extreme precipitation, must reach rural communities promptly to protect lives, livelihoods, and property. Additionally, implementing sustainable infrastructure maintenance and ensuring future developments occur in areas less prone to flooding and drought are key risk reduction strategies.

Vulnerability assessments of rural settlements, like those in Mopani District, are scarce, despite the fact that these communities, reliant on natural resources and rain-fed agriculture, are more vulnerable than urban areas. This study's findings contribute to understanding the factors influencing vulnerability in rural communities exposed to flood and drought hazards, compounded by challenges like inadequate water supply infrastructure and poor roads.

For policymakers in Limpopo Province, transformation requires a paradigm shift toward a radically different future. Participants suggested that the province should focus on creating employment opportunities and supporting small-scale projects to supplement incomes, empowering communities to become active stakeholders in areas previously inaccessible to them.

Village-level: quantitative results

This pilot study aimed to develop the Climate Change Jurisdictional Vulnerability Index (CC-JVI) for **Muyexe** and **Nkowankowa**, but it faced significant challenges that rendered it not feasible. In line with the pragmatic research paradigm, the data analysis incorporated both qualitative and quantitative methods, with thematic analysis interpreting qualitative data from FGDs and interviews, and the CC-JVI development employing computation of vulnerability indicators. However, the low response rate and lack of responses from these villages led to substantial data gaps, especially in variables key for the index construction. This limitation prevented the construction of said vulnerability index, as the data collected was insufficient to accurately depict the climate change vulnerability in these communities. As a result, the primary data analysis could not produce a reliable CC-JVI.

To address the data insufficiencies, the research team expanded the jurisdictional scope of the study beyond **Muyexe** and **Nkowankowa** to include broader regions across four provinces: Limpopo, Eastern Cape, Mpumalanga, and KwaZulu-Natal. This expansion aimed to collect a more complete and more representative dataset encompassing diverse climatic and socio-economic conditions. By incorporating secondary data from reliable sources, such as the Statistics South Africa Census 2011 and 2022 and official databases, the researchers gathered a wider range of vulnerability indicators, making the CC-JVI more applicable to multiple jurisdictions. This broader dataset enabled the calculation of climate vulnerability indices from the local municipality to provincial levels, covering variations in exposure, sensitivity, and adaptive capacity, and provided a more accurate basis for constructing the CC-JVI. There is a clear potential for administrative and development data for jurisdictions to provide systematic vulnerability assessment indices for climate change, which are enhanced by comprehensive qualitative data.

Provincial-level vulnerability asssessments

General climate change vulnerability of Limpopo

The Limpopo province, like many other regions, exhibits areas that are vulnerable to wildfires due to various factors such as climate conditions, vegetation types, land use practices, and human activities. The Vhembe District Municipality located in the northern part of the province includes diverse landscapes ranging from savannas to forests. Areas within the Vhembe District, such as the Soutpansberg Mountains and surrounding reserves, are susceptible to wildfires, especially during the dry season when vegetation becomes dry and flammable. The Mopani District Municipality situated in the northeastern part of the province comprises various ecosystems, including bushveld and riverine areas. The district's proximity to Kruger National Park and other conservation areas increases the risk of wildfires, particularly due to natural factors like lightning strikes and human-induced ignitions.

The Capricorn District Municipality, which covers the central part of the province, includes urban areas like Polokwane as well as rural areas with agricultural activities. While urban areas may face fire risks from sources like informal settlements or industrial incidents, rural parts of the district can experience wildfires, especially in grassland and bushveld areas. The Sekhukhune District in the southern part of the province includes landscapes such as the Drakensberg Mountains and agricultural lands. This mix of vegetation types and human settlements makes it susceptible to wildfires, particularly during periods of drought or when fire management practices are inadequate. The Waterberg District Municipality situated in the western part of the province encompasses diverse habitats, including grasslands and mountainous terrain. Areas like the Waterberg Biosphere Reserve and surrounding natural areas are prone to wildfires, with factors such as lightning strikes, agricultural burning, and accidental ignitions contributing to fire risks.

Efforts to address wildfire vulnerability in the Limpopo province often include implementing fire prevention measures, conducting controlled burns for vegetation management, especially in game parks, enhancing firefighting capabilities, promoting public awareness about fire safety, and collaborating with local communities and other stakeholders for effective fire management strategies.

Drought vulnerability analysis

The Limpopo province in South Africa has several municipalities that are particularly vulnerable to drought due to various factors such as climate patterns, water resource availability, socio-economic conditions, and infrastructure limitations, including those concerning irrigation. The Vhembe District Municipality in the northern part of the province encompasses towns like Thohoyandou, Musina, and Louis Trichardt. Drought vulnerability is a concern here due to erratic rainfall patterns and water scarcity in certain areas. The Waterberg District Municipality, covering areas such as Bela-Bela, Modimolle, and Mokopane in the western part of the province, faces water scarcity, and drought vulnerability is a significant issue in some parts, particularly affecting farming communities and rural areas. The Capricorn District Municipality in the central part of the province, with towns like Polokwane, Lebowakgomo, and Mankweng, is vulnerable to drought due to limited water infrastructure, reliance on groundwater sources, and the impact on agricultural production. The Sekhukhune District Municipality in the southern part of the province, encompassing areas like Burgersfort, Jane Furse, and Groblersdal, is vulnerable to drought due to water scarcity, reliance on rain-fed agriculture, and socio-economic challenges faced by communities (limited economic activity).

All the municipalities often face challenges related to water management, agricultural productivity, access to basic services, and resilience to climate variability, making them particularly susceptible to the impacts of drought. Efforts to address drought vulnerability in these areas typically involve implementing water conservation measures, improving water infrastructure, promoting sustainable agricultural practices, and enhancing community resilience through integrated development strategies.

Flash floods

Flash floods can occur in various districts of the Limpopo province in South Africa, particularly during periods of heavy rainfall or sudden storm events. Some districts in the province are more prone to flash floods due to factors such as topography, drainage systems, land use patterns, and soil conditions. Mopani District Municipality in the northeastern part is known for its rivers and waterways, including the Letaba River and the Olifants River. Areas within this district, such as Phalaborwa and Tzaneen, can experience flash floods during intense rainfall events, especially in low-lying areas and near riverbanks. Vhembe District Municipality in the northern part of the province has diverse landscapes, including mountains, valleys, and rivers such as the Limpopo River. Towns like Thohoyandou and Musina may be susceptible to flash floods, particularly in areas prone to runoff and poor drainage.

The Waterberg District Municipality in the west has varying terrain, including the Waterberg Biosphere Reserve, and towns like Bela-Bela and Modimolle may experience flash floods, especially in urbanised areas with inadequate stormwater management infrastructure. The Capricorn District Municipality in the central part of the province, including towns like Polokwane and Lebowakgomo, is not as prone to flash floods as some other areas. However, localised flooding can occur during heavy rains, particularly in urbanised zones with limited drainage capacity. The Sekhukhune District Municipality in the south covers areas with diverse landscapes, including the Drakensberg Mountains. Towns like Burgersfort and Groblersdal may face flash flood risks, especially in valleys and areas with poor soil infiltration.

Efforts to mitigate flash flood risks in these districts typically involve improving drainage systems, implementing rigorous land use planning strategies, raising public awareness about flood hazards, and enhancing emergency response capabilities. Additionally, climate change adaptation measures may be necessary to mitigate the potential increase in extreme weather events, which can lead to flash floods in the future.

Land use and land cover

The land use and land cover (LULC) map illustrates the diverse land cover patterns observed across the Limpopo province. Predominantly, the upper regions extending from the north to the north-west part of the study area are characterised by thicket bushland, interspersed with areas designated for mining, urban development, and unimproved grasslands. Moving towards the western part of the province, a significant presence of forests and woodlands is evident, stretching from the northern reaches in a continuous strip down to the southern territories. This wooded area constitutes a portion of the renowned Kruger National Park. In the lower regions of the province, commercial dryland farming dominates, with extensive agricultural activities, including commercial irrigation practices. Meanwhile, in the central parts towards the south-western areas of the province, there is a discernible increase in degradation levels marked by encroaching bush and the persistence of woodlands and unimproved grasslands.

Degradation status

In the central areas of the province stretching from the northwest to the south, there are concerns regarding land degradation getting worse. This degradation means that the land is not as healthy as it should be. One problem is soil erosion, where the soil gets washed away by water or wind, making it hard for plants to grow. Another issue is that bushes are spreading into areas where they should not be, taking over the land and making it hard for other plants and animals to survive. Additionally, the grasslands in these areas are not improving; they are staying the same or getting worse over time. All these factors combined contribute to the overall decline in the health of the land in the central parts of the province.

Disease

The results show that the cumulative positive animal rabies rates in northern parts of Limpopo were not influenced by increases in human population (Mogano et al., 2024). The local municipalities with high population densities did not consequently show high confirmed rabies case rates.

Municipalities with game reserves, particularly areas next to the nature reserves, were more vulnerable to rabies outbreaks. During earlier years, 1998-2002, rabies hot spots were observed in the western areas of Limpopo only but later spread to north and central areas during the period of 2018 to 2022. During the periods of 2008 to 2012, the rabies hot spots shifted to the east of the Limpopo Province.

Integrated Jurisdictional Vulnerability Index of the Limpopo Province

All the indicators that relate to hazards were integrated into a single vulnerability index. The Jurisdictional Vulnerability Index (JVI) for the Limpopo Province was constructed by integrating various environmental, social, and economic factors that impact the region. This index was devised to gain insights into the conditions that make the province susceptible to vulnerabilities. The development of the JVI stemmed from a comprehensive analysis of factors such as fire hazards, diseases, floods, land degradation, and drought, compared against the readiness of government responses. Upon examination, it became evident that many parts of the province exhibit extreme vulnerability, indicating significant challenges in coping with adverse events.

Discussion on alternative vulnerability assessment approaches

Traditionally, disasters were viewed as isolated natural events, and few linkages were made to the circumstances of the people affected. Technical solutions, relief, and rehabilitation actions were targeted at restoring pre-disaster conditions. Recently, driven by efforts from the UN International Strategy for Disaster Reduction (ISDR), the paradigm has shifted towards an approach which is more development oriented. The new focus combines hazard mitigation and vulnerability reduction with special attention given to social, economic, and ecological factors (UNISDR, 2004). Its broader goal is to achieve a comprehensive disaster risk management strategy. In this context, this study uses a JVI to examine the vulnerability of communities in the Limpopo Province to impacts such as droughts, fire, disease, and floods using remote sensing and GIS approaches. The study assesses factors contributing to vulnerability, including poverty, lack of access to resources, and weak infrastructure, and proposes adaptation strategies to enhance resilience.

The findings show that the Limpopo Province faces a complex interplay of climate impacts, weak access to resources, and inadequate infrastructure, and that adaptation efforts are crucial to mitigate risks and enhance resilience. Additionally, this research indicates that communities which are dependent largely on agriculture are particularly susceptible to variations in temperature, rainfall, floods, disease and drought. Figures 2 and 3 and 6 and 7 show that rural areas are the most vulnerable. Gradual changes in temperature and rainfall patterns, which permanently alter environmental conditions, increase the risk in the province. The province is experiencing increases in average temperatures with erratic rainfall patterns (see an example in Figure 2). Extreme events such as flash floods in areas with poor drainage infrastructure and droughts in prominent agricultural areas increase the vulnerability of those sections. Over the long term, Limpopo is expected to become hotter and drier (Moeletsi et al., 2023). Summer seasons may witness more extreme rainfall events, and thus, agriculture and food production are considered the most vulnerable sectors to climate risks in Limpopo. Adverse effects include livestock mortality and crop losses. Decreasing water security exacerbates vulnerability of the province and threatens the livelihoods of those who rely on climate-sensitive resources.

More than half of the population in rural Limpopo depended on government social grants (including the old age grant) and remittances as their primary income sources. The prevalence of lower-wage jobs and lower educational attainment contributed to the income challenges faced by households in this region (Makondo, 2022; Mears & Blaauw, 2010). This provides valuable insights for policymakers to address inequality and reduce vulnerability of the poor.

The above highlights the complex interplay of poverty, ineffective government assistance, and lack of education in rural Limpopo to understand the vulnerability of communities in the region.

In an era marked by escalating environmental threats from natural disasters due to the impacts of climate change, understanding and assessing community vulnerability has become paramount. The concept of vulnerability encompasses a community's susceptibility to harm because of various stressors and shocks.

To effectively address vulnerabilities and enhance resilience, policymakers, planners, and researchers must turn to tools such as the spatially explicit JVI. The JVI evaluates the vulnerabilities in the province in a comprehensive way and guides proactive interventions for building resilience. Community resilience is increasingly recognised as a critical component of disaster risk reduction and sustainable development efforts. By integrating socio-economic, environmental, and institutional indicators with a spatial context, the JVI provides valuable insights into the underlying drivers of vulnerability and informs evidence-based decision-making processes in Limpopo.

The study had a unique opportunity to conduct Jurisdictional Validity Assessments (JVAs) for five local district municipalities based on the satellite data. In conducting these JVAs, we developed a structured procedure for selecting data sources, core indicators and covariates, analytical methods, and the presentation and visualisation of findings. Using statistical and GIS-based methods, we calculated vulnerability scores and mapped the scores, along with the locations, to identify areas in significant need of urgent attention. This framework provides guidance on methods for other public community jurisdictions that may have varying levels of available data. Most crises and disasters in the context of natural hazards manifest themselves at the local level. However, many aspects of vulnerability and the respective drivers of disaster risk go far beyond the local level and therefore also require regional or international approaches. In this regard, a more systematic approach towards the identification of vulnerability and the root causes of disaster risk, as well as the evaluation of appropriate strategies to reduce risk, is needed.

When a community is hit by a shock, its coping strategies are an important indication of adaptation and vulnerability. Their responses could include coping strategies such as selling livestock, borrowing from banks or unregistered money lenders, receiving aid, migrating to another rural or urban area, seeking off-farm employment, or eating less (Mears & Blaauw, 2010). This could also reflect that households have already adapted to living in a drought-prone Limpopo. Households may be using drought-resistant seed varieties or other coping mechanisms that minimise the cost of droughts.

The report highlights that a shift in thinking is needed in disaster risk reduction, in the sense that disaster and crises cannot always be avoided but must be seen and used as windows of opportunity for change, reorganisation and transformation towards improving adaptive capacities. Interestingly, the understanding that vulnerability is seen as an internal side of risk and as an intrinsic characteristic of an element at risk can be applied to very different elements, such as communities and social groups, physical structures, and characteristics of buildings and lifelines, as well as ecosystem services. The notion of vulnerability as an internal side to risk is a clear contrast with frameworks that assume that disaster risk is mainly an outcome of the natural hazard or environmental phenomenon. The report emphasises the role of public policy in fortifying rural communities' abilities to adapt to a changing climate. Policymakers must consider context-specific responses that address both shocks and shifts.

This approach recognises the need for engagement at the community level and for integrating indigenous knowledge, which helps in identifying local needs and perceptions. The process should not be seen as top-down or bottom-up, but more as collaboration between the local communities and the different stakeholders (van Alst et al., 2008). Top-down approaches in disaster risk management may lead to inequitable and unsustainable results. Many such programmes fail to address the specific local needs of vulnerable communities, ignore the potential of local resources and capacities, and in some cases even increase people's social and economic vulnerability (Christie & Hanlon, 2001).

The JVI is designed to reduce the local population's risk. It aims to reduce vulnerabilities and increase the capacities of households and communities to withstand damaging effects of disasters. Such an approach contributes to people's empowerment and participation in achieving sustainable development and sharing its benefits.

The benefits are as follows:

- Communities are knowledgeable about their own environment. They have experience of coping with emergencies. These coping methods have evolved over time and demonstrated that they are best suited to the local economic, cultural, and political environment.
- This approach has the benefit of enabling communities to be less dependent on relief during disaster periods and to increase their capacities to support their own livelihoods.
- Participation will empower the community with new knowledge and skills and develop the leadership capability of community members and so strengthen their capacity to contribute to development initiatives.

A community-based indicator system was developed to improve the capacity of communities and local governments to measure key elements of their current disaster risk. Using indicators at the community level in this context is an innovative approach. The current framework systemises the key elements of risk management into the factors of hazard, exposure, vulnerability, and capacity and measures.

The validity of the modelled JVI

In research conducted by Odiyo and colleagues in 2019, significant vulnerability in specific regions of Vhembe were revealed. This vulnerability was starkly demonstrated when flash floods in 2011 led to the collapse of the Thathe Vondo bridge, disrupting transportation and causing significant damage. Moreover, the study highlighted instances of drought in 2014-2015, which resulted in crop failures in Mhinge Village, adversely impacting the livelihoods of local communities. Furthermore, the research documented a reduction in water levels in the Vondo dam in 2016, exacerbating water scarcity in the area. All these areas lie within the vulnerable areas shown in this current study. Interestingly, our findings regarding high to extreme vulnerability in Vhembe align closely with the flood reported by Musyoki and colleagues in 2016. This convergence underscores the persistent and multifaceted nature of vulnerability in the region, where both sudden-onset events like floods and gradual phenomena such as droughts pose significant challenges to the resilience and well-being of local populations. Such insights are crucial for developing effective strategies for disaster preparedness, mitigation, and adaptation, including early warning systems in vulnerable areas like Vhembe. The understanding of vulnerability across the province is crucial for informing targeted interventions and policy decisions aimed at bolstering resilience and reducing the impacts of potential hazards on communities and ecosystems. Assisted with the region's JVI assessments that characterise the vulnerability of the province, the government institutions can work with multidisciplinary stakeholders to bolster adaptation and mitigation investments for long-term development of the areas.

Quantitative results for CC-JVI: Limpopo, KZN, MP and EC Provinces

The Shapiro-Wilk test yielded p-values for both the 2001-2011 and 2012-2022 periods for KwaZulu-Natal Province (KZN) that were less than 0.05, as depicted in Table 8. This result indicates that the data for KZN's average maximum temperatures in both decades did not follow a normal distribution. The non-normal distribution of temperature data in KZN is indicative of significant variability in maximum temperatures, possibly due to factors such as increased frequency of extreme weather events or other climate change impacts. In contrast, Mpumalanga Province (MP) exhibited p-values greater than 0.05 for both periods, suggesting that the data for MP's average maximum temperatures was normally distributed for both the 2001-2011 and 2012-2022 decades. This implies a more stable pattern of temperature changes, which might still reflect a gradual increase in maximum temperatures without the extreme variations seen in KZN. The Eastern Cape (EC) showed differing results between the two decades. For the period from 2001-2011, the p-value was less than 0.05, indicating that the data was not normally distributed. However, for the period from 2012-2022, the *p*-value was greater than 0.05, suggesting that the data followed a normal distribution.

This shift from a non-normal to a normal distribution could indicate a stabilisation of temperature patterns in EC, although the reasons for this stabilisation would need further investigation, possibly looking into local climate adaptation measures or natural variability. Lastly, Limpopo Province (LP) had *p*-values greater than 0.05 for both decades, which indicates that the data for LP's average maximum temperatures was normally distributed for both decades. The consistent normal distribution suggests a less volatile but potentially significant upward trend in maximum temperatures, which aligns with broader global warming patterns.

The results of the paired samples tests further illustrate these changes, as shown in table 7. For KZN, both the student's t-Test, $t(43)=-5.601$, $p<.001$, and the Wilcoxon signed-rank test, $z=-4.7$, $p<.001$, show significant differences in average maximum temperatures between the two decades, indicating substantial changes in temperature patterns. For MP, the student's, $t(16)=-5.436$, $p<.001$, and the Wilcoxon signed-rank test, $z=-3.1$, $p=.002$, also revealed significant differences, confirming a considerable increase in maximum temperatures. In the Eastern Cape (EC), the student's t-Test results, $t(32)=-4.823$, $p<.001$, show a significant difference in average maximum temperatures between the two decades, aligning with the shift from non-normal to normal distribution observed in the normality test. This suggests that while the data distribution has stabilised, there has been a significant rise in temperatures. Lastly, in Limpopo Province (LP), the student's t-Test, $t(21)=0.402$, $p=.691$, indicates no significant difference in temperatures between the two decades, reflecting a consistent but non-volatile pattern in temperature changes. Table 7 provides these decadal changes in temperature diagrammatically.

Table 7: Comparison of average maximum temperature (2001–2011 & 2012–2022) by province

2001–2011 Average Max Temperature : 2012–2022 Average Max Temperature

Province	Test	Statistic	z	df	*p*
KwaZulu-Natal	Student	-5.601		43	<.001
	Wilcoxon	94.0	-4.7		<.001
Mpumalanga	Student	-5.436		16	<.001
	Wilcoxon	11.0	-3.1		0.002
Eastern Cape	Student	-4.823		32	<.001
Limpopo	Student	0.402		21	0.691

Table 8: Test of normality (Shapiro–Wilk) (Average maximum temperature (°C)

			W	*p*
KwaZulu-Natal	2001–2011 Average Max Temperature	2012–2022 Average Max Temperature	0.884	<.001
Mpumalanga	2001–2011 Average Max Temperature	2012–2022 Average Max Temperature	0.806	0.002
Eastern Cape	2001–2011 Average Max Temperature	2012–2022 Average Max Temperature	0.939	0.063
Limpopo	2001–2011 Average Max Temperature	2012–2022 Average Max Temperature	0.924	0.091

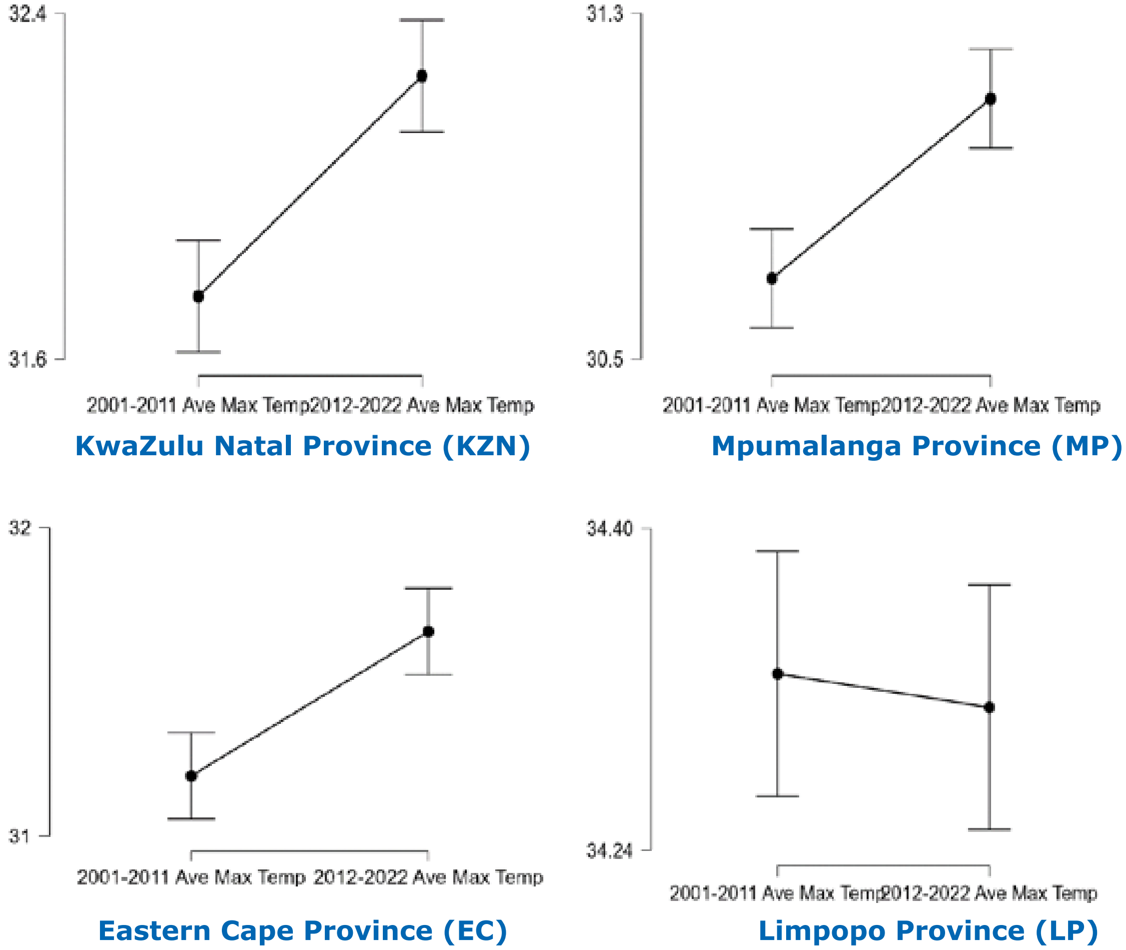


Figure 5: Average maximum monthly temperature (°C) descriptive plots

Table 9 presents the findings of the changes in average monthly precipitation between the periods 2001-2011 and 2012-2022 in four provinces (KZN, MP, EC, and LP). The normality of the precipitation data for each province over the two decades was assessed using the Shapiro-Wilk test. The null hypothesis for this test is that the data follows a normal distribution.

For KwaZulu-Natal Province (KZN), the Shapiro-Wilk test yielded p-values less than 0.05 for both periods, indicating that the data for average monthly precipitation in KZN deviates from a normal distribution. This non-normal distribution suggests significant variability in precipitation, possibly due to factors, such as changes in rainfall patterns and increased frequency of extreme weather events. In contrast, Mpumalanga Province (MP) exhibited p-values greater than 0.05 for both periods, suggesting that the data for MP's average monthly precipitation follows a normal distribution for both decades. This implies a more stable pattern of precipitation changes. Similarly, the Eastern Cape (EC) showed p-values greater than 0.05 for both periods, indicating that the data for EC's average monthly precipitation follows a normal distribution. Lastly, Limpopo Province (LP) also had p-values greater than 0.05 for both periods, indicating that the data for LP's average monthly precipitation follows a normal distribution.

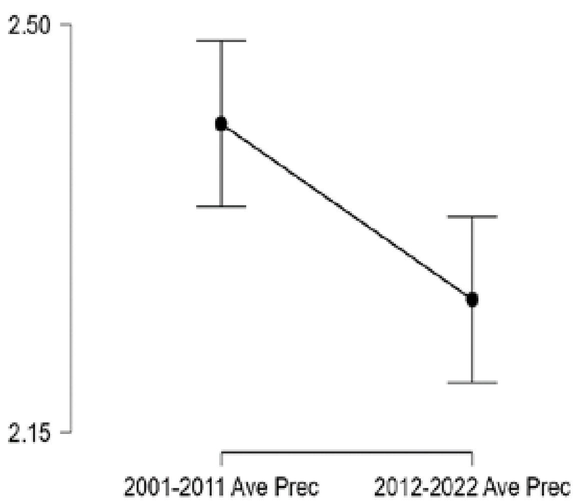
Based on the results of the normality test, the appropriate paired samples tests were conducted. The student's t-Test was used for normally distributed data, while the Wilcoxon signed-rank test was used for non-normally distributed data. In KZN, both the student's t-Test, t(43)=3.024, p=0.004, and the Wilcoxon signed-rank test, z=2.96, p=0.003, indicated significant changes in average monthly precipitation between the two decades. This result highlights substantial changes in precipitation patterns that could be linked to climate change. For MP, the student's t-Test, t(16)=−4.031, p<0.001, showed significant differences in precipitation. Similarly, in the Eastern Cape, the student's t-Test, t(32)=3.216, p=0.003, confirmed significant differences in average monthly precipitation, reflecting changes in regional precipitation patterns. In Limpopo Province, the 's t-Test, t(21)=−5.405, p<0.001, revealed significant changes in precipitation between the two periods.

Table 9: Comparison of average monthly precipitation by province (paired samples t-Test)

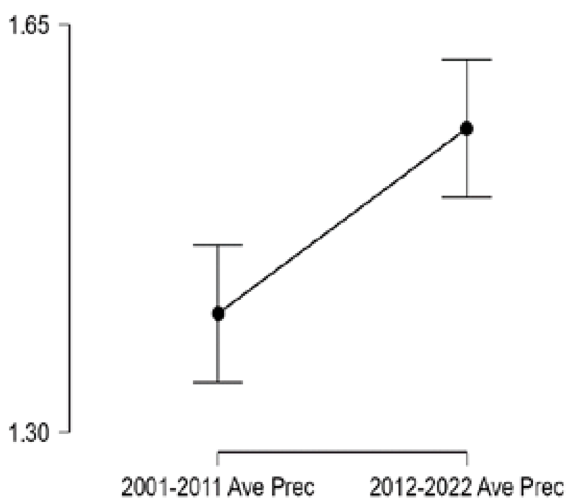
	2001–2011 Average Max Temperature	2012–2022 Average Max Temperature			
Province	**Test**	**Statistic**	**z**	**df**	***P***
	Student	3.024		43	< .004
KwaZulu-Natal	Wilcoxon	749.0	2.96		< .003
Mpumalanga	Student	-4.031		16	<.001
Eastern Cape	Student	3.216		32	.003
Limpopo	Student	-5.405		21	<.001

Table 10: Test of normality (Shapiro-Wilk) (Average monthly precipitation (mm))

	2001–2011 Average Max Temperature	2012–2022 Average Max Temperature		
			W	***p***
	2001-2011 ave precipitation	2012-2022 ave precipitation	0.942	< .004
KwaZulu-Natal	2001-2011 ave precipitation	2012-2022 ave precipitation	0.897	< .003
Mpumalanga	2001-2011 ave precipitation	2012-2022 ave precipitation	0.944	<.001
Eastern Cape	2001-2011 ave precipitation	2012-2022 ave precipitation	0.948	.003
Limpopo	2001-2011 ave precipitation	2012-2022 ave precipitation	21	<.001



KwaZulu Natal Province (KZN)



Mpumalanga Province (MP)

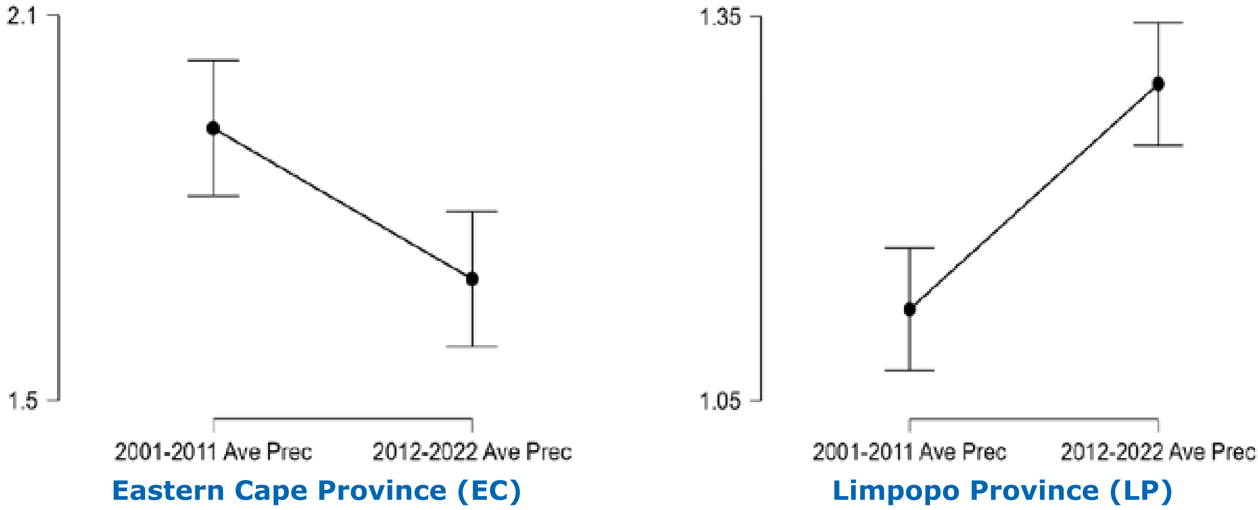


Figure 6: Average total monthly precipitation (mm) descriptive plots

The analysis of the key variables (temperature and precipitation) to climate change between 2001-2011 and 2012-2022 across KwaZulu-Natal (KZN), Mpumalanga (MP), Eastern Cape (EC), and Limpopo (LP) revealed significant regional variations and trends. KZN exhibited non-normal distributions in both temperature and precipitation data, suggesting heightened variability likely influenced by increased frequency of extreme weather events. In contrast, MP showed normally distributed temperature data with significant temperature increases, indicating a more stable but warming climate trend. EC transitioned from non-normal to normal temperature distributions, suggesting a stabilisation in temperature patterns alongside temperature rises. LP maintained normally distributed temperature data without significant changes, pointing to a steady warming trend but with less variability compared to other provinces. In order to assess or determine the Climate Change Jurisdictional Vulnerability Index (CC-JVI), additional factors beyond temperature and precipitation variability are considered in the subsequent section. These factors include socio-economic indicators, infrastructure resilience, sensitivity, and adaptive capacity of communities in the study area. Through the integration of these factors into the development of CC-JVI, policymakers and stakeholders can better understand and prioritise regions most at risk from climate change. This approach further enables targeted interventions to enhance resilience, mitigate risks, and foster sustainable development in the face of a changing climate.

Comparison of vulnerability across provinces

The vulnerability to climate change was computed and compared across four regions, KwaZulu-Natal (KZN), Mpumalanga (MP), Eastern Cape (EC), and Limpopo (LP), between two periods, 2001-2011 and 2012-2022 (present). The Mann-Whitney U test revealed that there was no significant difference in the vulnerability to climate change in KZN between 2001-2011 and 2012-2022; W=1118.00, p=0.210, as shown in Table 11. The effect size, as measured by the rank biserial correlation, was 0.155 (SE = 0.123). This effect size is considered small, indicating a weak association between the time periods and the levels of vulnerability. The lack of significant change in vulnerability suggests that the factors contributing to climate change vulnerability in KZN have remained relatively consistent over the two decades studied. The results imply that existing policies and interventions during these periods might not have significantly altered the region’s vulnerability to climate change, highlighting the need for continued monitoring and possibly revising current approaches to address climate change vulnerability in KwaZulu-Natal.

Table 12 reports the results for Mpumalanga (MP). The Mann-Whitney U test produced W=134.50, p= 0.970, indicating no significant difference in climate change vulnerability between the two periods. The rank biserial correlation was -0.011 with a standard error of 0.201, suggesting a negligible effect size. These findings suggest that the vulnerability in MP remained stable across the two periods, with no substantial changes detected. Table 13 shows the results for the Eastern Cape (EC). The Mann-Whitney U test yielded W = 508.000, p= 0.640, indicating no significant difference in vulnerability between the two periods. The rank biserial correlation was -0.067 with (SE=0.142), indicating a small effect size. These results suggest that the vulnerability to climate change in the Eastern Cape also remained relatively unchanged over the periods analysed. The Mann-Whitney U test resulted in W = 228.500, p= 0.961, showing no significant difference in climate change vulnerability between the two periods as shown in table 14 for Limpopo Province (LP). The rank biserial correlation was -0.011 with a standard error of 0.176, indicating a negligible effect size. This indicates that, similar to MP and EC, the vulnerability to climate change in LP has not experienced significant changes between the two periods examined.

The Mann-Whitney U tests across all four regions, KZN, MP, EC, and LP, demonstrate no significant changes in climate change vulnerability between the periods 2001 to 2011 and 2012 to 2022. The effect sizes were small or negligible, indicating weak associations between the time periods and the levels of vulnerability. These findings suggest a consistent pattern of vulnerability in these regions, highlighting a potential need for ongoing and perhaps more effective climate change policies and interventions. These non-changes are visually depicted in Figure 7.

Table 11: KZN climate change vulnerability, independent samples t-Test

	W	df	P	Rank-biserial correlation	SE rank-biserial correlation
VI	1118.000		0.210	0.155	0.123

Note: For the Mann-Whitney U test, effect size is given by the rank biserial correlation

Table 12: MP climate change vulnerability, independent samples t-Test

	W	df	P	Rank-biserial correlation	SE rank-biserial correlation
VI	134.500		0.970	-0.011	0.201

Note: For the Mann-Whitney U test, effect size is given by the rank biserial correlation

Table 13: EC climate change vulnerability, independent samples t-Test

	W	df	P	Rank-biserial correlation	SE rank-biserial correlation
VI	508.000		0.640	-0.067	0.142

Note: For the Mann-Whitney U test, effect size is given by the rank biserial correlation

Table 14: LP climate change vulnerability, independent samples t-Test

	W	df	P	Rank-biserial correlation	SE rank-biserial correlation
VI	228.500		0.961	-0.011	0.176

Note: For the Mann-Whitney U test, effect size is given by the rank biserial correlation

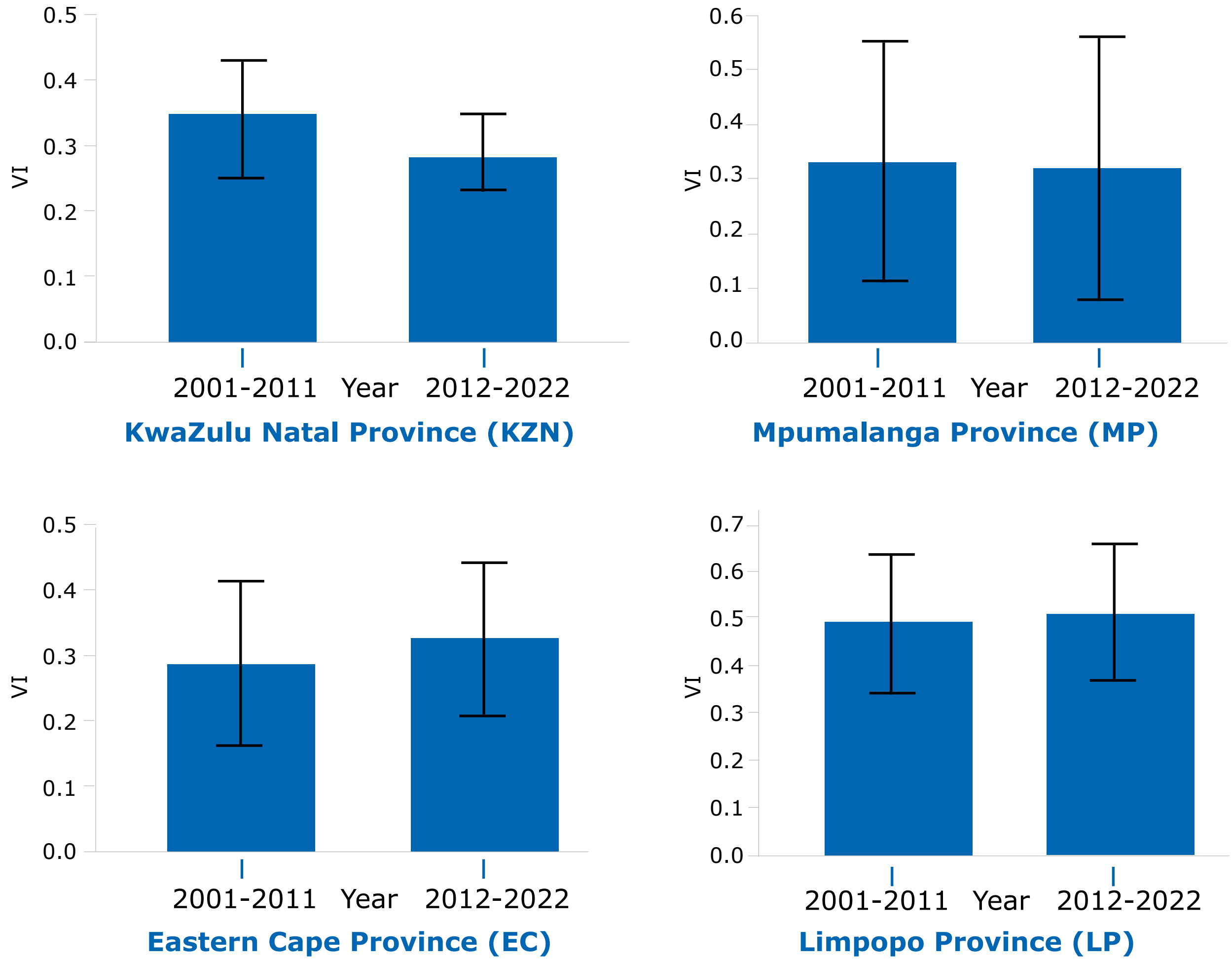


Figure 7: 2001-2012 vs 2012-2022 vulnerability indices

Table 15 shows a Kruskal-Wallis test, which was conducted to determine if there were statistically significant differences in climate change vulnerability across four provinces, KwaZulu-Natal (KZN), Mpumalanga (MP), Eastern Cape (EC), and Limpopo (LP), over the periods 2001-2011 and 2012-2022. The test revealed no significant differences in climate change vulnerability among the four provinces, $\chi^2(3) = 6.047$, $p = 0.109$. Despite the lack of significant findings, the test statistic (6.047) suggests some variation in vulnerability levels across the provinces, but this variation is not sufficient to reject the null hypothesis of no difference. Finally, the analysis indicates no statistically significant differences in climate change vulnerability across KwaZulu-Natal, Mpumalanga, Eastern Cape, and Limpopo over the periods studied. This result suggests that the factors influencing vulnerability are similar across these regions, or that the interventions and policies in place have resulted in comparable levels of vulnerability.

Table 15: Differences in climate change vulnerabilities across provinces (Kruskal-Wallis test)

Factor	Statistic	df	p
Province	6.047	3	0.109

Based on the descriptive statistics provided in Table 16 and the fractal stages of vulnerability described in Table 4, the current state of climate change vulnerability for the provinces of Eastern Cape (EC), KwaZulu-Natal (KZN), Limpopo (LP), and Mpumalanga (MP) can be summarised as follows: According to Table 16, the mean Vulnerability Index (VI) of 0.325 places the Eastern Cape in the "moderately vulnerable" range ($0.2 < VI < 0.4$). The coefficient of variation of 1.005 indicates substantial relative variability in vulnerability scores within the province. With a mean VI of 0.279, KwaZulu-Natal also falls into the "moderately vulnerable" category.

The coefficient of variation of 0.793 suggests moderate variability in vulnerability within the province. Limpopo's mean VI of 0.489 places it in the "vulnerable" range (0.4 < VI < 0.6). The lower coefficient of variation of 0.665 indicates relatively less variability in vulnerability scores compared to the other provinces. Mpumalanga's mean VI of 0.302 also falls into the "moderately vulnerable" range. However, the coefficient of variation of 1.426 shows the highest relative variability among the provinces, indicating significant differences in vulnerability levels within the province. The overall analysis indicates that, currently, Eastern Cape, KwaZulu-Natal, and Mpumalanga are "moderately vulnerable" to climate change, while Limpopo is "vulnerable." Despite the differences in mean vulnerability indices, variability within provinces is noteworthy, particularly in Mpumalanga, where vulnerability scores show the greatest spread. These findings suggest that while provincial averages provide a general sense of vulnerability, localised assessments are crucial for effective climate change adaptation and mitigation strategies.

Table 16: Descriptives: vulnerability index to climate change (CC-VI)

Province	N	Mean	SD	SE	Coefficient of variation
Eastern Cape Province (EC)	33	0.325	0.327	0.057	1.005
Kwazulu-Natal Province (KZN)	43	0.279	0.221	0.034	0.793
Limpopo Province (LP)	22	0.489	0.326	0.069	0.665
Mpumalanga Province (MP)	18	0.302	0.431	0.102	1.426

CONCLUSION AND RECOMMENDATIONS

Conclusion

The pilot study identified substantial challenges in the availability and quality of qualitative and quantitative data across the targeted communities. Quantitative data, such as demographic and socio-economic indicators, are more readily accessible through government reports and other secondary sources. However, these data lacked the granularity needed to capture localised vulnerabilities. The higher the jurisdictional level, the better the chances of getting complete and reliable vulnerability data. In contrast, qualitative data, which is key for understanding community perceptions, adaptive strategies, and localised impacts of climate change, were either incomplete or absent due to respondents not having responses. This was largely due to awareness and knowledge levels of local communities on some of these key data metrics. The lack resulted in a data gap that undermined the development of a complete and accurate vulnerability index as per the defined formula.

One of the key objectives of this study was to assess the feasibility of using local-level data to create a vulnerability index. However, the heterogeneity of data sources and the lack of data posed significant challenges to integrating this data into a cohesive index. The study found that developing a vulnerability index requires not only including localised data but also establishing a standardised framework for integration. This framework should be adaptable to diverse local contexts while ensuring consistency and comparability across different communities.

From this study, multiple challenges were revealed. One major challenge was the fragmented nature of data. This fragmentation led to inconsistencies and gaps in the data, complicating efforts to integrate and utilise this data effectively. Another challenge was the limited technical capacity at the local level, where communities often lacked appropriate responses to provide necessary information. Despite these challenges, the study also identified several opportunities. Mobile technology and community participatory approaches emerged as promising strategies for overcoming data collection barriers. Mobile data collection tools can facilitate real-time data gathering and sharing, while participatory approaches can ensure that data collection is culturally appropriate and inclusive.

Despite facing significant challenges, this study successfully laid the groundwork for developing a Climate Change Jurisdictional Vulnerability Index (CC-JVI). Initial attempts to construct the index revealed critical data gaps and methodological issues that limited the scope and accuracy of the index. The preliminary version of the CC-JVI incorporated a range of indicators, including demographic, economic, and environmental variables, to assess community-level vulnerability. However, the lack of high-resolution, community-specific data meant that the index could not fully capture the multidimensional nature of vulnerability across different jurisdictions. To address these limitations, the study focused on a higher jurisdictional level for data collection. Secondary data were collected from Statistics South Africa Census 2011 and 2022 and the NASA online database at the local municipality, then rolled up to provincial levels. Data from Statistics South Africa and the NASA online database were normalised and averaged across exposure, sensitivity, and adaptive capacity dimensions to calculate the CC-JVI. Statistical analyses were conducted to compare vulnerability levels across provinces and over time.

In conclusion, this study demonstrates significant regional variations in climate vulnerability across South Africa, with KwaZulu-Natal and Eastern Cape exhibiting heightened variability, while Mpumalanga and Limpopo show more stable warming trends. Eastern Cape, KwaZulu-Natal, and Mpumalanga were classified as "moderately vulnerable," while Limpopo was classified as "vulnerable". The Climate Change Vulnerability Index (CC-JVI) for South Africa unveiled significant regional climatic and socio-economic disparities, with KwaZulu-Natal exhibiting the highest level of variability. The Eastern Cape and Mpumalanga regions demonstrate a moderate level of vulnerability, while the overall vulnerability levels remained steady, showing the necessity for customised adaptation strategies. Strengthen climate data collection efforts, allocate resources for education and infrastructure, incorporate adaptation measures into development plans, foster regional collaboration, and secure international funding. Conduct periodic vulnerability assessments utilising the developed CC-JVI framework.

The pilot study explored various mechanisms for enhancing climate change resilience, focusing on communities most vulnerable to climate hazards. The findings suggest that a multilayered approach is necessary, involving interventions at both national and sub-national levels. At the national level, the study recommends the integration of climate change adaptation strategies into existing policy frameworks, such as the National Development Plan and the Disaster Management Act. This integration would ensure that climate resilience is considered in all aspects of national planning and development. At the sub-national level, the study highlights the importance of localised resilience-building initiatives, such as community-based disaster risk reduction programs and the development of local adaptation plans. These initiatives should be tailored to the specific vulnerabilities and capacities of each community, taking into account factors such as local climate conditions, socio-economic status, and existing coping mechanisms. The study also emphasises the need for capacity building at the local level, including training for community leaders and local government officials in climate adaptation and disaster management. Moreover, the study advocates for establishing a dedicated funding mechanism to support local resilience-building efforts, ensuring that resources are available to implement and sustain these initiatives. Combining top-down policy support with bottom-up community action, the study argues that a more resilient and adaptive society can be built, capable of withstanding the increasing impacts of climate change.

Recommendations

The study makes several recommendations, namely:

1. Creation of a centralised data repository

To address the disparities in data accessibility and quality across targeted communities, it is recommended that a centralised data repository be established that consolidates both qualitative and quantitative data from diverse sources, including government agencies, NGOs, and local communities at the municipal level. This repository should be designed to facilitate easy access for researchers, decision-makers, policymakers, and community members, thereby enhancing data sharing and collaboration.

2. Community-based data collection programmes

Additionally, community-based data collection programmes that actively involve local stakeholders in gathering qualitative data are needed. These programs should include training local volunteers in effective data collection techniques and setting up regular reporting mechanisms to ensure continuous data flow. Standardising data collection methodologies across different regions is crucial to ensure consistency and comparability. This can be achieved by developing guidelines that outline the types of data to be collected, the methods of collection, and the frequency of data updates.

3. Use of technology for collecting community-level data

There is potential to leverage technology such as mobile applications, and cloud-based platforms can greatly improve the accuracy and timeliness of data collection, overcoming many logistical challenges.

4. Multi-sectoral approach to data collection and integration

Fostering collaboration between various stakeholders, including government agencies, academic institutions, NGOs, and local communities, can significantly enhance data collection efforts by pooling resources and expertise, leading to more reliable data. Prioritising collection of data at municipal level is aligned with CCA's integration into IDPs, and both require institutional and governance strengthening for climate-informed development.

5. Incremental approach to CC-JVI development

The development of a Climate Change Jurisdictional Vulnerability Index (CC-JVI) requires a phased and iterative approach to address the limitations identified during the pilot study. Initially, conducting a baseline assessment using available data to identify key vulnerabilities and data gaps is recommended. Following this, targeted data collection efforts should be undertaken to fill these gaps, focusing on gathering high-resolution, community-specific data. Advanced analytical techniques, such as Geographic Information Systems (GIS) and remote sensing, should be integrated into the index development process to enhance spatial resolution and accuracy.

6. Community involvement in CC-JVI development

It is essential to involve local communities in validating the index through participatory methods, such as community workshops and feedback sessions. This will ensure that the index accurately reflects the realities on the ground and is relevant to stakeholders at various levels of governance.

7. Ongoing updating of CC-JVI

There is a need for establishing a mechanism for continuous data updating, and refinement of the index is important for maintaining accuracy and relevance over time. This can be achieved by setting up a monitoring and evaluation system that regularly reviews and updates the data and methodology used in the index. By following this approach, a more comprehensive and reliable CC-JVI can be developed, providing valuable insights for climate adaptation planning and policymaking.

8. Integration of climate adaptation strategies in provincial and national development strategies (i.e. climate change in all policies and programmes)

To effectively enhance climate change resilience at both national and sub-national levels, it is recommended that climate adaptation strategies be integrated into existing policy frameworks, such as the National Development Plan (NDP) and the Disaster Management Act (DMA). This integration would ensure that climate resilience is a core consideration in all aspects of national planning and development.

9. Building community resilience to climate change

At the sub-national level, localised resilience-building initiatives should be prioritised, including community-based disaster risk reduction programs and the development of local adaptation plans tailored to the specific vulnerabilities of each community. Capacity building is essential to support these efforts, and training programs should be implemented for community leaders and local government officials to equip them with the knowledge and skills necessary for effective climate adaptation and disaster management. Furthermore, establishing a dedicated funding mechanism to support local resilience-building initiatives is crucial. This funding could be used to improve infrastructure resilience, enhance early warning systems, and support community-based adaptation initiatives. Moreover, promoting public awareness and education campaigns about climate change impacts and adaptation strategies can empower communities to take proactive steps toward building resilience. By combining top-down policy support with bottom-up community action, a more resilient and adaptive society can be built, capable of withstanding the increasing impacts of climate change.

REFERENCES

Adejonwo-Osho, O. (2019). Nigeria's commitments under the climate change Paris Agreement: Legislative and regulatory imperatives towards ensuring sustainable development. *Law | Environment | Africa*, 2019, 61-78. https://doi.org/10.5771/9783845294605-61

Adeola, A., Kruger, A., Makgoale, T. E., & Botai, J. O. (2022). Observed trends and projections of temperature and precipitation in the Olifants River Catchment in South Africa. *PLoS ONE*, 17(7), e0271974. https://doi.org/10.1371/journal.pone.0271974

Afifah, S., Mudzakir, A., & Nandiyanto, A. B. D. (2022). How to calculate paired sample t-Test using SPSS software: From step-by-step processing for users to the practical examples in the analysis of the effect of application anti-fire bamboo teaching materials on student learning outcomes. *Indonesian Journal of Teaching in Science*, 2(1), 81-92.

Aizawa, M. (2016). Staying human-centric at the intersection of climate change and human rights, *Journal of Energy & Natural Resources Law*, 34(1), 86-94. DOI: 10.1080/02646811.2016.1117897

Apotsos, A. (2019). Mapping relative social vulnerability in six mostly urban municipalities in South Africa. *Applied Geography*. https://doi.org/10.1016/J.APGEOG.2019.02.012

Asadnabizadeh, M. (2019). Development of UN Framework Convention on Climate Change Negotiations under COP25: Article 6 of the Paris Agreement perspective. *Open Political Science*, 2(1), 113-119. https://doi.org/10.1515/openps-2019-0012

Babbie, E. (2016). The practice of social research (14th ed.). Cengage Learning.

Biesta, G. J., & Burbules, N. C. (2003). Pragmatism and educational research. Rowman & Littlefield Publishers.

Birkmann, J., Jamshed, A., McMillan, J. M., Feldmeyer, D., Totin, E., Solecki, W., ... & Alegría, A. (2021). Understanding human vulnerability to climate change: A global perspective on index validation for adaptation planning. *The Science of the Total Environment,* 803, 150065. https://doi.org/10.1016/j.scitotenv.2021.150065

Blamey, R. C., & Reason, C. J. C. (2009). Numerical simulation of a mesoscale convective system over the east coast of South Africa. *Tellus A: Dynamic Meteorology and Oceanography*, 61(1), 17-34.

Bonetti, S., Sutanudjaja, E., Mabhaudhi, T., Slotow, R., & Dalin, C. (2022). Climate change impacts on water sustainability of South African crop production. *Environmental Research Letters,* 17. https://doi.org/10.1088/1748-9326/ac80cf

Brauch, M., Touchette, Y., Cosbey, A., Gerasimchuk, I., Sanchez, L., Bernasconi-Osterwalder, N. & Petrofsky, E. (2019). Treaty on Sustainable Investment for Climate Change Mitigation and Adaptation: Aligning International Investment Law with the Urgent Need for Climate Change Action. *Journal of International Arbitration*, 36(1), 123-140.

Broberg, M. (2020). Interpreting the UNFCCC's provisions on 'mitigation' and 'adaptation' in light of the Paris Agreement's provision on 'loss and damage'. *Climate Policy*, 20(4), 527-533. https://doi.org/10.1080/14693062.2020.1745744

Broberg, M. (2020). Mainstreaming climate change resilience into development planning in Tanzania. *Environmental Science & Policy*, 105, 50-58. DOI: 10.1016/j.envsci.2020.01.010

Bustamante, M. M. C., Nobre, C. A., Smeraldi, R., Aguiar, A. P. D., Barioni, L. G., Ferreira, L. G., ... & Ometto, J. P. H. B. (2019). Environmental and social implications of the increase in the Brazilian Amazon deforestation rate. *Environmental Development*, 22, 49-58. DOI: 10.1016/j.envdev.2017.10.002

Bustamante, M., Silva, J. S., Scariot, A., Sampaio, A., Mascia, D., Garcia, E., Sano, E., Fernandes, G., Durigan, G., Roitman, I., Figueiredo, I., Rodrigues, R., Pillar, V., Oliveira, A. O., Malhado, A. C., Alencar, A., Vendramini, A., Padovezi, A., Carrascosa, H., Freitas, J., Siqueira, J. A., Shimbo, J., Generoso, L. G., Tabarelli, M., Biderman, R., Salomão, R. P., & Valle, R. (2019). Ecological restoration as a strategy for mitigating and adapting to climate change: Lessons and challenges from Brazil. *Mitigation and Adaptation Strategies for Global Change*, 24(7), 1131-1150.

Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R., & Ringler, C. (2014). Climate change and agriculture: Impacts and adaptation options in South Africa. *Water Resources and Economics*, 5, 24-48. https://doi.org/10.1016/J.WRE.2014.03.001

Chersich, M., Wright, C., Venter, F., Rees, H., Scorgie, F., & Erasmus, B. (2018). Impacts of climate change on health and wellbeing in South Africa. *International Journal of Environmental Research and Public Health*, 15(9), 1884. https://doi.org/10.3390/ijerph15091884

Creswell, J. W. (2014). Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.). SAGE Publications.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.). SAGE Publications.

Creswell, J. W., & Plano Clark, V. L. (2018). Designing and conducting mixed methods research (3rd ed.). SAGE Publications.

Field, A. (2013). Discovering statistics using IBM SPSS statistics (4th ed.). SAGE Publications.

Ford, J. D., & King, D. (2022). A framework for examining adaptation readiness. *Mitigation and Adaptation Strategies for Global Change,* 27, 13. https://doi.org/10.1007/s11027-021-09967-0

Ford, J. D., & King, D. (2022). Examining the use of vulnerability indices in climate change adaptation planning. *Sustainability*, 14(2), 700-715. DOI: 10.3390/su14020700

Forster, P., Smith, C. J., Walsh, T., Lamb, W., Lamboll, R. D., Hauser, M., ... & Zickfeld, K. (2023). Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence. *Earth System Science Data*, 15(2), 2295-2305. https://doi.org/10.5194/essd-15-2295-2023

Gbetibouo, G. A., Ringler, C., & Hassan, R. (2010). Vulnerability of the South African farming sector to climate change and variability: An indicator approach. *Natural Resources Forum*, 34(3), 175-187. https://doi.org/10.1111/J.1477-8947.2010.01302.X

Goldin, J., Botha, C., Koatla, T., Anderson, K., Owen, G., & Lebese, A. (2019). Towards a gender-sensitive vulnerability assessment for climate change: Lambani, Limpopo Province, South Africa. *Human Geography*, 12(1), 19-32. https://doi.org/10.1177/194277861901200102

Halkos, G., Skouloudis, A., Malesios, C., & Jones, N. (2020). A Hierarchical Multilevel Approach in Assessing Factors Explaining Country-Level Climate Change Vulnerability. *Sustainability*. https://doi.org/10.3390/su12114438

Happ, M., Bathke, A. C., & Brunner, E. (2019). Optimal sample size planning for the Wilcoxon Mann Whitney test. *Statistics in medicine*, 38(3), 363-375.

Hlalele, B. M. (2019). Iyengar-sudarshan method application to drought social vulnerability: Free State Province, South Africa. *Ecology Environment and Conservation Journal*, 25(3), 1473-1479.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., ... & Zhou, G. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science*, 365(6459), 222. DOI: 10.1126/science.aaw6974

Jamil, M. A., & Khanam, S. (2024). Influence of one-way ANOVA and Kruskal–Wallis based feature ranking on the performance of ML classifiers for bearing fault diagnosis. *Journal of Vibration Engineering & Technologies*, 12(3), 3101-3132.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), 14-26.

Juana, J., Mangadi, K., & Strzepek, K. (2012). The socio-economic impacts of climate change on water resources in South Africa. *Water International*, 37(3), 265-278. https://doi.org/10.1080/02508060.2012.687505

Jury, M. (2018). South Africa’s future climate: Trends and projections. *World Regional Geography Book Series*. https://doi.org/10.1007/978-3-319-94974-1_33

Jury, M. (2022). Historical and projected climatic trends in KwaZulu-Natal: 1950–2100. *Water SA*. https://doi.org/10.17159/wsa/2022.v48.i4.3991

Klein, R. J. T., & Smith, J. B. (2008). Enhancing the capacity of developing countries to adapt to climate change: a policy-relevant research agenda. *Risk Management*, 10(4), 179-199. DOI: 10.1057/rm.2008.9

Klenk, N., & Meehan, K. (2023). Climate adaptation planning: The role of social vulnerability and equity in South Africa. *Environmental Research Letters*, 18(4), 044005. https://doi.org/10.1088/1748-9326/acbd89

Kusangaya, S., Warburton, M., Garderen, E. A. V., & Jewitt, G. (2014). Impacts of climate change on water resources in southern Africa: A review. *Physics and Chemistry of The Earth*, 67, 47-54. https://doi.org/10.1016/J.PCE.2013.09.014

Le Roux, A., & Pauw, K. (2022). Measuring Social Vulnerability in South African Townships: A Case Study of Cape Town. *International Journal of Disaster Risk Reduction*, 74, 102897.

Li, L., Cao, R., Wei, K., Wang, W., & Chen, L. (2019). Adapting climate change challenge: A new vulnerability assessment framework from the global perspective. *Journal of Cleaner Production*. https://doi.org/10.1016/J.JCLEPRO.2019.01.162

Mafi-Gholami, D., Pirasteh, S., Ellison, J., & Jaafari, A. (2021). Fuzzy-based vulnerability assessment of coupled social-ecological systems to multiple environmental hazards and climate change. *Journal of Environmental Management*, 299, 113573. https://doi.org/10.1016/j.jenvman.2021.113573

Mahlalela, P., Blamey, R., & Reason, C. (2018). Mechanisms behind early winter rainfall variability in the southwestern Cape, South Africa. *Climate Dynamics*, 53, 21-39. https://doi.org/10.1007/s00382-018-4571-y

Mahlalela, P., Blamey, R., Hart, N., & Reason, C. (2020). Drought in the Eastern Cape region of South Africa and trends in rainfall characteristics. *Climate Dynamics*, 55(9), 2743-2759.

Makhubele, J., Shokane, A. L., & Mabasa, M. A. (2016). Rural perspectives, challenges and strategies of climate change amongst small-holder farmers in Mopani district of Limpopo Province. *Indilinga: African Journal of Indigenous Knowledge Systems*, 15, 151-174.

Masingi, V. N., & Maposa, D. (2021). Modelling long-term monthly rainfall variability in selected provinces of South Africa: Trend and extreme value analysis approaches. *Hydrology*, 8(2), 70.

Maxcy, S. J. (2003). Pragmatic threads in mixed methods research in the social sciences: The search for multiple modes of inquiry and the end of the philosophy of formalism. *Handbook of mixed methods in social and behavioral research*, 51-89.

Mechler, R., Bouwer, L. M., & Cardenas, V. (2020). Managing uncertainty and risk in climate change adaptation: Addressing policy gaps through integration. *Climatic Change*, 161(3), 309-328. DOI: 10.1007/s10584-020-02726-2

Mechler, R., Singh, C., Ebi, K., Djalante, R., Thomas, A., James, R., ... & Revi, A. (2020). Loss and Damage and limits to adaptation: recent IPCC insights and implications for climate science and policy. *Sustainability Science*, 15(5), 1245-1251. https://doi.org/10.1007/s11625-020-00807-9

Mensah, A. S., & Amponsah, O. (2023). Assessing Vulnerability of Coastal Communities to Climate Change in Ghana: A Case Study of the Volta Delta. *Climate and Development*, 15(3), 255-267.

Mingaleva, Z. A. (2020). Institutional Features of International Financing for Climate Change Adaptation Programs. *Review of Business and Economics Studies*, 12(4), 10-25. https://doi.org/10.31107/2075-1990-2020-4-10-25

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of cardiac anaesthesia*, 22(1), 67-72.

Moreira, L. L., de Brito, M. D., & Kobiyama, M. (2021). Effects of Different Normalization, Aggregation, and Classification Methods on the Construction of Flood Vulnerability Indexes. *Water*, 13(1), 98. https://doi.org/10.3390/w13010098

Morgan, D. L. (2014). Pragmatism as a basis for mixed methods research: Mixed methods in social & behavioral research. SAGE Publications.

Mosase, E., & Ahiablame, L. (2018). Rainfall and temperature in the Limpopo River Basin, Southern Africa: Means, variations, and trends from 1979 to 2013. *Water*, 10(4), 364.

Moyo, B., & Abegunde, V. O. (2022). Assessing Climate Change Vulnerability among Smallholder Farmers in the Eastern Cape, South Africa. *Land Use Policy*, 118, 106162.

Mpandeli, S. (2014). Evaluation of crop production practices by farmers in Tshakhuma, Tshiombo and Rabali areas in Limpopo Province of South Africa. *The Journal of Agricultural Science*, 6(8), 10.

Mthethwa, S., & Zegeye, E. W. (2022). Household vulnerability to climate change in South Africa: A multilevel regression model. *Development Southern Africa*, 40(4), 466-481. https://doi.org/10.1080/0376835X.2022.2085667

Mukwada, G., Mazibuko, S. M., Moeletsi, M., & Robinson, G. (2021). Can famine be averted? A spatiotemporal assessment of the impact of climate change on food security in the Luvuvhu River catchment of South Africa. *Land*, 10(5), 527. https://doi.org/10.3390/LAND10050527

Munyai, R. B., Chikoore, H., Musyoki, A., Chakwizira, J., Muofhe, T. P., Xulu, N. G., & Manyanya, T. (2021). Vulnerability and adaptation to flood hazards in rural settlements of Limpopo Province, South Africa. *Water*. DOI: 10.3390/w13243490

Ndlovu, M., & Demlie, M. (2020). Assessment of Meteorological Drought and Wet Conditions Using Two Drought Indices Across KwaZulu-Natal Province, South Africa. *Atmosphere*. https://doi.org/10.3390/atmos11060623

Ndlovu, M., Clulow, A., Savage, M. J., Nhamo, L., Magidi, J., & Mabhaudhi, T. (2021). An assessment of the impacts of climate variability and change in KwaZulu-Natal Province, South Africa. *Atmosphere*, 12(4), 427. https://doi.org/10.3390/atmos12040427

Nhemachena, C., Nhamo, L., Matchaya, G., Nhemachena, C. R., Muchara, B., Karuaihe, S., & Mpandeli, S. (2020). Climate change impacts on water and agriculture sectors in Southern Africa: Threats and opportunities for sustainable development. *Water*, 12(10), 2673. https://doi.org/10.3390/W12102673

Olsson, L., Jerneck, A., & Thoren, H. (2023). Resilience through adaptation: Addressing vulnerability in the global south. *Global Environmental Change*, 74, 102560. DOI: 10.1016/j.gloenvcha.2023.102560

Omukuti, J., Barrett, S., White, P., Marchant, R., & Averchenkova, A. (2022). The green climate fund and its shortcomings in local delivery of adaptation finance. *Climate Policy*, 22(8), 1225-1240. https://doi.org/10.1080/14693062.2022.2093152

Otieno, P. O., & Odhiambo, M. O. (2022). Flood Vulnerability Assessment in Informal Settlements: A Case Study of Kibera, Nairobi. *Journal of Environmental Management*, 310, 114682.

Paumgarten, F., Locatelli, B., & Witkowski, E. (2020). Archetypes of climate-risk profiles among rural households in Limpopo, South Africa. *Weather, Climate, and Society*. DOI: 10.1175/wcas-d-19-0134.1

Pietrapertosa, F., Salvia, M., De Gregorio Hurtado, S., Geneletti, D., D'Alonzo, V., & Reckien, D. (2021). Multi-level climate change planning: An analysis of the Italian case. *Journal of Environmental Management*, 289, 112469. https://doi.org/10.1016/j.jenvman.2021.112469

Polit, D. F., & Beck, C. T. (2017). Nursing research: Generating and assessing evidence for nursing practice (10th ed.). Wolters Kluwer.

Quinn, C. H., Huby, G., Kiwasila, H., & Lovett, J. C. (2018). Integrated assessment of ecosystem services in Tanzania. *Journal of Environmental Management*, 44(2), 71-82. DOI: 10.1016/j.jenvman.2018.02.010

Rankoana, S. (2023). A review of rural communities' vulnerability to climate change: The case of Limpopo Province in South Africa. *International Journal of Environmental, Sustainability, and Social Science*. DOI: 10.38142/ijesss.v4i6.722

Rimmer, M. (2019). Beyond the Paris Agreement: Intellectual Property, Innovation Policy, and Climate Justice. *Laws*, 8(1), 7. https://doi.org/10.3390/LAWS8010007

Rodriguez-Cordero, A.L., Balaguera-Reina, S. Morales-Franco J.C., Munn, M., Densmore L.D, (2022). Predicting habitat suitability of *Caiman yacare* and assessing the role of protected areas under current and future climate and deforestation models. Climate risk management, 35: 100407; https://doi.org/10.1016/j.crm.2022.100407

Roppongi, H. (2020). From Global to Local: A Multilevel Approach to the Local Implementation of Climate Policies in Japan. *In Proceedings of the Springer Nature Book Series*, 543-558. https://doi.org/10.1007/978-3-030-42630-9_27

Sang, Z., & Hamann, A. (2022). Climatic limiting factors of North American ecosystems: a remote-sensing based vulnerability analysis. *Environmental Research Letters*, 17. https://doi.org/10.1088/1748-9326/ac8608

Sbai, M., Larabi, A., Fahs, M., & Doummar, J. (2021). A New Normalized Groundwater Age-Based Index for Quantitative Evaluation of the Vulnerability to Seawater Intrusion in Coastal Aquifers: Implications for Management and Risk Assessments. *Water*, 13(18), 2496. https://doi.org/10.3390/w13182496

Schneiderbauer, S., Baunach, D., Pedoth, L., Renner, K., Fritzsche, K., Bollin, C., ... & López, M. del R. R. (2020). Spatial-Explicit Climate Change Vulnerability Assessments Based on Impact Chains. Findings from a Case Study in Burundi. *Sustainability*, 12(16), 6354. https://doi.org/10.3390/su12166354

Schneiderbauer, S., Pedoth, L., & Renner, K. (2020). A new approach for assessing local vulnerability: The case of the alpine regions. *Environmental Science & Policy*, 106, 1-10. DOI: 10.1016/j.envsci.2020.01.004

Seddon, N., Daniels, E., Davis, R., Harris, R., Hou-Jones, X., Huq, S., Kapos, V., Mace, G., Rizvi, A., Reid, H., Roe, D., & Wicander, S. (2019). Global recognition of the importance of nature-based solutions to climate change impacts. *Nature Sustainability*, 2(1), 24-29.

Sherbinin, A., Bukvic, A., Rohat, G., Gall, M., McCusker, B., Preston, B., Apotsos, A., Fish, C., Kienberger, S., Muhonda, P., Wilhelmi, O. V., Macharia, D., Shubert, W., Sliuzas, R., Tomaszewski, B. M., & Zhang, S. (2019). Climate vulnerability mapping: A systematic review and future prospects. *Wiley Interdisciplinary Reviews: Climate Change*, 10, e600. https://doi.org/10.1002/wcc.600

Sheriff, G. (2019). Burden Sharing under the Paris Climate Agreement. *Journal of the Association of Environmental and Resource Economists*, 6(2), 275-318. https://doi.org/10.1086/701469

Shikwambana, S., Malaza, N., & Shale, K. (2021). Impacts of rainfall and temperature changes on smallholder agriculture in the Limpopo Province, South Africa. *Water*, 13(20), 2872. https://doi.org/10.3390/w13202872

Statistics South Africa. (2022). Census 2022 shows South Africa's population grew to 62 million. Accessed from: https://www.statssa.gov.za/?p=16711 Date of access: 11 June 2024.

Stephenson, S., Oculi, N., Bauer, A., & Carhuayano, S. (2019). Convergence and Divergence of UNFCCC Nationally Determined Contributions. *Annals of the American Association of Geographers*, 109(5), 1240-1261. https://doi.org/10.1080/24694452.2018.1536533

Tessema, Y. A., et al. (2023). Drought Vulnerability and Livelihood Diversification in Rural Ethiopia: An Empirical Analysis. *Environmental Development*, 41, 100758.

The National Aeronautics and Space Administration (NASA), (2024). Power Data Access. Accessed from: https://power.larc.nasa.gov/data-access-viewer/ Date of access: 11 June 2024.

Thomas, D. S. G., Twyman, C., Osbahr, H., & Hewitson, B. (2007). Adaptation to climate change and variability: Farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change*, 83(3), 301-322.

Tschakert, P., & Tuana, N. (2022). Uncertainty, collaboration, and climate change adaptation in Africa: learning from a pilot study in Ghana. *Climatic Change*, 171(1-2), 2. https://doi.org/10.1007/s10584-021-03130-3

United Nations Framework Convention on Climate Change. (2015). Paris Agreement. Retrieved from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

van Wilgen, N. J., Goodall, V., Holness, S., Chown, S., & McGeoch, M. (2016). Rising temperatures and changing rainfall patterns in South Africa's national parks. *International Journal of Climatology*, 36(3), 937-950. https://doi.org/10.1002/joc.4377

Wang, W., Shi, F., Zhang, M., Xu, C., & Zheng, J. (2020). A Vulnerability Risk Assessment Method Based on Heterogeneous Information Network. IEEE Access, 8, 148315-148330. https://doi.org/10.1109/ACCESS.2020.3015551

Wu, J. (2016). Climate change, global food security, and the US food system. *Bioscience*, 66(4), 356-368. DOI: 10.1093/biosci/biw023

Ziervogel, G., & Parnell, S. (2022). The role of vulnerability assessments in building resilience in Southern Africa: Lessons from recent studies. *Climate and Development*, 14(6), 543-554. https://doi.org/10.1080/17565529.2021.1978042

Ziervogel, G., & Taylor, A. (2023). A co-produced national climate change risk and vulnerability assessment framework for South Africa. *Frontiers in Climate*. https://doi.org/10.3389/fclim.2023.1197167

Zhang, Y. F., Ruckelshaus, M., Arkema, K., Han, B., Lu, F., Zheng, H., & Ouyang, Z. (2019). Synthetic vulnerability assessment to inform climate-change adaptation along an urbanized coast of Shenzhen, China. *Journal of Environmental Management*, 255, 109915. https://doi.org/10.1016/j.jenvman.2019.109915

Zhu, J., Chen, Y., & Zhang, S. (2020). Analysis of the Impact of Climate Change on National Vulnerability Based on Fuzzy Comprehensive Evaluation. *Discrete Dynamics in Nature and Society*, 2020, 1-10. https://doi.org/10.1155/2020/3527540

APPENDIX A: Data collection tool

Introduction and instructions

The purpose of this hybrid tool is to collect relevant data towards the construction of a context-specific climate change vulnerability index. It is a hybrid tool in that it will be used to collect data from three main sources: secondary data sources or official statistics, Focus Group Discussions (FGDs) using consensus-based responses, and key informant interviews (KIIs). Whilst there is additional data to be collected through qualitative means, the core data is what will be used to develop the vulnerability index. FGDs are to be used to build consensus around several parameters as done in Household Economy Approach (HEA). The data collection teams must therefore organise themselves to ensure that that data is collected from relevant sources and that at the end of the fieldwork, there is a consolidated completed tool for each of the selected sites plus additional data from FGDs and KIIs.

A. BACKGROUND INFORMATION (SOCIO-ECONOMIC STATUS, RACE & ETHNICITY)

QUESTION/VARIABLE	RESPONSES	DATA SOURCE
Province:		
District:		
Ward:		
Village:		
Township:		
GIS coordinates		
Population:		

POPULATION: AGE AND GENDER	RESPONSES	DATA SOURCE
Race/Category (%):		
Black		
White		
Indian		
Coloured		
Foreigner (African)		
Foreigner (White)		
Other (specify)		
Average age		
Median age		
Males (%)		
Females (%)		
Prefer not to say (%)		
Under 18 years (%)		
Under 5 years, 65 years and over (%)		
Disability (%)		
Unmarried		
Primary languages spoken (%) in this area:		
Afrikaans		
English		
Sesotho		
Zulu		
isiXhosa		
siSwati		
Setswana		
Ndebele		

Tshivenda		
Tsonga		
Sepedi		

Number of households:		
Employment status of HHD (%):	Yes/No	
Formal (%):		
Informal (%):		
If employed, in what sector:		
1) Agriculture (%)		
2) Mining (%)		
3) Industry (%)		
4) Other (%) (specify):		
Proportions of combined household average income in the area:		FGD/StatsSA
1 = NO INCOME		
2 = < 1500		
3 = 1501-3000		
4 = 3001-4500		
5 = 4501-6000		
6 = >6000		
Household value/assets	Use HEA type asset categories	FGD/StatsSA
Household head (%):		
1) Female-headed		
2) Male-headed		
3) Child-headed		
Average household size		
Education levels (%):		
1) No education		
2) Primary		
3) Secondary		
4) Tertiary		
Percentage of households receiving some form of social grant		
Home ownership status (%):		
1) Owned		
2) Rented		
3) If rented how much do you pay monthly		

B. INFRASTRUCTURAL VULNERABILITY (PHYSICAL/TELECOM SYSTEMS)

Type of settlement:	Formal/ informal	StatsSA/FGD
1) Formal		
2) Informal		
Type of housing (%):		
1) Brick and mortar		
2) Non-brick and mortar		
Roadways in kilometres:		
1) % (km) surfaced		
2) % (km) non-surfaced:		
Number of electric power transformers in the area (per 1000 households)		
Number of farms in the area		
Number of hospitals in the area		
Number of clinics in the area		
Number of old age homes in the area		
Number of banks in the area		
Number of waste-treatment plants in the area		
Number of schools (all types) in the area		
Number of colleges/universities in the area		
Proportion of household with renewable energy sources		
Proportion of households by sanitation types: 01 = Flush toilet connected to a public sewerage system 02 = Flush toilet connected to a septic or conservancy tank 03 = Pour flush toilet connected to a septic tank (or septage pit) 04 = Chemical toilet 05 = Pit latrine/toilet with ventilation pipe 06 = Pit latrine/toilet without ventilation pipe 07 = Bucket toilet (collected by municipality) 08 = Bucket toilet (emptied by household) 09 = Ecological Sanitation Systems (e.g. urine diversion) 10 = Open defecation (e.g. no facilities, field, bush) 11 = Other (specify)		StatsSA/FGD
Sources of water (%): 01 = Piped (tap) water in dwelling/house 02 = Piped (tap) water in yard 03 = Borehole in yard 04 = Rain-water tank in yard 05 = Neighbour's tap 06 = Public/communal tap 07 = Water-carrier/tanker 08 = Water vendor (charge involved) 09 = Borehole outside yard 10 = Flowing water/stream/river 11 = Stagnant water/dam/pool 12 = Well 13 = Spring 14 = Other (specify)		StatsSA/FGDs

Length of water supply pipes per residential space (settlement)		
Internet connectivity of area:		
1) Excellent		
2) Average		
3) Poor		
Length of telecommunication lines in this area (km^2)		
Number of cell phone towers in the area		

C. AGRICULTURAL/FOOD AND NUTRITION VULNERABILITY

What is the proportion of households involved in agriculture?		
What is the proportion of households by type of agriculture?		
1) Crop farming		
2) Livestock farming		
3) Forestry		
4) Fisheries		
5) Other (specify)		
What is the proportion of households by agricultural practice?		
1) Rain-fed agriculture		
2) Irrigation agriculture		
What proportion of households are food insecure?		NFNSS
What proportion of households are nutrition insecure?		NFNSS
Proportion of households that are planting drought resistant crops		
Proportion of households supported with food parcels		
Proportion of learners on school feeding programmes		

D. HEALTH AND SAFETY VULNERABILITY (ENVIRONMENTAL AND HUMAN HEALTH SYSTEMS)

What is the population density (units/km2) of this area?		StatsSA
What is the number of green areas/parks in this area?		GIS/Depart
What is the summertime average noon air temperature in this area?		Met
What is the wintertime average night chill air temperature in this area		Met
What is the highest wind speed (hurricanes/tornadoes) in this area?		Met
What is the rainy season highest rainfall intensity in this area (in mm)?		Met
How often do you experience floods in this area? 1) Every year 2) Every 2 years 3) Every 5 years 4) Other (specify)		Met/FGD
What is the percentage of surface water area in this area?		GIS
What is the percentage of slope areas greater than 10%?		GIS
What is the number of mining waste and other wastes piles per unit area (in this area)?		Municipality
What is the length of shoreline per area (where applicable)?		GIS
What is the number of open fish ponds in this area?		
What is the percentage of grazing fields per area (in this area)?		GIS
What is the percentage of bare ground in this area?		GIS
What is the recorded average wind speed in this area?		Met office

What are the annual hospitalisation rates for communicable diseases in this area?		DoH (district/ province)
What are the annual hospitalisation rates for non-communicable diseases in this area?		DoH (district/ province)
How would you rate the potential occurrence/occurrence of zoonotic diseases in this area? 1) High 2) Average 3) Low		FGD/AGRIC
What is the number of protected animal or plant species in this area? 1) Animals (%) 2) Plants (%)		Parks/GIS
How would you rate the loss of plant and animal species in this area? 1) Increasing 2) Staying the same 3) Decreasing		

E. OCCUPATIONAL AND INDUSTRIAL SYSTEMS

Percentage of unemployment (%):		
Type of businesses in the areas (%): 1) Formal small business 2) Formal large businesses 3) Informal businesses		
Numbers by employment type:		
1) Formal		
2) Informal (vendors, etc)		
Proportion of people employed in the following sectors:		
1) Agriculture		
2) Extractive industries		
3) Tourism and hospitality		
4) Fisheries		
5) Manufacturing		
6) Construction		
7) Social services		
8) Other (specify)		

F. GOVERNANCE, FINANCIAL AND SOCIAL SERVICES SYSTEM

How do you rate existing democratic structures in the area?		FGDs/Government officials
1) Inadequate		
2) Average		
3) Adequate		
How do you rate existing of regulations on facilities and operations in the area?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate existing government facilities maintenance department or units in the area?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate existing government formal procurement processes in this area?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate existing government auditing processes in this area?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate health emergency services (public and private)?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate the existence of insurance service for flood damages, fire, etc.?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate public awareness programmes on climate change in this area?		As above
1) Inadequate		
2) Average		
3) Adequate		
How do you rate early warning systems for climate change related disasters in this area?		
1) Inadequate		
2) Average		
3) Adequate		
Percentage of population covered by health insurance:		StatsSA/PDoH officials
1) Inadequate		
2) Average		

3) Adequate		
How do you rate existing disaster contingency plans for this area?		As above
1) Inadequate		
2) Average		
3) Adequate		

G. GENERAL INFORMATION

What do you see as the major vulnerabilities of your community to climate change?		FGD/KII
What do you think your community should do to reduce vulnerability to climate change?		FGD/KII
In your view, is the government doing enough to reduce climate change vulnerability to your community? And why?		FGD/KII
Is the community adequately involved in finding solutions to:		FGD/KII
1) Reducing climate change vulnerabilities?		FGD/KII
2) Mitigation activities to climate change?		FGD/KII
Is your traditional or local leadership regularly and actively involved in climate change activities?		FGD/KII

THANK YOU

APPENDIX B: Categorised variables from Muyexe and Nkowankowa, Limpopo

	Category	Variable	Percentage/ Value	Classification	Explanation
Muyexe	Population	Total population	3228	Sensitivity	Larger population indicates greater potential impact of hazards.
	Population: age and gender	Males	42%	Sensitivity	Demographic factors such as age and gender influence vulnerability.
		Females	58%	Sensitivity	Higher female population might indicate higher sensitivity due to social and economic factors.
		Under 18 years	52%	Sensitivity	Higher proportion of children increases sensitivity due to dependency.
		Under 5 years	14.52%	Sensitivity	Young children are particularly vulnerable to health and environmental risks.
		65 years and over	5.06%	Sensitivity	Elderly population is more vulnerable to health issues and environmental changes.
	Health and safety vulnerability	Population density (units/ Km^2)	50.4	Exposure	Higher density can increase the impact of hazards such as disease outbreaks.
	Climate details	Summertime average noon temperature	33.75°C	Exposure	Higher temperatures indicate exposure to heat stress and related health risks.
		Wintertime average night chill temperature	11°C	Exposure	Lower temperatures could indicate exposure to cold-related vulnerabilities.
	Rainfall	Rainy season highest rainfall intensity (mm)	400	Exposure	High rainfall intensity could lead to flooding and water-related issues.
	Number of households	Total households	826	Sensitivity	Number of households can indicate potential impact and need for resources during hazards.

Nkowankowa	Population	Total population	390095	Sensitivity	Large population size can lead to higher impact of hazards.
	Population: age and gender	Males	181558	Sensitivity	Male population might be less vulnerable in some contexts but more in others.
		Females	204469	Sensitivity	Higher female population might indicate higher vulnerability due to various socio-economic factors.
		Disability	14879	Sensitivity	Disabled population has increased vulnerability to environmental and health hazards.
		Unmarried	261666	Sensitivity	Higher number of unmarried individuals might indicate higher social vulnerability.
	Primary languages spoken	Tsonga	159074	Sensitivity	Dominant language could impact access to information and services.
		Sepedi	179572	Sensitivity	Similar to above, language could influence communication in times of hazard.
	Household details	Households with no income	14573	Sensitivity	Economic vulnerability increases sensitivity to hazards due to lack of resources.
		Female-headed households	52052	Sensitivity	Female-headed households might face additional social and economic challenges.
	Education levels	No education	19%	Sensitivity	Lower education levels reduce the ability to respond and adapt to hazards.
		Primary education	16%	Adaptive capacity	Primary education provides basic skills for adaptation and resilience.
		Secondary education	35%	Adaptive capacity	Higher education level enhances adaptive capacity through knowledge and skills.
		Tertiary education	9%	Adaptive capacity	Tertiary education indicates higher capacity to adapt and recover from hazards.
	Infrastructural vulnerability	Type of settlement: Formal	92%	Adaptive capacity	Formal settlements are better equipped to deal with hazards due to infrastructure.
		Type of settlement: Informal	3%	Sensitivity	Informal settlements are more vulnerable due to lack of infrastructure and services.
		Type of settlement: Traditional	4%	Sensitivity	Traditional settlements might face more challenges during hazards.
	Land area	Municipal land area	3240 km^2	Exposure	Large land area can indicate diverse exposure to different environmental hazards.

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