Assessing Barriers to Climate Smart Subsistence Agriculture in Northeastern Namibia

Marissa Lazaroff, Kiana Lindsay, Lynn Socha
Dr. Avik Basu

UNFCCC

Global Water Partnership
Southern Africa

UNAM
UNIVERSITY OF NAMIBIA

SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY
UNIVERSITY OF MICHIGAN

CRAVE
CLIMATE RESILIENT AGRICULTURE IN THREE VULNERABLE EXTREME NORTHERN CROP GROWING REGIONS

Acknowledgements

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Best,

Marissa, Kiana, and Lynn

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Acronym and Abbreviation List

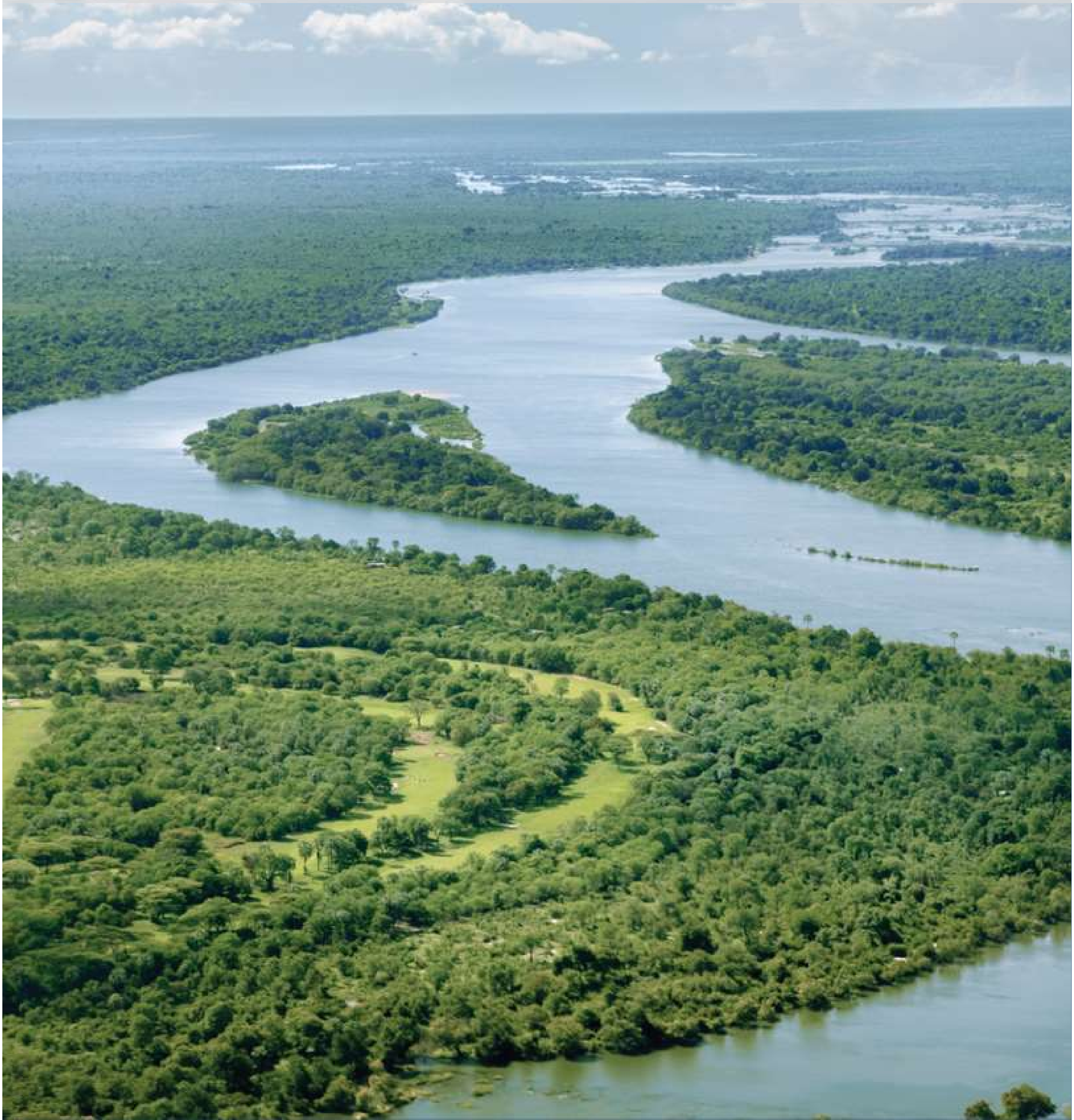
AF	Adaptation Fund
AgriBusDev	Agricultural Business Development Agency
AMTA	Agro-Marketing & Trade Agency
CDM	Clean Development Mechanism
CIF	Climate Investment Funds
CRAVE	Climate Resilient Agriculture in three of the Vulnerable Extreme northern crop growing regions
EIF	Environmental Investment Fund of Namibia
ENSO	El Niño–Southern Oscillation (consisting of El Niño and La Niña phases)
FAO	Food and Agriculture Organization
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse gas emissions
GWPSA	Global Water Partnership South Africa
HOH	Head of Household
IOD (+IOD or -IOD)	Indian Ocean Dipole (positive phase or negative phase)
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
LAKI	Lima Adaptation Knowledge Initiative
LDCF	Least Developed Climate Fund
MAWF	Ministry of Agriculture, Water and Forestry (currently known as MAWLR)
MAWLR	Ministry of Agriculture, Water and Land Reform (formerly MAWF)
MCRACE	Mashare Climate Resilient Agriculture Centre of Excellence
MEL	Monitoring, Evaluation and Learning
MET	Ministry of Environment and Tourism
NAB	Namibia Agronomic Board
NDA	Nation Designated Authority

NGO	Non-Government Organization
OGEMP	Off Grid Energisation Master Plan
PV	Photovoltaic
RCP	Representative Concentration Pathway
SCCF	Special Climate Change Fund
SHL	Saharan Heat Low
SIOD (+SIOD or -SIOD)	Subtropical Indian Ocean Dipole (positive phase or negative phase)
SME	Small Medium Scale Farmers
SSF	Small-scale farmers
SST	Sea surface temperatures
STH	Subtropical High-Pressure
UNAM	University of Namibia
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Abstract

Global climate change threatens the livelihoods of subsistence farmers in northeastern Namibia but there is uncertainty about how these impacts will be experienced. This study examined impacts climate change may have on Namibian subsistence agriculture and the barriers farmers may face in adapting their agricultural practices. Based on a review of regional climate features, four potential climate scenarios were developed for Namibia (Extreme Rainfall and Flooding, Extreme Heat, Drought, and Shortened Wet Season). To better understand existing Namibian agricultural practices as well as potential financial and sociocultural barriers to climate adaptation, a literature review, expert stakeholder interviews, and a survey of 205 Namibian farmers were carried out. The study suggested that there are substantial barriers preventing subsistence farmers from implementing climate smart agricultural approaches including: growing resilient crops, implementing effective irrigation strategies, access to financial resources, and gender disparities. Recommendations were formulated to address these barriers and increase resilience in subsistence farming communities. A Climate Scenario Planning Toolkit integrated findings from this project into a participatory workshop in which farmers can learn about and plan for adaptations to possible climate scenarios.

Chapter 1: Climate Risks to Namibian Subsistence Farmers



Agriculture directly supports more than 70% of Namibia's population. Over 50% of the population are subsistence farmers who rely solely on agriculture to feed and support themselves and their families (FAO, 2020; Republic of Namibia, 2015). While the exact impacts climate change will have on Namibia are uncertain, it is likely to have significant consequences for Namibia's agricultural systems and the people who rely on them, straining farmers' ability to maintain their livelihoods. Adapting to these changes will require overcoming many barriers. This study aims to identify and address some potential barriers that Namibian subsistence farmers may face in adapting to a changing climate.

1.1. Climate Risks to Subsistence Farming

Subsistence Farming. Subsistence farming (used synonymously with subsistence agriculture) in Namibia is characterized by farm size, crop types, and irrigation approaches. Typically, farm sizes are smaller than 11 hectares (Ministry of Agriculture, Water, and Forestry & AgriBusDev, n.d.). Subsistence farmers usually grow staple crops—maize, sorghum, and pearl millet—and may also grow horticultural crops such as groundnuts, beans, and fruits and vegetables including grapes, onions, potatoes, and squash (Green Climate Fund, 2017). These crops are either grown exclusively with rainwater or with an irrigation system, such as sprinklers or surface flooding (Green Climate Fund, 2017).

Climate Risk. In this project, climate risk was evaluated using the Intergovernmental Panel on Climate Change (IPCC, 2013) risk assessment framework (Figure 1.1), which describes risk in terms of potential climate hazards, vulnerabilities, and exposure. This study focuses in particular on the hazards climate change presents to northeastern Namibia and the vulnerabilities of farmers in that region.

Climate Hazards. Namibian subsistence farmers will face a range of climate hazards including variations in temperature and precipitation, extreme weather events such as droughts, and degradation or complete loss of crops.

Namibia is the most arid country in sub-Saharan Africa, with desert conditions on the coast and much of the interior (Desert Research Foundation of Namibia & Climate Systems Analysis Group, 2008; MET, 2015). Comparatively, northeastern Namibia is semi-arid, with the highest annual precipitation. The region has some of the highest temperatures in the country (Figure 1.2).

Between 2045-2065, climate change will lead to an expected increase in temperature. between 1-4°C and an expected decrease in precipitation (MET, 2015; Republic of Namibia, 2015). Extreme events are expected to occur more frequently with greater severity and longer time-frames than in the past (Rood, personal communication, 2021).

These climate changes will impact agriculture and water resources necessary for crop production. For instance, changes to rainfall patterns or increasing temperature could reduce crop yields. These changes could also result in declining soil moisture, increased evapotranspiration, and decreased water availability for irrigating crops (MET, 2015).

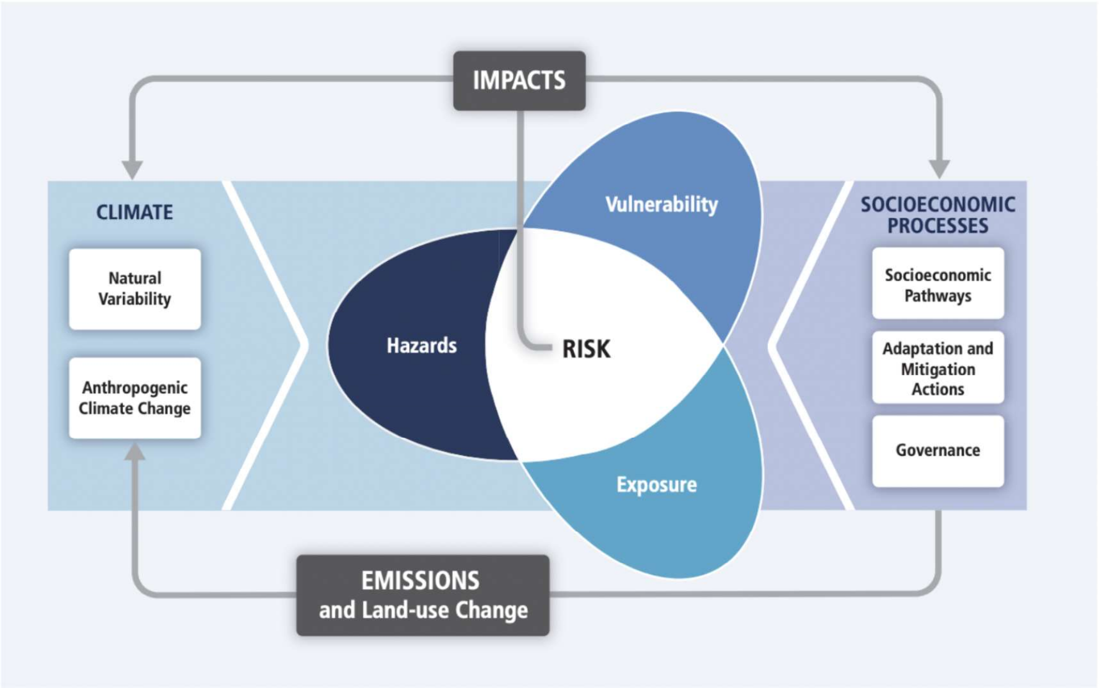


Figure 1.1: IPCC risk assessment framework (IPCC, 2014) This framework shows that hazards and vulnerability are at the core of risk. This study recognizes that farmers are exposed to climate change and therefore focus on the uncertainties of hazards and vulnerability when promoting solutions to reduce farmer's risk to climate change.

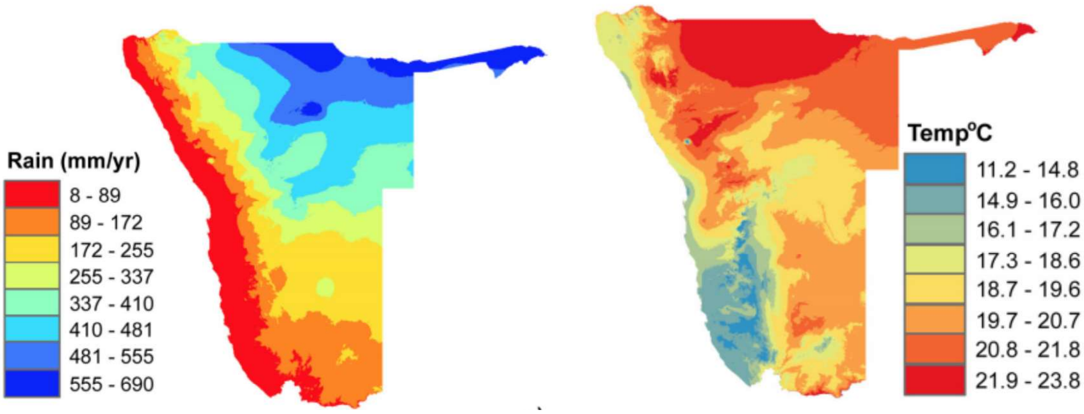


Figure 1.2: Average annual a) precipitation in millimeters per year and b) temperature in degrees Celsius between 1960-2010 (Kaseke et al., 2016)

Farmer's Vulnerability. Vulnerability refers to the susceptibility to be negatively affected by climate change. Subsistence farmers are particularly vulnerable to climate hazards because of their reliance on agricultural production to sustain their livelihoods. Farmers can face physical or social vulnerabilities (Adger & Kelly, 1999; IPCC, 2018; Kapuka & Hlásny, 2020). An example of physical vulnerability is reliance on unpredictable river flows, while a social vulnerability is exemplified by literacy. Specifically, the vulnerabilities explored in this study are related to crops, technologies, finances, and gender.

1.2. Building Resilience through Climate Smart Agriculture

Resilience. Reducing the vulnerability of farmers requires increasing their resilience to impending climate changes that may disrupt their farming practices (IPCC, 2018). A resilient approach to subsistence farming would "anticipate, absorb, accommodate, or recover" from climate change impacts (Bergstrand et al., 2015; IPCC, 2018; Kapuka & Hlásny, 2020; Saja et al., 2019).

This study focuses on two approaches to increasing resilience: adaptive capacity and Climate Smart Agriculture (CSA).

Adaptive Capacity. Adaptive capacity refers to all of the resources available to an individual or community to prepare for and engage in adaptations that reduce the harm from climate hazards. For subsistence farmers, resources could include irrigation technologies, loans for building new infrastructure, seasonal climate knowledge, or adaptive seeds. Increasing adaptive capacity in turn increases resilience by providing subsistence farmers with tools and resources (IPCC, 2018).

Climate Smart Agriculture. Climate Smart Agricultural (CSA) approaches are meant to identify systems within agricultural production in which adaptation or mitigation are most possible. A system refers to any part of the agricultural process such as irrigation or choosing seeds. These approaches help stakeholders at all levels—international, national, and local—to choose the agricultural adaptation strategies that are most appropriate for local climate conditions (Lewis, 2019).

CSA approaches are context-specific in order to maximize benefits for local farmers and their crops based on local climate conditions (FAO, 2019b). The approach is therefore not a promotion of a specific technique or a new production system, but optimizes existing systems within current production that best respond to the impacts of climate change. This could mean modifying existing water storage approaches instead of adopting entirely new ones (Lewis, 2019). Specifically a farmer could use more water storage tanks to store rainwater instead of transporting water from a faraway water source.

CSA rest on three main pillars:

1. Sustainably increase agricultural productivity and incomes;
2. Build resilience and adapt to climate change;
3. Reduce and/or remove GHG emissions, where possible (FAO, 2019a, 2019b, 2019c; Lewis, 2019).

This study focuses on pillars one and two, addressing the vulnerabilities associated with agricultural productivity and increasing the resilience of subsistence farmers. Each pillar is further broken down into 3 categories in accordance with the United Nations Sustainable Development Goals. Overcoming barriers to adaptation in subsistence farming communities means addressing the diversification of farming systems and farmer's livelihoods (1B and 2B in Table 1.1). As these approaches mirror the community needs, these approaches will evolve as the climate continues to change (FAO, 2019b).

Table 1.1: CSA assessment framework from the FAO that integrates CSA approaches with the Sustainable Development Goals (SDGs) (FAO, 2019b).

CSA Pillar 1 – Sustainably increase agricultural productivity and incomes
CSA Action Category 1.A – Increase resource use efficiency **1.A Efficiency** CSA actions that increase the production per unit of inputs and reduce the material footprint of food production, e.g. breeding of high-yielding crop varieties; recycling of by-products and waste as farm inputs.
CSA Action Category 1.B – Diversify production systems **1.B Diversification** CSA actions, both on- and off-farm, that improve food producers' livelihoods through creation of additional income sources, e.g. adopting integrated crop-livestock systems; establishing local processing facilities.
CSA Action Category 1.C – Manage agro-ecosystems, ecosystem services and biodiversity **1.C Ecosystem** CSA actions that enhance ecosystem services which support the productivity of food production systems and allow for reduced use of external inputs, e.g. sustainable soil management to increase soil fertility; creation of habitats for wild animal species that provide biological pest control.
CSA Pillar 2 – Build resilience and adapt to climate change
CSA Action Category 2.A – Diversify production systems **2.A Diversification** CSA actions, both on- and off-farm, that distribute the climate risk over a greater number of elements of a production system/livelihood, e.g. introduction of crop rotation; adoption of agroforestry.
CSA Action Category 2.B – Adjust production activities to reduce risk exposure, sensitivity, and adapt to changing conditions **2.B Exposure** CSA actions that adapt specific elements of a production system to changing climate conditions and reduce their exposure or sensitivity to a given climate risk, e.g. constructing water harvesting ponds for supplemental irrigation of crops; switching to heat-tolerant livestock breeds or species.
CSA Action Category 2.C – Manage agro-ecosystems, ecosystem services and biodiversity **2.C Ecosystem** CSA actions that increase the capacity of agro-ecosystems to absorb climate shocks and other climate change-related stressors, e.g. mangrove restoration for coastal protection and fish stock regeneration; adoption of agroforestry to buffer impacts of extreme temperatures and rainfall events.

1.3. Research Collaborators

CRAVE. This research has been conducted in collaboration with the Climate Resilient Agriculture in three Vulnerable Extreme northern crop growing regions (CRAVE) Project, a Green Climate Fund project with the goal to reduce vulnerability and food insecurity to climate risk, and increase resilience and adaptive capacity of subsistence farmers in these regions that are threatened by climate change (Green Climate Fund, 2017). This project, which began in 2017, works directly with subsistence farmers to increase their adaptive capacity and climate change resilience, and decrease their exposure to risk. Another important part of this project is learning and knowledge sharing with farmers and across stakeholders. The Climate Scenario Planning Toolkit produced with this report has been developed specifically for trainings with farmers in the CRAVE Project as part of this knowledge sharing initiative.

UNFCCC LAKI. This research was conducted in consultation for the United Nations Framework Convention on Climate Change (UNFCCC)'s Lima Adaptation Knowledge Initiative, which aims to improve information sharing between scientists, policy makers and stakeholders that allow for improved access to data and more effective climate change adaptation (UNFCCC, 2021). This report contributes to the Southern Africa Region knowledge gap of "limited knowledge on technologies available for adaptation in the agricultural sector" (UNFCCC, 2018).

1.4. Study Roadmap

The following chapters work to address the central question of how climate change will impact subsistence farmers and the barriers that they could face in adapting to climate change. Specifically, this study will examine the potential climate change scenarios for northeastern Namibia, the impacts of those scenarios on subsistence farmers under current agricultural practices, and barriers that farmers might face in adapting those practices to climate change. The study concludes with recommendations for adaptation as well as a Climate Scenario Planning Toolkit to be utilized by farmers, extension workers, and farmer training centers while planning for the identified climate scenarios.

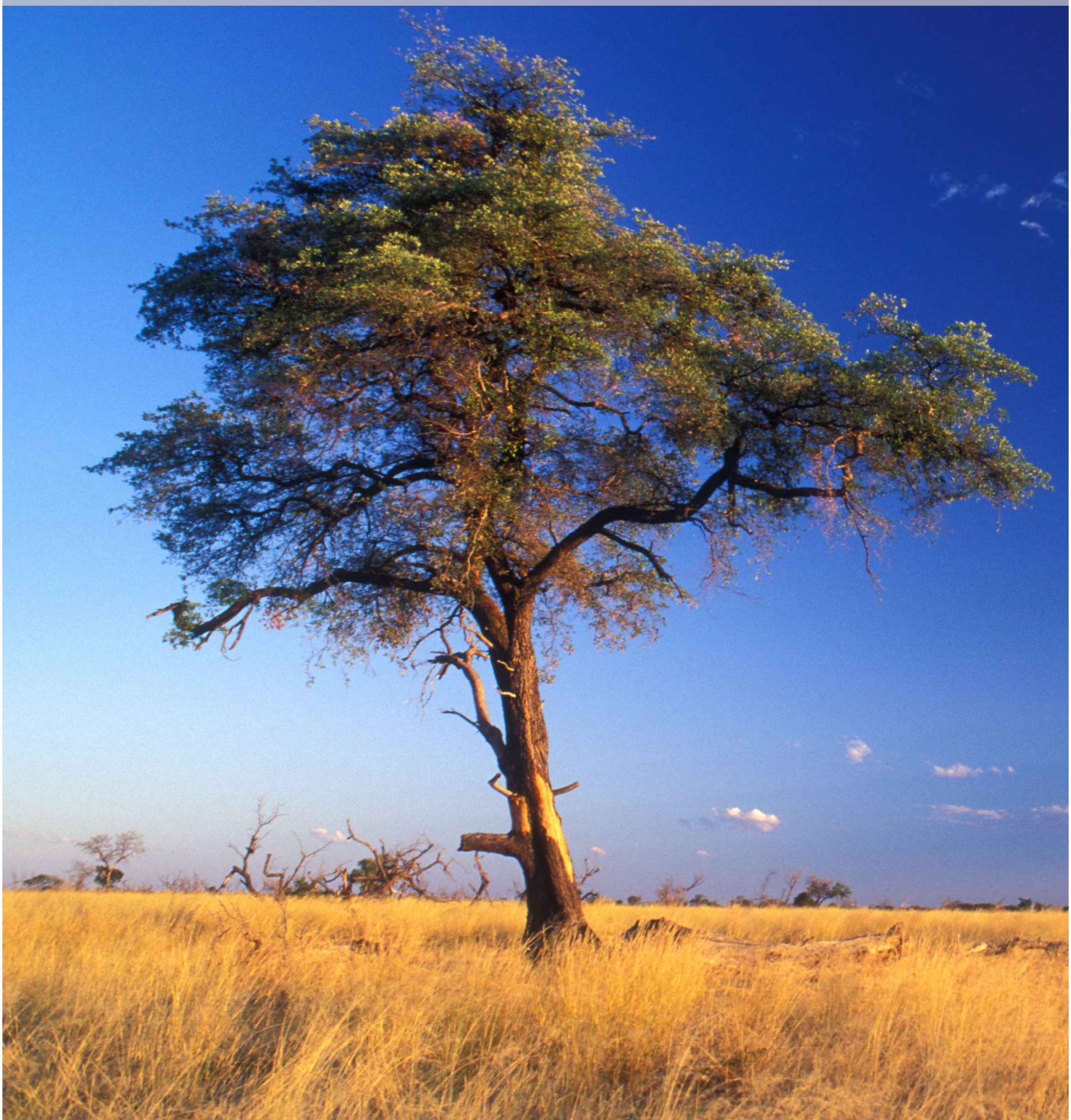
Chapter 2: Potential Climate Scenarios for Northeastern Namibia describes the climate hazards facing northeastern Namibia. An analysis of global and regional climate features leads to four possible climate scenarios for the region.

Chapter 3: Reducing Vulnerabilities: Crops, Irrigation, Finance, and Gender identifies farmers' vulnerabilities and potential barriers to climate change adaptation that can reduce their adaptive capacity and resilience.

Chapter 4: A Survey of Subsistence Farmers in Northeastern Namibia details the results of a survey with local subsistence farmers to understand their social identities, current farming practices, and their personal barriers for adaptation to climate change.

Chapter 5: Recommendations for Climate Smart Agriculture is the final section of the paper. This chapter showcases a number of recommendations in line with climate smart agricultural solutions for various stakeholders that could increase adaptive capacity and resilience.

Chapter 2: Potential Climate Scenarios for Northeastern Namibia



A climate scenario describes changes to climate conditions of temperature and precipitation, extreme events like droughts and floods, and impacts to ecosystems and humans (Figure 2.17). Climate scenarios are developed by examining the different ways that climate change can alter atmospheric and atmospheric-oceanic climate processes, their interactions, and subsequent climate outcomes (GLISA, n.d.). These climate outcomes, in turn, have impacts on subsistence farmers in northeastern Namibia.

2.1. Climate Scenario Planning

The climate scenario planning approach, developed by the U.S.-based Great Lakes Integrated Sciences and Assessments (GLISA), accounts for a range of possible climate outcomes. Instead of developing strategies in response to one climate future, a climate scenario can be used to plan for several plausible climate futures, which aids decision-making under conditions of uncertainty. This involves an iterative process incorporating new climate information as it becomes available (GLISA, n.d.)

The developed climate scenarios are used to create a Climate Scenario Planning Toolkit (Appendix B) which can be utilized in a workshop or training setting with farmers and other stakeholders. This toolkit provides recommended instructions for the facilitated workshop. It was developed in consideration of social vulnerabilities, such as literacy and translation challenges, regional contexts, and accessibility. GLISA's approach to climate scenario planning involves the co-production of climate scenarios with stakeholders (GLISA, n.d.). While this project's Climate Scenario Planning Toolkit incorporates prepared, rather than co-produced, scenarios for northeastern Namibia, the workshops and trainings which utilize the toolkit provide opportunities for the co-production of adaptation approaches.

The Climate Scenario Planning Toolkit is intended to be administered by CRAVE extension workers to Namibian subsistence farmers. This toolkit is meant to aid in agricultural planning, serving as an educational tool to help subsistence farmers imagine and plan for the four climate scenarios and their agricultural impacts.

The aims of this toolkit are to:

- Contextualize local climate trends, features, and future scenarios for sharing across farming communities.
- Provide a set of climate scenarios tailored to the agricultural needs of northeastern Namibia.
- Help CRAVE extension workers and farmers better understand scenario planning to adapt agricultural activities to align with scenarios.
- Allow CRAVE extension workers and farmers to more clearly picture how northeastern Namibian agricultural activities are impacted by climate change.

The toolkit consists of a three-step process: Step 1 provides brief descriptions of the four scenarios and the scenarios flowchart (Figure 2.17). Steps 2 and 3 include templates for a facilitated workshop through which subsistence farmers will brainstorm agricultural technologies and financial strategies to enhance their resilience.

2.2. Methods

2.2.1. Literature Review and Expert Guidance

Climate scenarios for northeastern Namibia were developed by integrating findings from a review of literature on climate processes occurring around southern Africa (Table 2.1). Development of climate scenarios and the Climate Scenario Planning Toolkit was supported by Dr. Richard Rood of the University of Michigan Climate and Space Sciences and Engineering Department.

Table 2.1. Literature Review for the Climate Section

Key Words	Resources	Number of documents
• Climate change • Extreme events (e.g., Drought, Flood, Extreme Heat) • Rainfall • Intertropical Convergence Zone (ITCZ) (e.g., Hadley Cells, High- and Low- Pressure Systems) • Southeast African Monsoon • El Niño-Southern Oscillation (ENSO) (El Niño and La Niña) • Indian Ocean Dipole (IOD) • Subtropical Indian Ocean Dipole (SIOD)	Web of Science Database IPCC NOAA Desert Research Foundation of Namibia & Climate Systems Analysis Group Republic of Namibia, Ministry of Environment & Tourism The World Bank	54

Global and regional climate, atmospheric, and atmospheric-oceanic circulation processes, known as *climate features*, influence Namibia's current and future climate. *Climate conditions,* characterized by temperature and precipitation levels, may be considered a hazard if it could potentially damage ecosystems or humans. Extreme events like extreme heat, droughts, and floods can be considered climate hazards (R. Rood, personal communication, 2021). Historic extreme weather events for Namibia were described in scholarly (e.g., Nakanyete et al., 2020) and news sources (e.g., BBC).

The global and regional circulation models (GCMs and RCMs), created by international and national organizations (e.g., IPCC, 2013; World Bank, 2021; NOAA, n.d.; Desert Research Foundation of Namibia & Climate Systems Analysis Group, 2008) and the Namibian government (e.g., MET, 2011), were used to model a range of climate projections based on Representative Concentration Pathways (RCP) of emissions (IPCC, 2018). RCP8.5 depicts "business-as-usual" high emissions without mitigation policies and is utilized in this study to understand how worst-case climate change would alter climate features and impacts (R. Rood, personal communication, 2021). These models were used to analyze climate features, modulations and interactions, and projected changes under climate change. A *modulation* is when a climate feature alters the processes, location, or strength of another simultaneously occurring feature, low-, or high-pressure system. This leads to altered associated climate conditions and hazards. An *interaction* is a modulation that occurs between atmospheric-oceanic features to strengthen or weaken their individual modulating effects (Hoell et al., 2016; R. Rood, personal communication, 2021). Increasing global temperatures and variability due to climate change increase the strength and frequency of climate feature outcomes respectively (Mason, 2001; Gaughan et al., 2015). This leads to increased negative climate impacts on agriculture and water resources (Hoell et al., 2016; Hoell et al., 2017).

2.2.2. Climate Variability and Uncertainty

Climate systems are highly variable and the modulations/interactions between climate features are complex and dynamic. Data limitations on scaling down of regional models added a complexity to understanding climate scenarios at the regional level, leaving potential gaps in the creation of the climate scenarios for northeastern Namibia. Understanding the multiple types of climate variability and uncertainty are important prior to assessing current/future climate outcomes.

Climate Variability. Inter-event variability of features occurs due to specific global and regional location, air and ocean temperature patterns, and interactions with other features causing differential climate conditions and impacts associated with each climate event. Intra-annual variability is present within one year, characterized by differences in seasons and weather events. Inter-annual variability occurs across multiple years characterized by trends in seasonal and annual differences. Long-term changes to features occur over one or multiple decades (i.e., decadal and multi-decadal variations). All scales of climate variability create uncertainty in observational climate data and model projections (Hoell et al., 2017; IPCC, 2018).

In Namibia, persistent anomalous warm/wet patterns are less probable than persistent warm/dry patterns given Namibia's historical climate conditions and extreme events (Section 2.3). The character of variability is changing due to climate change. The frequency of warm/dry climate conditions and extreme events are increasing while warm/wet patterns are decreasing. This leads to extreme events, in particular droughts, which are occurring with higher frequency, greater severity, and longer time-frames than in the past (R. Rood, personal communication, 2021).

Climate Uncertainty. The RCP scenarios of future greenhouse gas (GHG) emissions are dependent on uncertain global and regional climate policies, population, fossil fuel production/consumption trends, and mitigation technologies (Hawkins & Sutton, 2011; IPCC, 2018; Rood, 2019). When predicting multiple decades into the future, higher uncertainty is represented as the RCP scenarios diverge given different input assumptions and their anticipated outcomes. Given this, climate models forecast future climate conditions with some uncertainty (R. Rood, personal communication, 2021).

Global and regional climate models simplify global climate systems, such as atmospheric and atmospheric-oceanic climate features, using mathematical equations based on an understanding of climate processes, observational data, and forecasted RCP scenarios (NOAA, n.d.). This inherent simplification leads to model uncertainty, causing multiple iterations of one climate model to create a range of climate projections (Hawkins & Sutton, 2011). Climate models estimate future conditions at the model's scale, causing higher uncertainty at smaller spatial scales and shorter time frames given climate variability. Models are useful for exploring potential changes to climate features and future scenarios, but the inherent uncertainty must be recognized (R. Rood, personal communication, 2021).

2.3. Namibia's Climate Hazards

2.3.1. Current Climate

Namibia is the most arid country in sub-Saharan Africa (MET, 2015). A Subtropical High-Pressure (STH) zone dominates the region, with cool, dry air from the Atlantic Ocean leading to desert conditions on the coast and much of the interior (Desert Research Foundation of Namibia & Climate Systems Analysis Group, 2008; MET, 2015). The lack of moisture in the air and heating from the Sun results in high daytime temperatures, high evaporation rates, low soil moisture, and rapid temperature loss at night. Only north-central and northeastern Namibia experience semi-arid conditions with a summertime rainy season between December to March (Gaughan et al., 2015; Hoell et al., 2016). Historical monthly observations between 1986-2005 of temperature and precipitation for the Kwando watershed in northeastern Namibia are shown in Figures 2.1 and 2.2 (World Bank, 2021). This watershed is bordered by the Okavango (Cubango) and Kwando (Cuando) Rivers and overlaps with the Zambezi Region of Namibia (Gaughan & Waylen, 2012). The climate conditions of this watershed are representative of northeastern Namibia, as demonstrated by spatial variability of current and future conditions (Figures 1.2 and 2.5 through 2.8). Temperatures for the Kwando watershed range from 16 to 26°C (World Bank, 2021). This area also receives the most precipitation in the country approximately 500 mm annually and monthly

Namibia narrowly supports current crop production (Table 3.1), agriculture is also dependent on rainfall originating in Angola and Zambia that flows into the region through rivers (Figure 2.12; Gaughan & Waylen, 2012).

2.3.2. Extreme Events

Historical records of extreme events informs the understanding of associated climate features and scenario development.

2019 Drought. The 2019 drought was one of the most severe in the country's history. Seasonal rainfall was 60-70% below normal (Figure 2.3). Approximately 36% of the population was at-risk of hunger and relied on support from drought relief programs. Water consumption rations were put in place as the reservoir at Hardap Dam was dry, the largest in the country located in central Namibia. Farmers reduced irrigation by 40% to save water. Due to decreased rainfall and reduced irrigation, cereal production was 42% below average (Nakanyete et al., 2021). Both the 2019 and 2015-2016 droughts were tied to climate features (Section 2.4), like a strong El Niño that delayed and reduced rainfall, the Intertropical Convergence Zone (ITCZ), and Southeast African

rainfall averages between 0 and 172 mm (Beyer et al. 2016; World Bank, 2021). Given that rainfall in

Monsoon. The earlier drought delayed crop planting by an average of 45 days (Di Liberto, 2016).

2016 Floods. When the rainy season arrived in 2016 following the 2015-2016 drought, rainfall increased from 25% below to 400% above average. The following inundation, similar to the 2013 flood (Figure 2.4), resulted in a severe flooding event with more than 100,000 hectares of farmland underwater, 300,000 people displaced, and 400 killed across Southeast Africa. Extreme rainfall and flooding were widespread, including in the neighboring countries of Botswana and Zimbabwe (Di Liberto, 2015a, 2015b).

2.3.3. Future Climate

Global mean surface temperature is predicted to increase an average 2.0°C by 2046–2065 and 3.7°C by 2081–2100 under RCP8.5 for GHG emissions (IPCC, 2013). Specifically within Namibia, projected country-wide temperature increases by 2046-2065 are 1°C to 3.5°C in summer and 1°C to 4°C in winter (MET, 2015).

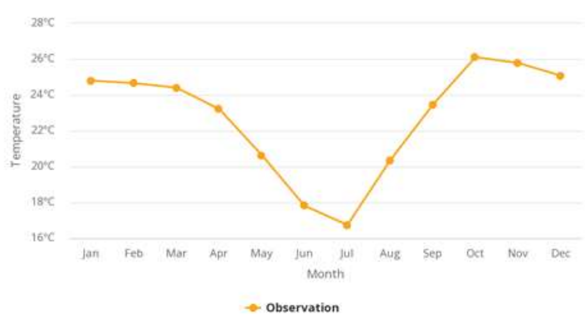


Figure 2.1: Historical Observed Monthly Temperature for the Kwando watershed for 1986-2005 (World Bank, 2021).

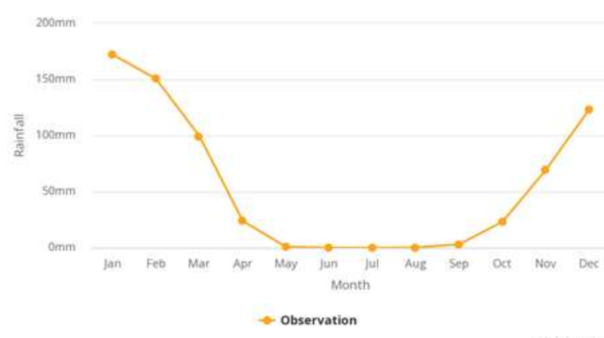


Figure 2.2: Historical Observed Monthly Precipitation for the Kwando watershed for 1986-2005 (World Bank, 2021).

Figure 2.3: Drought in northern Namibia in 2019 (Morocco World News Staff Writer, 2019).

Figure 2.4: A village abandoned due to flooding in the Zambezi region of Namibia in March 2013 (Peard, 2013).

For 2080-2099, projected changes in monthly temperature and precipitation compared to the historical monthly observations between 1986-2005 (Figure 2.1 and 2.2) for the Kwando watershed are graphed in Figures 2.5 through 2.8 (World Bank, 2021). The projections from the World Bank's tool were created using an ensemble of 35 GCMs that were also used for the IPCC 5th Assessment Report (IPCC, 2014). Maps are also provided to show locational or spatial differences. For this watershed, projected monthly temperature change from the historical mean varies between an ensemble median increase of 4 to 6°C. Monthly precipitation change varies between an ensemble median decrease of 46.39 to 0.49 mm, with the highest uncertainty between November to March overlapping with the early (October to December) and peak rainy seasons (December to March) (Gaughan et al., 2015; Hoell et al., 2016)

2.4. Climate Features

A climate feature is a global or regional climate, atmospheric, and atmospheric-oceanic circulation process that produces temperature and precipitation conditions. The Atlantic and Indian Oceans and low- and high-pressure systems (denoted as L and H symbols in Figure 2.16) influence climate outcomes in Namibia created by climate features through affecting the strength and location of these systems. Climate features are grouped in the following categories: atmospheric and atmospheric-oceanic. Atmospheric features produce low-pressure systems associated with rising air, tropical processes, and rainfall while displacing high-pressure systems characterized by drying, sinking air. Atmospheric-oceanic features modulate or alter the processes of L/H systems directly or indirectly through atmospheric features to affect climate conditions and extreme events (Cenedese & Gordon, 2018; R. Rood, personal communication, 2021; UCAR, 2021b).

2.4.1. Atmospheric Features

ITCZ, Hadley Cells. The Intertropical Convergence Zone (ITCZ) is a global low-pressure band formed by surface solar heating, converging air and moisture from the northerly and southerly trade winds, (i.e., Hadley Cells) (Figures 2.9 and 2.10). Surface heating in the deep tropics causes rising motion and precipitation, associated with low-pressure systems. The ITCZ causes cloud formation and intense rainfall near the equator (0°), creating the tropics and supplying 32% of global precipitation (Byrne et al., 2018).

Moving from the equator towards the north or south poles, the air that rises in tropics dries and descends associated with high-pressure systems causing dry conditions and deserts. Northeastern Namibia is located on the edge of the ITCZ and the southern STH (~30°S at equinox) (Byrne et al., 2018).

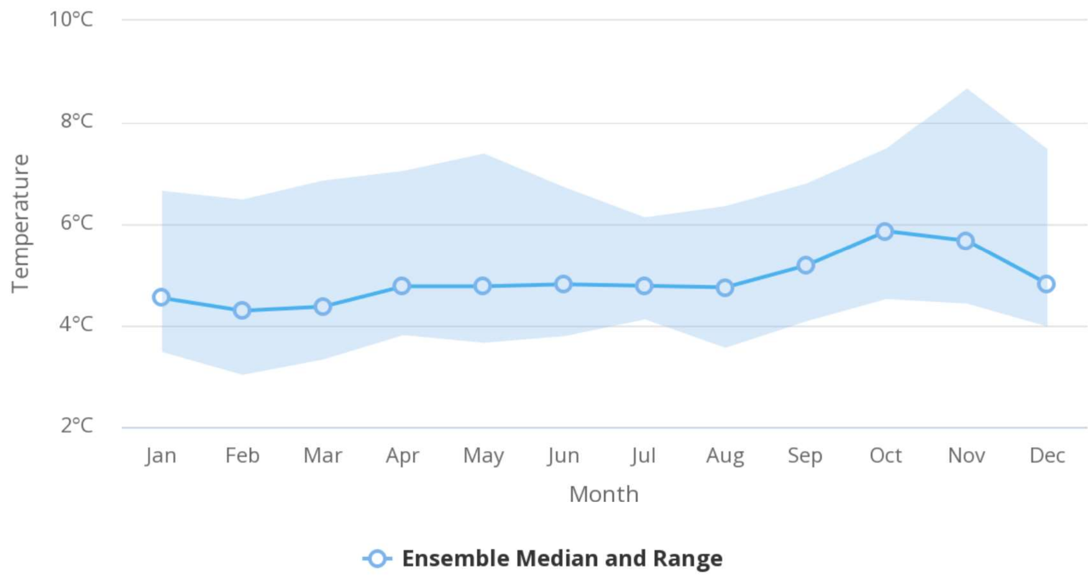


Figure 2.5: Projected Change in Monthly Temperature of the Kwando watershed for 2080-2099 (Compared to 1986-2005) (World Bank, 2021).

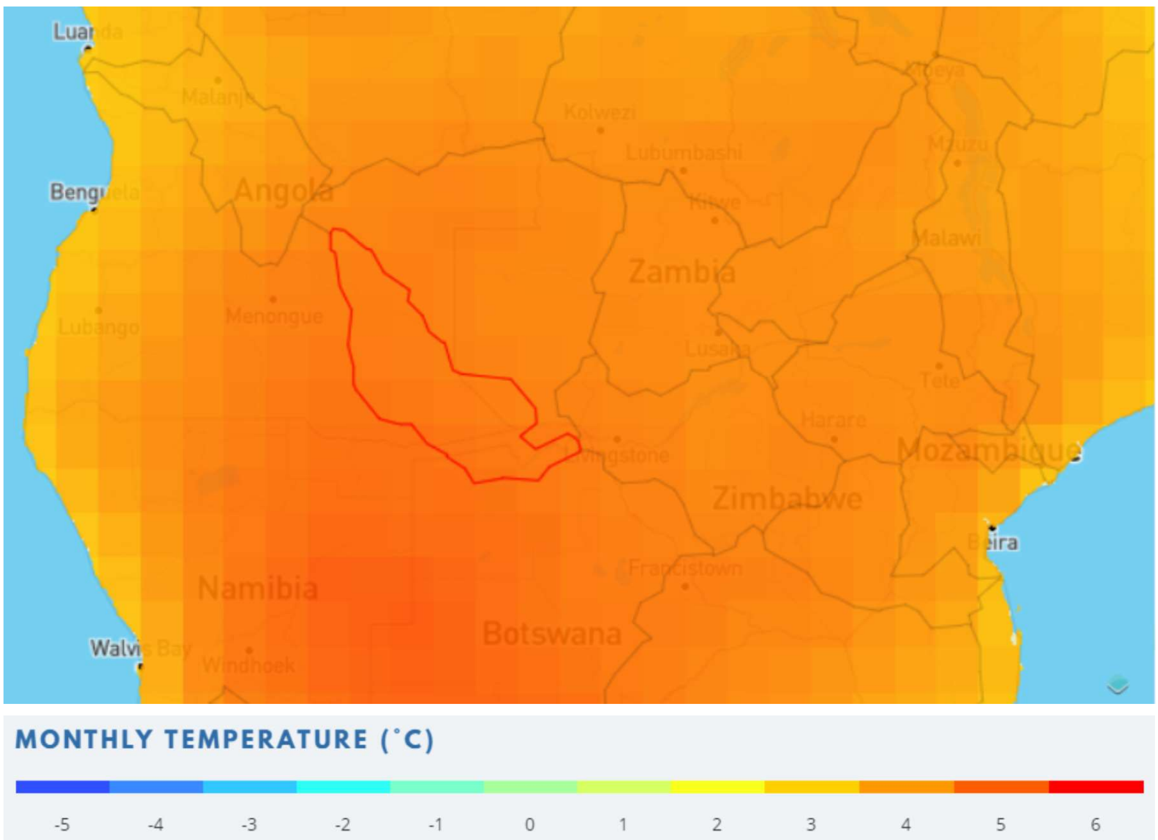


Figure 2.6: Spatial Variation for Average Projected Change in Monthly Temperature of the Kwando watershed for 2080-2099 (Compared to 1986-2005) (World Bank, 2021).

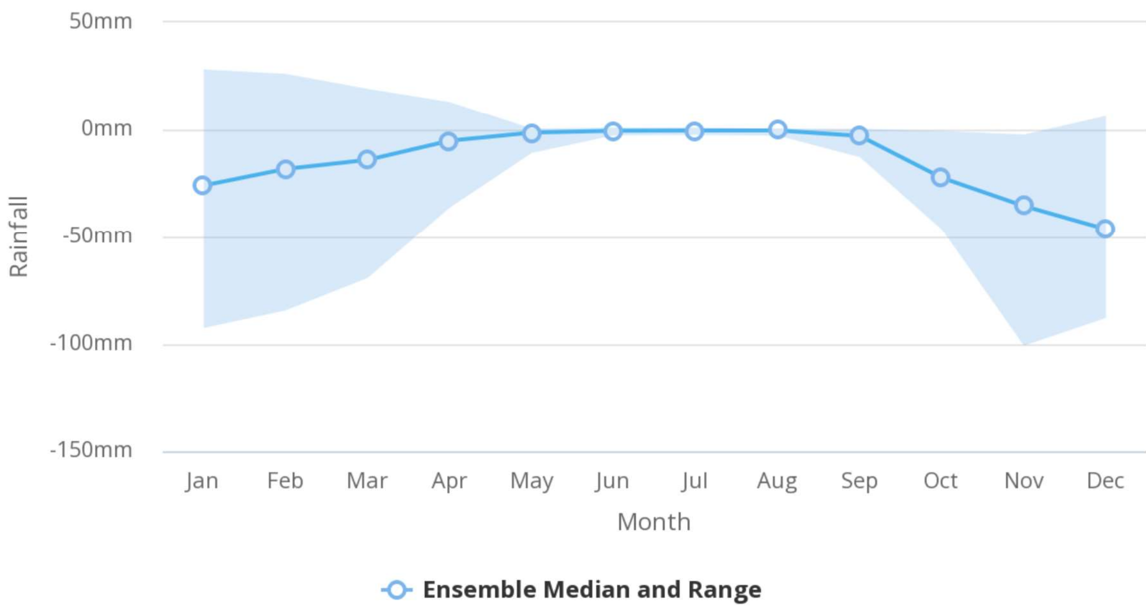


Figure 2.7: Projected Change in Monthly Temperature of the Kwando watershed for 2080-2099 (Compared to 1986-2005) (World Bank, 2021).

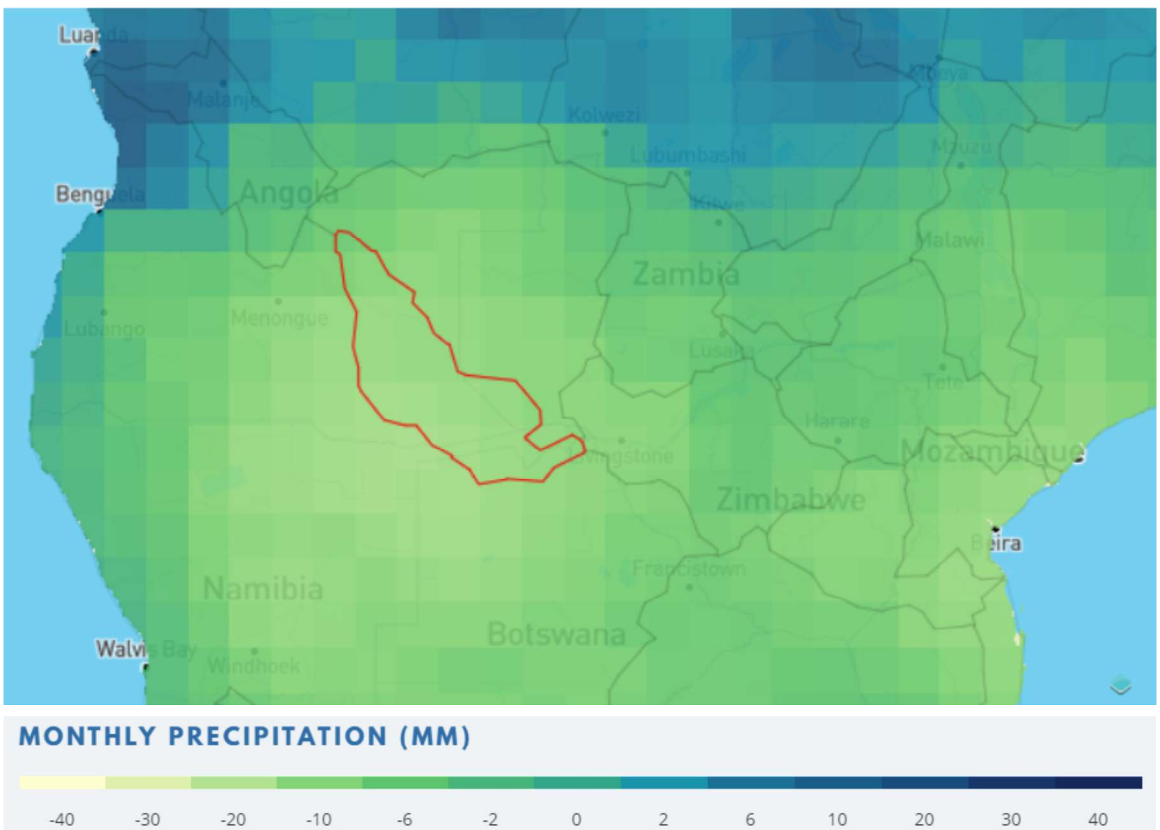


Figure 2.8: Spatial Variation for Average Change in Monthly Precipitation of the Kwando watershed for 2080-2099 (Compared to 1986-2005) (World Bank, 2021).

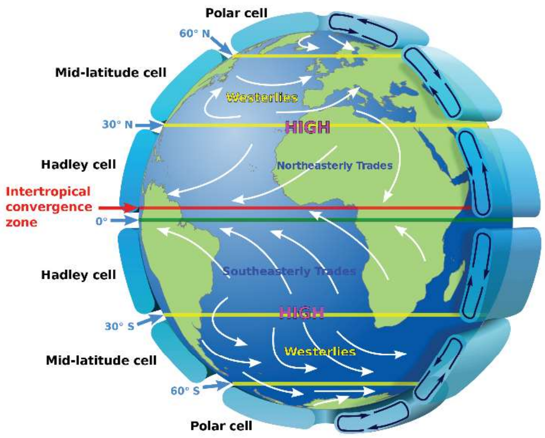


Figure 2.9: Atmospheric circulation at Earth's equinox highlighting the ITCZ, hadley cells, trade winds, and subtropical high pressure zones (Woollings, 2020).

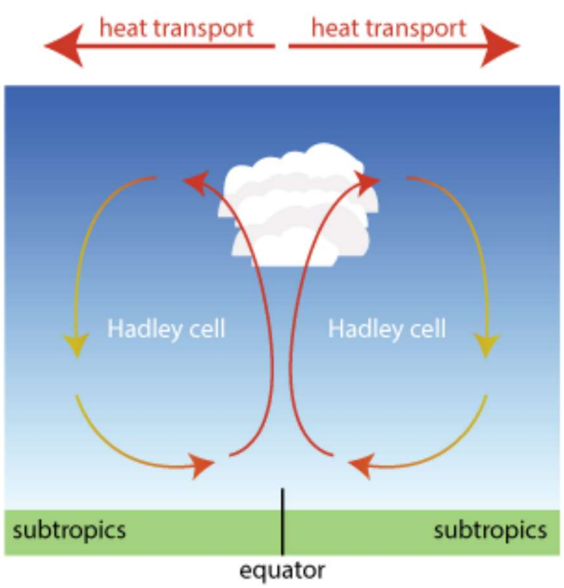


Figure 2.10: Hadley circulation depiction near the equator (through the ITCZ) of warming, rising air forming clouds (and low pressure systems) then transporting heat by flowing towards the poles, where it cools and then falls downward in the subtropics (creating high pressure) and flows back to the equator (trade winds) (UCAR, 2021b).

The ITCZ has traditionally been termed "the tropical rainbelt" by climatologists within Africa and worldwide, but the synonymous use of these terms has been challenged. The tropical rainbelt is characterized by areas where maximum rainfall occurs (Nicholson, 2009, 2018) along a seasonal migration route following solar insolation between approximately 20°N to 20°S in austral winter and summer (Byrne et al., 2018; Dezfuli, 2017) (Figure 2.11a and 2.11b). The asymmetrical course is caused by "differential heating from topographical changes and differing temperatures of marginal coastal waters" (Gaughan & Waylen, 2012). Areas where maximum rainfall occur may not directly correspond with surface convergence of the ITCZ, especially over land as in West Africa, challenging the synonymous use of these terms (Nicholson, 2009; Nicholson, 2018). ITCZ will be used interchangeably with the tropical rainbelt in this document, but given these competing theories, discussions of ITCZ will focus only on characteristics tied to rainfall not convergence unless otherwise specified.

Precipitation in Namibia, Angola, and Zambia varies with the ITCZ seasonal migration and the strength and direction of Hadley Cell trade winds. The ITCZ abuts Northeastern Namibia during the summer which is when the region is sensitive to ITCZ changes in location and strength. This leads to the ITCZ-fueled rainy season in Namibia during the austral summer maximum between December and March (Figure 2.11b and 2.11c; Gaughan et al., 2015; Hoell et al., 2016).

As a water source, rainfall is less consistent in northeastern Namibia than the river flows coming from the neighboring countries to the north (Figure 2.12; Gaughan & Waylen, 2012). The majority of subsistence farms in northeastern Namibia lie along rivers within floodplains and rely on this along with rainfall as a water source.

Southeast African Monsoon. The summer rainy season in northeastern Namibia relies on the Southeast African Monsoon bringing moisture from the Indian Ocean. Monsoons occur when land becomes hotter than an adjacent ocean in summer, i.e., differential heating, causing moist air to flow in creating upward convection and causing rainfall (Figure 2.11b; R. Rood, personal communication, 2021). Monsoonal rainfall is tied to the converging winds, increased convection, and seasonal migration of the ITCZ (UCAR, 2021a).

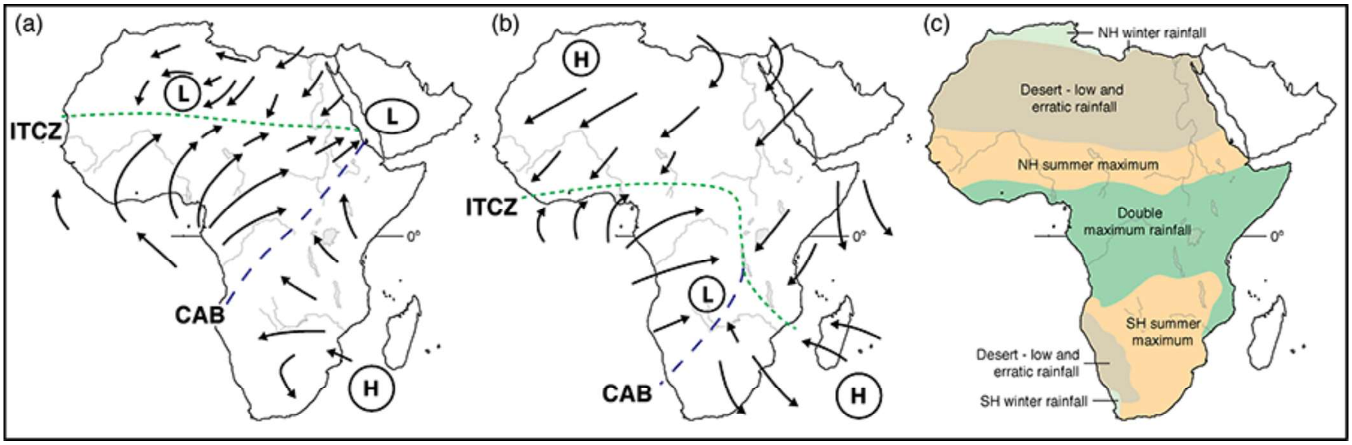


Figure 2.11: Atmospheric circulation of the ITCZ, Congo Air Boundary (CAB), surface winds (arrows), High and Low pressure systems (H/L) over Africa during (a) winter and (b) summer and (c) seasonal rainfall distribution patterns (Holmes & Hoelzmann, 2017).

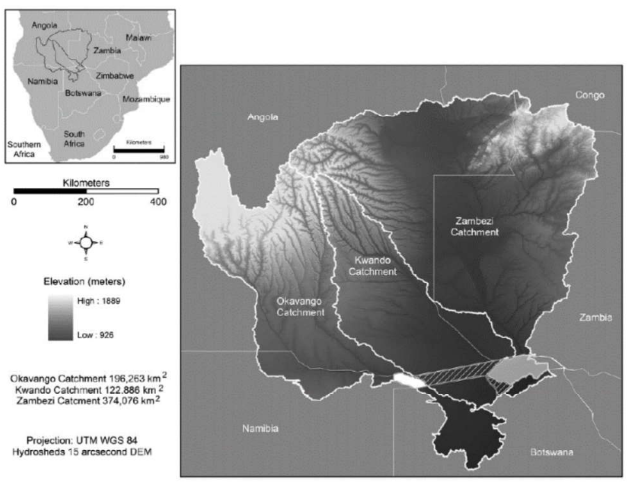


Figure 2.12: Rainfall in the Okavango-Kwando-Zambezi catchment watersheds flow into the Kavango West, Kavango East, and Zambezi regions through the following rain-fed rivers originating in Angola and Zambia: Okavango (Cubango), Kwando (Cuando, which also links to the Chobe and Linyanti Rivers), and Zambezi Rivers (Gaughan & Waylen, 2012).

Impact on Namibia's Climate and Farmers. Northeast Namibia's rainy season and rain-fed agriculture depends on the Southeast African Monsoon more so than the ITCZ. The ITCZ does not consistently travel far enough South to create rainfall in Namibia, but rather flows through rivers from Angola and Zambia. The timing and strength of the monsoon impact water availability for millions. If the monsoon is delayed or lasts shorter than usual, some crops may be prevented from reaching maturity (Di Liberto, 2015a). Reduced total rainfall will also prevent growth and cause crop degradation or loss.

2.4.2. Atmospheric-Oceanic Features

ENSO. The El Niño-Southern Oscillation (ENSO) is a coupled atmospheric-oceanic climate feature caused by heat transfers between the ocean and the atmosphere through oceanic circulation and trade winds beginning in the Pacific Ocean (NOAA Climate, 2016). ENSO is capable of altering temperature and precipitation worldwide, outweighing the influences from other features and their interactions (L'Heureux, 2014).

ENSO has three phases—El Niño (warm/dry), La Niña (cool/wet), and Neutral (long-term average)—that correspond with global and regional climatic changes (Figures 2.13 and 2.14; Table 2.2) (Hoell et al., 2016; L'Heureux, 2014; R. Rood, personal communication, 2021). When either El Niño or La Niña occur, there is an increased probability of ENSO-related climate conditions and impacts in northeastern Namibia compared to influences from other features and their interactions and thus should be considered separately (Gaughan et al., 2015).

Table 2.2: Global and regional climatic changes associated with El Niño-Southern Oscillation (ENSO) phases (L'Heureux, 2014).

Global and Regional Climatic Changes	El Niño-Southern Oscillation (ENSO) Phase		
	Neutral	La Niña	El Niño
Pacific Ocean Air and Sea Surface Temperatures (SST)	Average	Below average	Above average
Wind Direction along Equator	Easterly winds: east to west	Easterly winds	Weaker easterly winds or reversed to westerly winds: west to east
Wind Strength (Equator)	Average	Stronger	Weaker or reversed
Subtropical High-Pressure (STH) and Low-Pressure Systems (Hoell et al., 2016; R. Rood, personal communication, 2021)	STHs in warm Indian Ocean and cold Atlantic Ocean in their mean position	Warm Indian Ocean STH is shifted toward Southern Africa and amplified relative to cold Atlantic Ocean STH	Cold Atlantic Ocean STH is shifted toward Southern Africa and amplified relative to warm Indian Ocean STH
Precipitation in Southern Africa (Hoell et al., 2016)	Average	Increased If strong event: floods	Decreased If strong event: drought
Coupled Atmosphere and Ocean	Yes, or only atmosphere/ocean may have El Niño or La Niña traits not both	Yes	Yes

El Niño and La Niña phases occur irregularly every three to seven years, with La Niña typically following El Niño, especially when it is strong (Enfield, 2020; NOAA Climate, 2016). Phases and their strength are determined by the Niño3.4 index that measures anomalies in average sea surface temperatures (SST) in a portion of the Pacific Ocean. El Niño corresponds to an anomaly greater than 0.5°C and La Niña corresponds to an anomaly less than -0.5°C (Hoell et al., 2016, 2017). Both have a duration between 9-12 months. It is uncommon for El Niño to last longer than a year, but La Niña can span more than 2 years. Both begin to form between March and June, peak in intensity from November to February, and weaken between March and June (NOAA Climate, 2016). ENSO has strong influences on temperature and wet or dry conditions during both Namibia's early rainy season (October to December) and especially its peak (December to March) (Gaughan et al., 2015; Hoell et al., 2016).

ENSO phases alter the strength and location of low- and high-pressure systems directly (Figure 2.16). La Niña directly shifts the Indian Ocean high-pressure system towards Southern Africa and amplifies its warmth relative to the cold Atlantic high-pressure system that is moved further into the ocean. This creates a low-pressure system for warm/wet conditions and subsequent flooding in Namibia. On the contrary, El Niño shifts the Atlantic high-pressure system towards Southern Africa and amplifies its coolness relative to the warm Indian high-pressure system that is pushed outward, influencing warm/dry conditions and drought (Gaughan et al., 2015; Hoell et al., 2016).

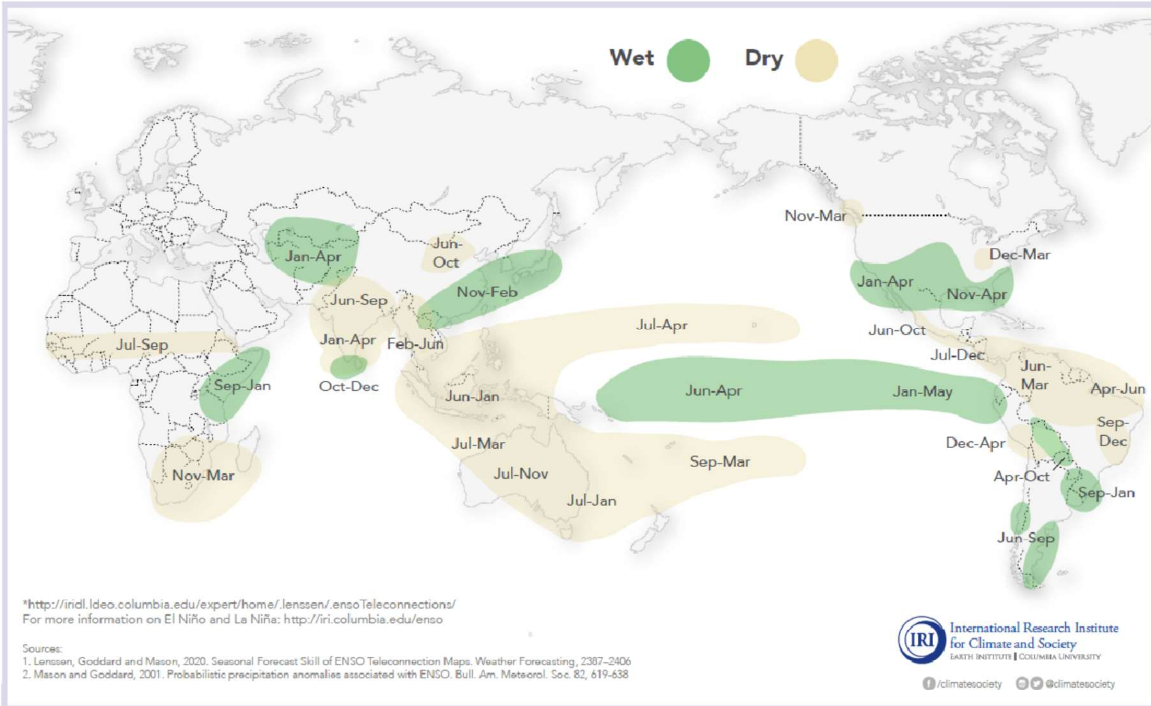


Figure 2.13: Typical (though not guaranteed) regional wet/dry conditions and time periods associated with El Niño in the Pacific Ocean (IRI, 2020a).

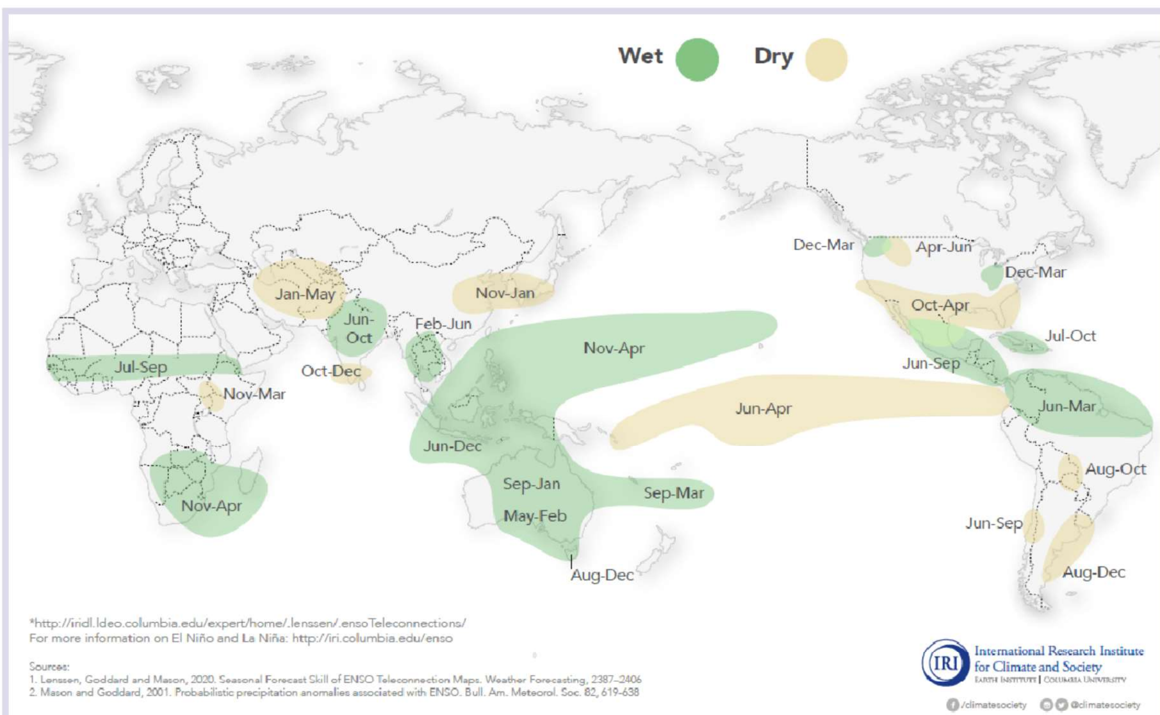


Figure 2.14: Typical (though not guaranteed) regional wet/dry conditions and time periods associated with La Niña in the Pacific Ocean (IRI, 2020b)

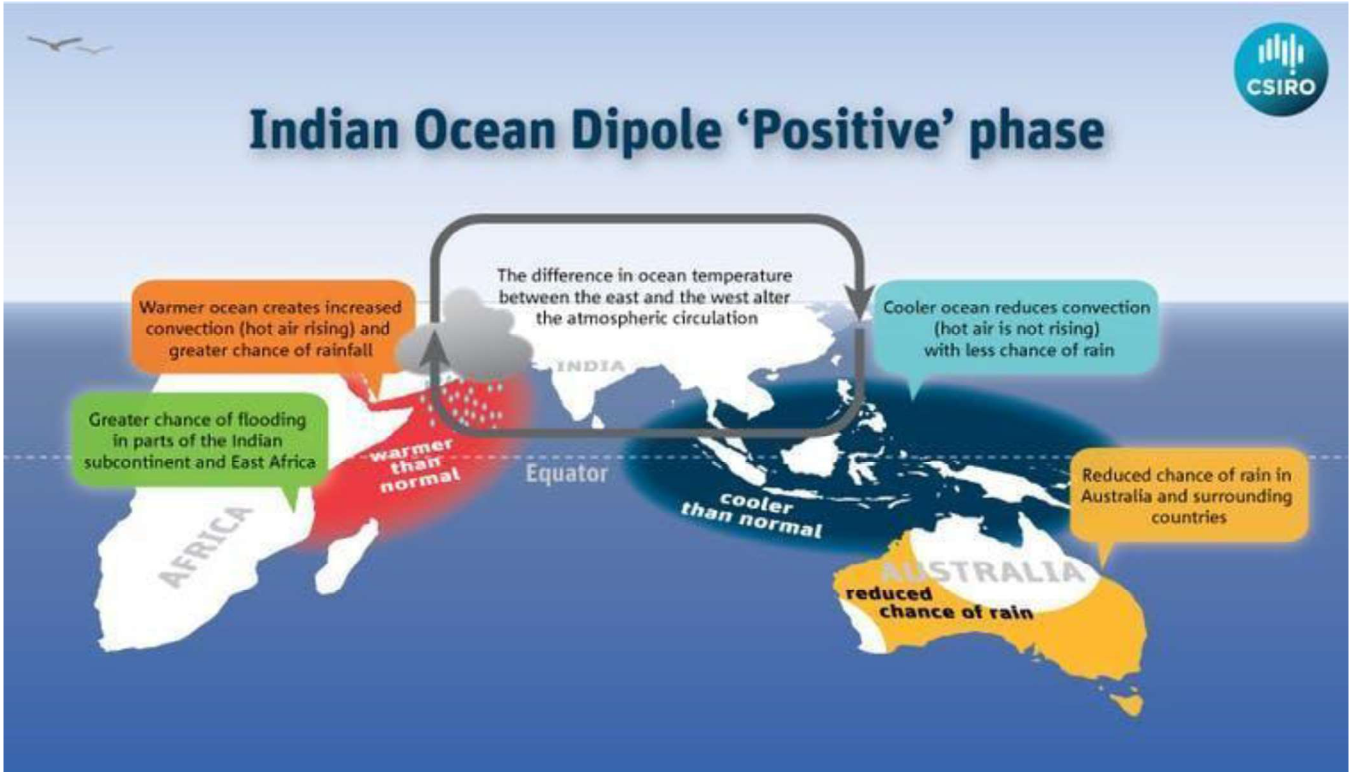


Figure 2.15: The positive Indian Ocean Dipole (IOD) phase is characterized by cooler-the-average sea surface temperatures (SST) near Indonesia and warmer-than-normal SST near East Africa's coast that alters oceanic circulation from east to west. Warm water causes increased convection, cloud formation, and rainfall in East Africa. The warm air then circulates from west to east where it cools and drives cool SST, closing the dipole loop (Cai, 2013; Johnson, 2020).

The phase and strength of ENSO can be predicted up to a year in advance of impacts using climate models and observations, making it an important feature to monitor (L'Heureux, 2014; NOAA Climate, 2016)

IOD. The Indian Ocean Dipole (IOD) reflects the opposing atmospheric, temperature, and rain patterns on either side of the northern Indian Ocean. For example, warm events in the western Indian ocean occur alongside dry events in northern Namibia (Landman & Mason 1999).

The IOD is categorized in three phases: positive (Figure 2.15), negative, and neutral, which is a brief transition between the dipole. The positive (negative) phase is associated with warm (cool) SSTs near the horn of Africa and cool (warm) SSTs near Indonesia creating wet (dry) conditions in Southern Africa (Johnson, 2020).

The positive or negative phase occurs between September and November (Johnson, 2020). In Namibia, land-use and planting decisions are made in the early rainy season from October to December (Gaughan et al., 2015), prior to the rainy season between December and March (Gaughan et al., 2015; Hoell et al., 2016). Positive and negative phases alter every one-to-two years with extreme positive events associated with severe flooding every 17.3 years (Australian Government Bureau of Meteorology, 2021; Uchoa, 2019). The IOD strength is measured by the difference in SST between the eastern and western Indian Ocean using the Dipole Mode Index (Johnson, 2020).

Moisture transport from a positive IOD into northern Africa may also disrupt moisture into southern Africa tied to the Southeast African Monsoon and ITCZ. This interaction may lead to decreased rainy season precipitation in Namibia from both of these atmospheric features, especially as oceans warm due to climate change (Dunning et al., 2018).

SIOD. The Subtropical Indian Ocean Dipole (SIOD) in the southern Indian Ocean behaves similarly to the northern IOD, with contrasting east-west oceanic conditions located south of Madagascar and near Western Australia creating a dipole of SST anomalies (Gaughan et al., 2015). These anomalies affect climate conditions near Madagascar and Western Australia by altering regional atmospheric-oceanic circulation, moisture transport, and subsequently precipitation (Hoell et al., 2017). The positive (negative) phase is associated with warm (cool) SSTs south of Madagascar and cool (warm) SSTs near Western Australia creating wet (dry) conditions in Southern Africa (Gaughan et al., 2015). Because the SIOD is closer to Southern Africa than IOD, it has a larger relative impact on climate in Namibia.

SIOD phases typically develop between December and January, reach their peak in February, and resolve in May or June (Behera & Yamagata, 2001). Typically, only one event occurs every two to five years, but two consecutive events are possible (Behera & Yamagata, 2001; Hoell et al., 2016, 2017).

IOD and SIOD. Like ENSO, the IOD and SIOD alter the strength and location of L/H systems directly as well as indirectly through atmospheric features to create climate conditions (Figure 2.16). +IOD and +SIOD features create anomalously warm SST in the Indian Ocean off the East African or Southern African coast. This can directly form a low-pressure system, similar to La Niña, to cause warm/wet conditions and subsequent flooding in Namibia. Climate conditions can also occur indirectly through modulations to the atmospheric features, strengthening their rainfall amount and intensity during the rainy season, causing flooding. Both result in the Indian Ocean high-pressure system moving towards Australia (Gaughan et al., 2015, Hoell et al., 2016).

The -IOD and -SIOD are characterized by anomalously cool waters near Africa (not shown in Figure 2.16). These have similar alterations to the high-pressure systems as El Niño when directly shifting the Atlantic high-pressure system towards Southern Africa. This imposes its coolness relative to the warm Indian high-pressure system that is pushed outward, influencing warm/dry conditions and drought in Namibia. Alternatively, these climate conditions can be created by modulating the ITCZ and Southeast African Monsoon, leading to reduced rainfall and drought in Namibia (Gaughan et al., 2015, Hoell et al., 2016).

Impact on Namibia's Climate and Farmers. Because ENSO has a higher influence on climate conditions in Southern Africa than other features (Gaughan et al., 2015), forecasting the warm/dry El Niño and cool/wet La Niña phases are key for agricultural planning. Strong El Niño and La Nina events cause severe drought and floods (Hoell et al., 2017). Negative/positive IOD and SIOD phases are also associated with dry/wet conditions and can cause drought and flooding (Landman & Mason 1999; Gaughan et al., 2015). The interactions between ENSO and IOD or SIOD phases typically make slight changes to the ENSO climate impacts, but have the potential to disrupt or enhance ENSO (Hoell et al., 2016).

2.5. Interactions Between Climate Features

This section will explore how the interactions between climate features, within and across categories, influence the climate of northeastern Namibia and potential future climate scenarios. A climate scenario that occurs in a specific season or depends on one phase of a climate feature (e.g., El Niño, La Niña) may be altered by other climate features, producing multiple climate scenarios given the climate features, seasons, and phases (R. Rood, personal communication, 2021).

ENSO and IOD. Specifically for the early rainy season between October to December, when ENSO and the IOD interact, ENSO is the primary influence on precipitation and IOD is secondary (Gaughan et al., 2015). Above- or below-average rainfall is directly tied to cool or warm land surface temperature anomalies (Hoell et al., 2017).

When ENSO and IOD occur at the same time and are in concurrent La Niña and +IOD or in El Niño and -IOD phases, there is a positive feedback loop that enhances the precipitation or aridity of the ENSO event. Whereas when ENSO and IOD are in opposing phases, i.e., a La Niña and -IOD or an El Niño and +IOD, primarily ENSO conditions occur but can be disrupted or weakened by the opposing IOD phase. Although, a +IOD phase during October to December, both solo and when combined with El Niño, has been associated with dry years in northeastern Namibia between 1950-2007 (Gaughan et al., 2015).

ENSO and SIOD. ENSO and the SIOD in Southern Africa from December to March have similar phase relationships compared to ENSO and the IOD (Table 2.3) along with agricultural implications (Hoell et al., 2016, 2017). This timeframe is important because it is the rainy season and when ENSO has the greatest impact on climate in Southern African (Hoell et al., 2016). The SIOD contributes more directly to climate in northeastern Namibia given its proximity compared to the IOD.

ENSO, IOD, and SIOD. During highly influential ENSO phases (Gaughan et al., 2015), IOD or SIOD phases typically make slight changes to the ENSO climate impacts, but have the potential to disrupt or enhance ENSO (Hoell et al., 2016).

Impacts to Namibia's Climate and Farmers. If ENSO occurs during the rainy season, the warm/dry and cool/wet conditions of El Niño or La Niña dominate. The cool/wet and warm/dry conditions associated with La Niña and El Niño can be further amplified by the same IOD or SIOD phase causing increased or decreased runoff, soil moisture, and evapotranspiration, impacting agricultural planting and production (Table 2.3; Hoell et al., 2016, 2017).

2.6. Ocean Temperature and Air Pressure Influences on Rainfall

Namibia is the most arid country in southern Africa because of a STH zone that originates from the Atlantic and Indian Oceans, represented by the two H symbols (Figure 2.16; Desert Research Foundation of Namibia & Climate Systems Analysis Group, 2008; MET 2015). The STH is associated with drying, sinking air that dominates the region for most of the year (Figures 2.9 and 2.10; UCAR, 2021b). Despite both being STH systems, the warm Indian and cold Atlantic Oceans create differentiated temperature and precipitation conditions (Cenedese & Gordon, 2018). The cool Atlantic Ocean SST alongside western Namibia creates dry conditions that dominate the country and prohibit rainfall, specifically for the deserts along the coast (R. Rood, personal communication, 2021).

Rainfall ranging from 10 to greater than 60 cm across the African continent is primarily fueled by the atmospheric features of the ITCZ and secondarily the West African and Southeast African Monsoons (Figure 2.16; Gentilli et al., 2012). Only the northeastern portions of Namibia experience a summer rainy season between December and March with precipitation primarily influenced by the warm Indian Ocean (Gaughan et al., 2015; Hoell et al., 2016). The ITCZ and Southeast African Monsoon bring rain to southern Africa from central Africa and the Indian Ocean through low-pressure systems that push the STH further into the oceans (R. Rood, personal communication, 2021)

Table 2.3: Combined effects of El Niño–Southern Oscillation (ENSO) and Subtropical Indian Ocean Dipole (SIOD) phasing compared to ENSO alone for December-March in Southern Africa (Hoell et al., 2016, 2017).

		El Niño–Southern Oscillation (ENSO) Phase	
		El Niño	La Niña
Subtropical Indian Ocean Dipole (SIOD) Phase	Positive (+) SIOD	**EN+SIOD** *Weaker or insignificant* decreased precipitation and increased surface air temperature anomalies, causing *less impactful* dry conditions with decreased runoff, soil moisture, and evapotranspiration. Overall results are less statistically significant and more spatially varied than EN-SIOD.	**LN+SIOD** *Stronger* increased precipitation and decreased surface air temperature anomalies, causing *severe* wet conditions with increased runoff, increased soil moisture, and decreased evapotranspiration. Overall results are more statistically significant and less spatially varied than LN-SIOD.
	Negative (-) SIOD	**EN-SIOD** *Stronger* decreased precipitation and increased surface air temperature anomalies, causing *severe* dry conditions with decreased runoff, decreased soil moisture, and increased evapotranspiration. Overall results are more statistically significant and less spatially varied than EN+SIOD.	**LN-SIOD** *Weaker or insignificant* increased precipitation and decreased surface air temperature anomalies, causing *less impactful* wet conditions with increased runoff, soil moisture, and evapotranspiration. Overall results are less statistically significant and more spatially varied than LN+SIOD.

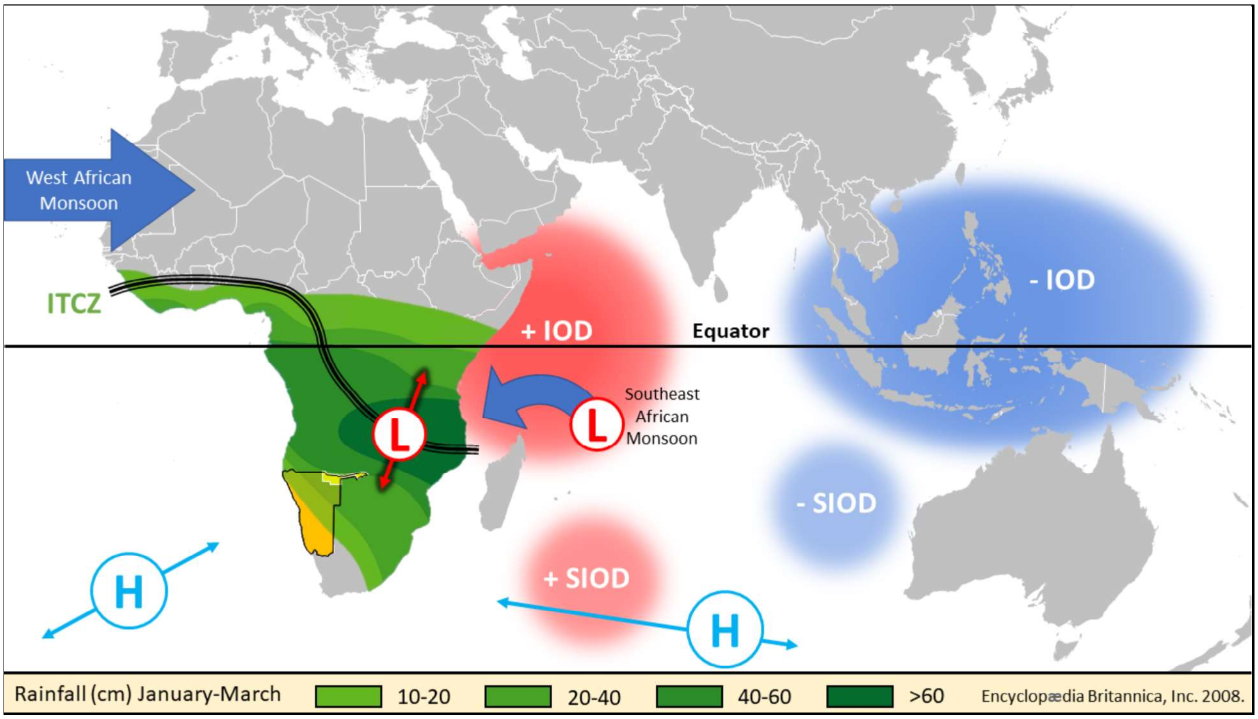


Figure 2.16: Schematic of all climate features except for El Niño-Southern Oscillation (ENSO). Low- and high-pressure systems are noted by the L and H symbols. Note: only the positive phase of Indian Ocean Dipole (IOD) and Subtropical Indian Ocean Dipole (SIOD) are portrayed and may not occur at same time. Adapted from: (Australian Government Bureau of Meteorology, 2021; Di Liberto, 2015b; Gentilli et al., 2012; Hoell et al., 2016; Holmes & Hoelzmann, 2017).

All climate features discussed in this Chapter are displayed in the schematic (Figure 2.16), except for the ENSO, an atmospheric-oceanic feature (Figures 2.13 and 2.14). When either the El Niño or La Niña phase occurs, it is an important factor impacting Namibian climate conditions, outweighing the influences from other features and their interactions and thus should be considered separately (L'Heureux, 2014).

2.7. Projected Climate Changes

This section discusses how climate conditions, features, and their interactions may be altered by climate change. These changes inform the four potential climate scenarios.

Changes to the ITCZ. Climate change is projected to intensify anticipated precipitation and upward circulation at the ITCZ center, while its width and circulation near the edges will decrease (Byrne et al., 2018). This *deep tropics squeeze* has been observed over the past three decades and climate models project it will continue with increasing global temperatures (Wodzicki & Rapp, 2016). Narrowing has been demonstrated by the southward edge of the ITCZ shifting northward, resulting in reduced precipitation over northern Namibia (Byrne et al., 2018). Given that the ITCZ center covers northern Zambia, where the head-catchments of the Zambezi River are located, amplified rainfall may increase the frequency and magnitude of downstream flooding (Beyer et al. 2016). This may also be the case for the Okavango or Kwando rivers beginning in neighboring Angola and Zambia (Gaughan & Waylen, 2012). While climate models have not incorporated the deep tropics squeeze, the majority of models predict a complementary widening of Hadley cells and dry STH systems, which effectively incorporate the deep tropics squeeze in model outputs (Byrne et al., 2018; Dezfuli, 2017).

The ITCZ follows solar insolation along an asymmetrical seasonal migration route (Byrne et al., 2018) between approximately 20°N to 20°S in austral winter and summer (Figure 2.11a and 2.11b; Dezfuli, 2017). Climate change may shift the seasonal migration route northward to above 20°S in summer. There are competing theories about whether the location of the ITCZ, defined as the area between the southern and northern Hadley cell boundaries, will shift. Byrne et al. (2018) stated that the ITCZ location is well-studied and will not change, thus this has been incorporated into climate models. Dunning et al. (2018) discussed how peak rainfall associated with the tropical rainbelt is anticipated to shift north due to the intensification of the Saharan Heat Low (SHL), located over the Saharan desert in Western Africa and tied to the West African Monsoon, caused by increasing temperatures.

Under the RCP8.5 scenario, the ITCZ location is projected to shift north 0.8°–1.2° on average between August to December from its historic position. This may preclude portions of northeastern Namibia from receiving rainfall. A shift in ITCZ location would also postpone the seasonal ITCZ progression towards southern Africa by over 12 days on average. This delayed onset is also associated with less moisture transport from northern to southern Africa and reduces relative humidity there between August and October. In Namibia, this means fewer rain events after the wet season begins, leading to a shortened season and reduced total seasonal rainfall, although individual rain events are estimated to have increased rainfall (Dunning et al. 2018).

Changes to ENSO. Multi-decadal climate trends are associated with increased variability, drier conditions, and reduced average annual precipitation in Southern Africa. These observations have been partly attributed to ENSO and IOD, with increased frequency of El Niño-derived dry years (Gaughan et al. 2015).

Climate change is anticipated to increase the duration and intensity of El Niño as well as increase its frequency relative to La Niña (Mason, 2001; Gaughan et al., 2015). This causes more severe and prolonged warm/dry conditions with decreased precipitation leading to drought. When El Niño occurs, it temporarily raises global air and ocean temperatures, therefore slightly enhancing global warming. On the other hand, La Niña occurrences lower global air and ocean temperatures and slightly reduce global warming (NOAA Climate, 2016). ENSO may become more difficult to forecast as temperature anomalies become more difficult to detect, decreasing prediction times from 18 months in advance to six (Mason, 2001).

Changes to the IOD and SIOD. Climate change influences on the SIOD have a larger relative impact on climate in Namibia because it is closer to Southern Africa than IOD. All phases if IOD/SIOD are projected to become more frequent and severe due to climate change. These changes are caused by warming overall global temperatures for -IOD/-SIOD and increasing SST in the western Indian Ocean for +IOD/+SIOD (Dunning et al., 2018; Gaughan et al., 2015).

Under RCP8.5, extreme +IOD events are projected to occur once every 17.3 years instead of 6.3 years by 2100, causing extreme rainfall and flooding in East Africa (Australian Government Bureau of Meteorology, 2021; Uchoa, 2019). While normal +IOD events are typically associated with rainfall in Namibia, extreme +IOD events disrupt moisture transport tied to the Southeast African Monsoon and ITCZ features from northern into southern Africa. A warming of the northwestern Indian Ocean is predicted to further disrupt and weaken moisture transport into southern Africa by delaying the onset of rainfall and the total amount (Dunning et al., 2018).

Impacts to Namibia's Climate and Farmers. Projected changes to the ITCZ and associated rainfall are expected to especially impact farmers practicing rain-fed agriculture (Table 2.4).

Projected changes to ENSO, IOD, or SIOD due to climate change may impact subsistence farmers by affecting warm/wet conditions and extreme events like droughts and floods through modulations of L/H systems directly or indirectly through atmospheric features (Dunning et al., 2018; Gaughan et al., 2015; Mason, 2001).

ENSO is an important feature without outweighed influence on climate in northeastern Namibia (L'Heureux, 2014). The anticipated increases in duration, intensity, and frequency (relative to La Niña) of El Niño and its associated warm/dry conditions due to climate change contribute to the drought scenario. Table 2.5 describes associated changes and impacts to subsistence farmers caused by the projected change to El Niño (Gaughan et al., 2015; Mason, 2001).

The anticipated increases in strength and frequency of the -IOD/-SIOD as global temperatures warm contribute to the warm/dry scenarios of drought, extreme heat, and shortened wet season. Another plausible scenario is that the strength of the +IOD/+SIOD increases as SST warms, contributing to the Extreme Rainfall and Flooding scenario. Although extreme +IOD may disrupt moisture transport from northern to southern Africa, leading to warm/dry scenarios. Table 2.6 describes associated changes and impacts to subsistence farmers caused by the projected changes to the IOD/SIOD.

Table 2.4: Projected Intertropical Convergence Zone (ITCZ) Climatic Changes and Associated Changes to Climate Outcomes and Impacts to Namibia's Subsistence Farmers (Byrne et al., 2018; Dezfuli, 2017; Dunning et al., 2018; Gaughan & Waylen, 2012; Wodzicki & Rapp, 2016).

Projected ITCZ Climatic Changes	Changes to Climate Outcomes	Impact to Subsistence Farmers
Seasonal migration shifted North and delayed	Delayed rainfall onset	Delayed planting dates
	Shortened wet season	Prevent some crops from reaching maturity
	Decreased total rainfall	Crop degradation /loss
Deep Tropics Squeeze	Increased rainfall intensity	Runoff, soil erosion
All		Reduced yields

Table 2.5: Projected El Niño-Southern Oscillation (ENSO) Climatic Changes and Associated Changes to Climate Outcomes and Impacts to Namibia's Subsistence Farmers (Gaughan et al., 2015; Mason, 2001).

Projected ENSO Climatic Changes	Changes to Climate Outcomes	Impact to Subsistence Farmers
↑ Duration of El Niño	Longer term, multi-year droughts	Some crops prevented from reaching maturity Groundwater depletion Crop degradation or loss Water scarcity for humans and crops
↑ Intensity and Frequency (relative to La Niña) of El Niño	↑ Evaporation rate from water sources ↑ Evapotranspiration from crops ↓ Soil moisture ↓ Total rainfall Shortened wet season	

Table 2.6: Projected Indian Ocean Dipole and Subtropical Indian Ocean Dipole (IOD/SIOD) Climatic Changes and Associated Changes to Climate Outcomes and Impacts to Namibia's Subsistence Farmers (Dunning et al., 2018; Gaughan et al., 2015; Australian Government Bureau of Meteorology, 2021; Uchoa, 2019).

Projected IOD/ SIOD Climatic Changes	Changes to Climate Outcomes	Impact to Subsistence Farmers
↑ Strength and frequency of +IOD/ +SIOD	↑ Rainfall intensity ↑ Total rainfall ↑ River & field flooding	Soil over-saturation Water runoff and soil erosion, especially following a dry period Crop degradation or loss
↑ Strength and frequency of -IOD/ -SIOD	↑ Evaporation rate from water sources ↑ Evapotranspiration from crops ↓ Soil moisture ↓ Total rainfall Longer term, multi-year droughts ↓ Total rainfall Shortened wet season	Some crops prevented from reaching maturity Groundwater depletion Crop degradation or loss Water scarcity for humans and crops
↑ Frequency of extreme +IOD events	↓ Moisture transport and relative humidity from northern Africa	

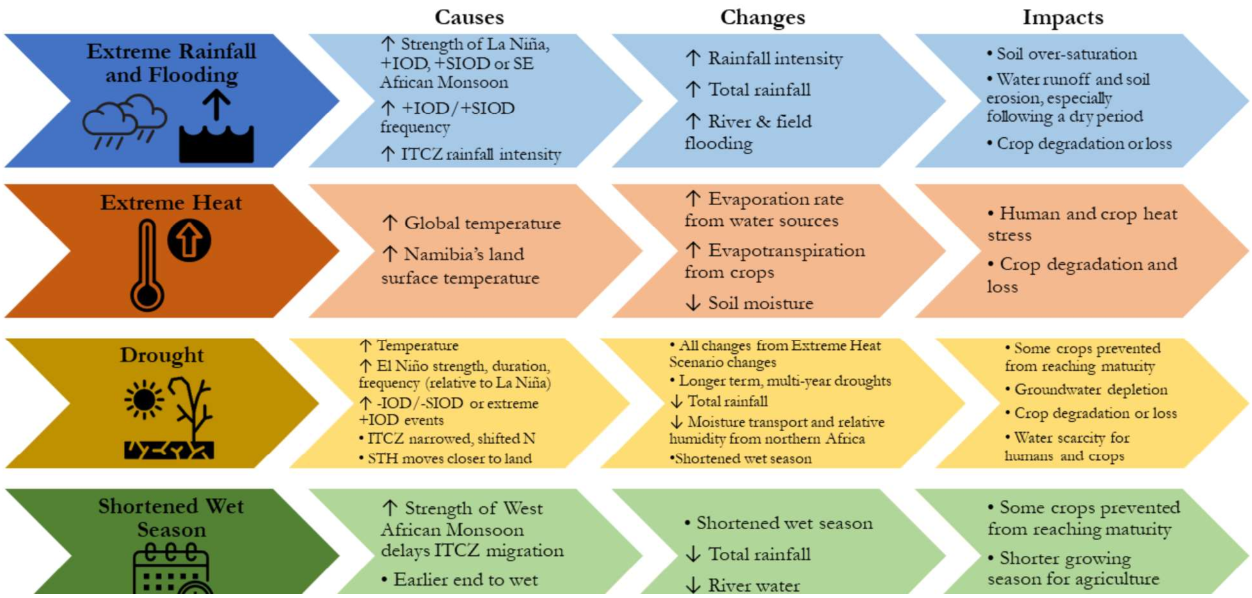


Figure 2.17: The four climate scenarios: Extreme Rainfall and Flooding, Extreme Heat, Drought, and Shortened Wet Season. Scenarios capture a causal relationship: (1) climate change effects on atmospheric and atmospheric-oceanic features causing (2) changes to climate conditions and extreme events in Namibia (3) resulting in impacts to subsistence farmers.

2.8. Future Climate Scenarios

The four climate scenarios outline projected changes in climate and associated agricultural impacts to subsistence farmers caused by changes in climate features and their interactions discussed in previous sections (Figure 2.17).

Persistent anomalous warm/wet patterns are less probable than persistent warm/dry patterns given Namibia's historical climate conditions and extreme events (R. Rood, personal communication, 2021). This is why there is a singular warm/wet scenario of Extreme Rainfall and Flooding, whereas the warm/dry category was divided into three scenarios given three groups of similarly changing climate features resulting in warm/dry conditions: Extreme Heat, Drought, and Shortened Wet Season.

All scenarios are plausible and should receive equal consideration for planning of adaptation strategies and policies. Monitoring of climate features and conditions is necessary to track alignment with scenarios and plans should be flexible to address altering scenarios and combinations (R. Rood, personal communication, 2021). Given increased variability of weather and climate events with climate change, altering wet and dry conditions during one (i.e., short-term weather variability) or multiple growing seasons (i.e., long-term climate variability) should also be considered (Hoell et al., 2017; IPCC, 2018).

Across all scenarios, climatic changes lead to impacts on subsistence farmers of crop degradation or loss, reduced agricultural yields and, depending on the severity of extreme events, subsequent food insecurity. Severity of impacts depends on several factors including its length of occurrence, agricultural stages it overlaps with, and the types of crops grown by subsistence farmers (MET, 2015).

2.8.1. Warm and Wet Scenario

Scenario 1: Extreme Rainfall and Flooding

The changes and impacts tied to the warm and wet scenario of Extreme Rainfall and Flooding are location-dependent. Downstream flooding is caused by rainfall in Angola or Zambia that flows down rivers into northeastern Namibia, whereas local flooding is caused by rainfall directly in the area (Figure 2.12; Gaughan & Waylen, 2012).

Downstream floods require large amounts of rainfall to occur over an extensive region and timeframe, otherwise only upstream floods will occur in Angola or Zambia without riverine flooding in Namibia. The impacts of downstream flooding will be more limited to farms along river floodplains than local flooding (Nelson, 2015).

The Extreme Rainfall and Flooding scenario is caused by warm air and ocean surface temperatures that strengthen the +IOD, +SIOD, Southeast African Monsoon, and La Niña. Although La Niña is anticipated to occur less frequently compared to El Niño, frequency of both +IOD and +SIOD may increase (Dunning et al., 2018; Gaughan et al., 2015). ITCZ rainfall is predicted to be more intense, although its shift in location may increase downstream riverine flooding more than local flooding (Byrne et al., 2018; Dunning et al., 2018). Changes associated with these features include increased rainfall intensity and total, river flooding (local or downstream) and field flooding (local or tied to local/downstream river flooding).

Impacts to subsistence farmers include increased evapotranspiration, soil over-saturation, water runoff, and soil erosion, especially following a dry period. When extreme rainfall occurs, soil and plants release excess water to the atmosphere through evaporation and transpiration to relieve soil over-saturation that threatens plant growth. When the soil becomes oversaturated, field flooding occurs. If the flooding is severe or long-term, this leads to water and soil runoff that removes nutrients and crops (Hoell et al., 2016, 2017).

2.8.2. Warm and Dry Scenarios

There are three warm/dry climate scenarios: Extreme Heat, Drought, and Shortened Wet Season. The three staple crops in the regions require between 250-800 mm of water total to grow (Table 3.1). Given that regional rainfall narrowly supports crop production currently without using river water and/or water storage, reduced precipitation due to climate change may reduce yields or prohibit production without adaptive strategies.

Scenario 2: Extreme Heat

The Extreme Heat scenario is caused by global warming and associated differential localized temperature increases. Extreme heat is characterized by temperature exceeding 35°C for one or more days to weeks (Ali et al., 2020). Events need not be consecutive to have major impacts (MET, 2015). Changes associated with these events include: increased evapotranspiration from crops, reduced soil moisture, and an increased evaporation rate from water sources of approximately 5% with each degree of global warming (MET, 2011).

Impacts of these changes to subsistence farmers include human and crop heat stress. Farmers must work less and avoid direct sunlight during the hottest times of the day to avoid dehydration, heat exhaustion, and heat stroke, potentially reducing their productivity (MET, 2015). Heat stress in crops varies by plant, but can affect photosynthesis, water use, and development of roots, seeds, and shoots. Crop heat stress can result in crop degradation or loss (Ali et al., 2020; MET, 2015; Nakanyete et al., 2020).

Scenario 3: Drought

A combination of the meteorological and agricultural drought definitions is used given the focus of this research (Denchak, 2018; Wilhite & Glantz, 1985). Drought is defined in this study as a sustained dry period, lasting weeks to years, with less rainfall than normal that cannot adequately support crop development. The amount of rainfall and time considered 'normal' is dependent on the location, crop, and soil. The causes, changes, and impacts associated with Extreme Heat are also applicable to the Drought scenario. Additional causes are associated with the following climate features and their projected changes: increased strength and frequency of El Niño relative to La Niña, ITCZ location shifted north and narrowed, and the STH moves closer to land due to El Niño, -SIOD, -IOD, or a combination. These factors lead to 10 to 30% reductions in total rainfall predicted for the entire country by 2050 and 2080 (MET, 2011). The ITCZ causes less moisture transport from northern into southern Africa and reduced relative humidity. The prolonged warm/dry conditions lead to longer term, seasonal to multi-year drought events compared to the Extreme Heat scenario causing a shortened wet season.

Impacts to subsistence farmers include some crops prevented from reaching maturity, crop degradation or loss, human and crop water scarcity, and groundwater depletion. Rainfall amounts below the required levels for crops will negatively impact plant growth and lead to crop degradation or loss without using other water sources. Long-term drought can lead to water shortages for people and agriculture. When rainfall or rivers do not replenish groundwater that is continually extracted through boreholes, depletion can occur (MET, 2015).

Scenario 4: Shortened Wet Season

Lastly, the Shortened Wet Season scenario is caused by a shift in ITCZ location due to the West African Monsoon and SHL (Byrne et al., 2018; Dunning et al., 2018). Under RCP8.5, these features interact to postpone by 12 days the seasonal ITCZ migration towards southern Africa. This shift may preclude portions of northern Namibia from receiving rainfall (Dunning et al. 2018). The rainy season typically begins gradually between October and December and reaches its peak between December and March (Gaughan et al., 2015; Hoell et al., 2016).

Indigenous subsistence farmers have predicted shortened wet seasons when the first day of rain is unusually heavy and fills up water ponds known as *Eendobe* (Nakanyete et al., 2020). This aligns with predicted climatic changes associated with the ITCZ that lead to intensified rainfall. Fewer days of rainfall with later onset and earlier cessation lead to a shortened wet season with reduced total rainfall. Unless water storage techniques are used, a shorter wet season with altered conditions may prevent crops from reaching maturity and reduce the growing season of rain- and river-fed crops (Nakanyete et al., 2020).

Scenarios under the warm dry category should be planned for both independently and together with other warm/dry scenarios, as they may occur simultaneously.

Chapter 3: Reducing Vulnerabilities: Crops, Irrigation, Finance, & Gender

Subsistence farmers may face barriers to adapting to climate change that decrease their resilience. This chapter explores four categories of subsistence farmers' vulnerabilities - crops, technologies, finance, and social identities- and the potential barriers for adaptation as a result of each vulnerability.

3.1. Methods

Literature Review. A literature review was conducted to understand farming practices and farmers' identities, their vulnerabilities to climate change, and barriers that they might face in adapting to climate change. This literature review was conducted over 12 months and included five groups of resources and databases:

1. Namibia government documents and websites;
2. International NGOs including the IPCC, FAO, and World Bank;
3. Articles from African Agricultural journals;
4. Articles found using Google Scholar, and the University of Michigan library services; and
5. Namibian banks websites.

Resources were initially found through keyword searches on databases such as the University of Michigan library and Google Scholar (Table 3.1). Additional sources were gleaned from the reference sections and citations of peer reviewed documents. This snowball approach was used for all sections of the literature review. For the financial portion of the study, individual searches on bank websites were used to identify current financial structures.

Priority was placed on using research conducted in Namibia and by Namibian people to emphasize local contexts, knowledge, and practices.

Expert Interviews. Expert guidance from 22 individuals throughout the partner organizations informed the study. This included: 17 individuals from the faculty, staff, and administrators at UNAM, 2 employees of GWPSA, 2 members of the CRAVE Project, and 1 project manager from the UNFCCC. Discussions with these experts helped fill gaps in local farming practices and culturally appropriate data collection strategies that were not identifiable through literature review. These discussions took place via email, instant messenger, and virtual conferencing platforms, and were recorded informally.

Limitations. Due to COVID-19, U.S.-based researchers on this project were unable to visit northeastern Namibia which prevented a deeper understanding of local ways of life. Much of the analysis in this report relied on literature reviews. Because of remote work, documents such as local loan applications that were available only within Namibia remained inaccessible to the researchers.

3.2. Staple Crops

Three staple crops are grown by subsistence farmers in northeastern Namibia: Maize, Sorghum, and Pearl Millet (colloquially known as Mahangu) (Table 3.2). While farmers also grow other crops (e.g. beans, cowpeas, nuts, watermelons, pumpkins, spinach), farmers rely heavily on these three cereals (Green Climate Fund, 2017). Climate change could impact the yield of each of these crops.

Table 3.1: Summary of literature review keywords, databases accessed, and number of articles utilized per vulnerability

Key Words	Resource and Databases	Number of documents
CROPS ● Maize ● Sorghum ● Mahangu ● Drought tolerant plants in Namibia ● Farming practices in Namibia ● Seed saving in Namibia	Google Scholar Namibian Agronomic Board The Namibian UN Food and Agriculture Organization University of Michigan Library	26
TECHNOLOGIES ● Drip Irrigation ● Boreholes ● Earthdams ● Rainwater ● Ponds, pans and tanks ● Drip irrigation ● Surface irrigation ● Solar pumps ● Irrigation in Namibia ● Farming practices in Namibia	Google Scholar UN Food and Agriculture Organization University of Michigan Library	26
FINANCE ● Multilateral Climate Finance ● Green Climate Fund ● Global Environment Facility ● Adaptation Fund ● Climate Investment Fund ● Namibia bilateral climate funds ● Microfinance ● Microfinance in Namibia ● Namibian agricultural loans	Adaptation Fund Climate Investment Fund Environmental Investment Fund of Namibia Global Environment Facility Google Scholar Government aid websites (e.g. USAID) Green Climate Fund Namibian bank websites (First National Bank, Agribank, etc.) The World Bank	48
social identities CHARACTERISTICS ● Vulnerability to Climate Change ● Social Vulnerability ● Adaptive Capacity ● Climate Risks and Hazards ● Resilience to Climate Change ● Climate Equity ● Climate Justice ● Gender and Climate Change	Elsevier Google Scholar JSTOR Namibia National Statistics Agency PLOS One University of Michigan Library	32

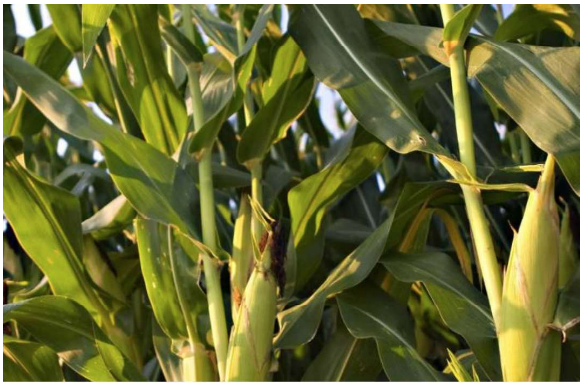


Figure 3.1: Close-up image of white maize (Namibia Agronomic Board, 2019).

3.2.1. Maize

Maize (*Zea mays*) is the most commonly grown staple crop by subsistence farmers (Green Climate Fund, 2017; Irish, 2012a; Namibia Agronomic Board, 2019).

Two types of maize are grown in Namibia. Yellow maize is produced exclusively for animal feed while white maize is grown exclusively for human consumption (Namibia Agronomic Board, 2019). For the purposes of this report, all further references to *maize* will pertain to *white maize* because that is the crop primarily grown by subsistence farmers.

Subsistence farmers grow maize in both rain-fed and irrigated systems. The growing season for this crop depends on the irrigation system. The planting season for rain-fed systems normally occurs between December and January but is dependent on the timing of the rainy season (Irish, 2012; Namibia Agronomic Board, 2019). Crops grown under irrigation conditions have more certainty in their growing season which occurs cyclically; crops planted between August/September will be harvested in February/March, and crops planted in December/January will be harvested in May/June (Namibia Agronomic Board, 2019). The average total growing period for maize is 80 to 100 days (Abhishek, 2020), and plants need between 500-800mm of water to reach maturity (Brouwer & Heibloem, 1986).

Of the three staple crops, maize is expected to be most impacted by climate change due to its intolerance to both drought and temperature variations. Although there are a number of factors leading to low yields of maize in Western and Southern Africa including pests, low soil fertility, and low nutrient availability, changes to precipitation and temperature are the major drivers for a decrease in crop yield. Temperature increases result in increased evapotranspiration that could be further exacerbated by drought conditions (Cairnes et al., 2013), leading to a decrease in yields. Climate models suggest a possible 12% decrease in yield by 2050 and 20% decrease by 2080 (Tesfaye et al., 2015), which would be problematic for farmers who rely heavily on maize as their primary source of income and sustenance.

3.2.2. Sorghum

Sweet Sorghum (*Sorghum bicolor var. saccharatum*) has been grown in Northern Namibia for longer than recorded history (Irish, 2012b).

Sorghum is a more drought and heat resistant cereal than maize. In fact, the plant is considered heat loving, and seeds will not germinate if the ground temperature does not warm above 10℃ (Chisi & Peterson, 2019; Seed Savers Exchange, 2021) Over its 120-130 day growing season, sorghum plants only need 500-700mm of water, however with increasing drought, moisture conservation is deemed critical (Chisi & Peterson, 2019). With a longer growing period and a lesser water requirement than maize, individual sorghum plants can be more resilient and adaptive to the precipitation patterns each season. Sorghum plants are also self-pollinating (Wang et al., 2016), which could be helpful for continued growing if climate change impacts wind patterns and disrupts natural cross-pollinating processes of other plants.

Figure 3.2: Close-up image of sorghum taken from Kew Science (Kew Science, 2017).

A 2016 study showed that sorghum was predicted to perform well under four agricultural models (GFDL-ESM2M and MIROC-ESM-CHEM), that model agricultural production under various climate models, ranging from the wettest to the driest climate extremes (Orr et al., 2016). Of the three staple crops, sorghum was shown to have the most resilient yield under temperature and drought conditions. In fact, by 2050, predictions show that there could be an increase in sorghum yield of 11-33% across Africa. This increase comes predominantly from an increase in planting, as there is already a seasonal correlation of increasing sorghum production to make up for decreased maize production (Orr et al., 2016). Sorghum cannot be stored for significant periods of time under wet conditions, so under climate predictions of higher temperatures and decreased precipitation, sorghum can be stored for longer periods of time (Chisi & Peterson, 2019),, making it a potentially valuable crop for subsistence farmers.

3.2.3. Pearl Millet

Pearl Millet, known locally as Mahangu, is predominantly a subsistence crop in Namibia, with over 50% of the country's population currently relying on it. Because of its importance to local farmers, the Namibian government made Mahangu a controlled crop in 2008, meaning that the government prohibits the import or export of Mahangu until the entire local harvest is sold (Namibia Agronomic Board, 2017).

Figure 3.3: Close-up image of Mahangu (Namibia Agronomic Board, 2017).

Similarly to Sorghum, Mahangu is a highly adaptive plant that is expected to do well under various climate change scenarios due to its limited vulnerability to environmental stressors (Matsuura & An, 2020). Mahangu thrives with high ground surface temperatures (30-40C), has a low precipitation requirement of between 250-700mm per growing season and has a variable growing period of 105-140 days (Chisi & Peterson, 2019); this variability in growing period allows individual plants more time to adapt to the current weather patterns. Mahangu is also known to grow better and become more productive in low nutrient soils (Matsuura & An, 2020). These low maintenance and adaptive qualities make Mahangu one of the most drought-resistant cereal plants (Chisi & Peterson, 2019). The Namibian Agronomic Board specifically mentions that the plant is well adapted to the prevailing soil conditions and low rainfall in the Kavango regions (Namibia Agronomic Board, 2017).

Although Mahangu does well under drought and climate change conditions, unlike sorghum, farmers are not increasing their mahangu production to replace decreasing maize yield. However, there is expected to be an increase in yield by 2050 as farmers are predicted to decrease their maize production and increase their Mahangu production. Mahangu can be stored for long periods of time (Orr et al., 2016), and farmers in Namibia have developed a traditional grain storage basket that can store their Mahangu for up to five years (Namibia Agronomic Board, 2017). This is critical for subsistence farmers who are dependent on their crop for their livelihoods and may experience varying crop yields as a result of climate change.

3.2.4. Barriers for Crop Selection as an Adaptation Strategy

Growing resilient crops could be a useful adaptive strategy under potential climate schemes. For example, growing Mahangu might be more sustainable because it has higher yields under different climate scenarios and can be stored for longer periods than other staple crops. However, such changes in agricultural practices face a number of challenges.

Lack of Knowledge. Lack of knowledge is one of the most prominent barriers to adaptation according to Davies et al. (2020) study on mapping barriers for adaptation in Namibia. The authors argue that because adaptation is centralized at the national scale, coordination vertically to local communities and horizontally across sectors (government, NGOs, communities, researchers and the private sector) is difficult and leaves individual farmers without the knowledge to adapt (Davies et al., 2020). A second study (Ofoegbu et al., 2020) looked specifically at dissemination of information to subsistence farmers in the Omusati region (not included in our study region but a similar study looking at barriers for agricultural adaptation); the authors found that the majority of climate knowledge coming from the government, specifically the Meteorological Office, is disseminated from a top down approach, but as there are more subsistence farmers than extension workers, this information is often not relayed in an efficient manner.

The information is also directed at long-term scales, but most farmers are seeking information for short-term time-frames based on planting and harvesting. In this region, the researchers also found that subsistence farmers were only meeting once a year with extension workers tasked with dissemination of information (Ofoegbu et al., 2020).

This lack of integrated and usable information, even if received in a timely manner, limits a farmer's individual capacity to adjust their crops or growing practices to the specific climate patterns of the upcoming growing season.

Limited Access to Seeds. Utilizing genetic variations of staple crops that are more drought resistant or have been genetically modified to withstand the impacts of climate could be a useful crop selection adaptation strategy. There is however little evidence of farmers switching to drought-resistant crops (Davies et al., 2020).

The Namibian Access to Biological and Genetic Resources and Associated Traditional Knowledge Act 2 of 2017 could potentially further hinder access to these seeds. The law enacted in compliance with the international Nagoya Protocol, has a number of aims:

- To regulate access to biological or genetic resources and associated traditional knowledge, and innovation, practices and technologies associated with biological and genetic resources and traditional knowledge;
- To protect the rights of the local communities over biological and genetic resources and associated traditional knowledge;
- To provide for fair and equitable mechanism for benefit sharing; and
- To establish the necessary administrative structures and processes for the implementation and enforcement of such principles to provide for incidental matters.

While this law is predominantly meant to protect communities from having their traditional knowledge of local plants for pharmaceuticals and medicine exploited, it could also have negative implications for distribution of and research on biological resources including genetically modified, climate resilient seeds (Chinsembu & Chinsembu, 2020).

Inertia to Adapting. There are also cultural barriers to changing crops. In particular, there is a traditional attachment to Mahangu that makes some farmers unwilling to grow other crops. A stakeholder from the Davies et al. (2020) study explained that when a development project from the United States delivered seeds for potentially more climate tolerant bean and sorghum plants, farmers did not accept the new varieties because they were not the same as their traditional counterparts.

Table 3.2: Table showing comparisons between irrigation scheme, growing period, amount of rain needed, impact on predictions on yield and adaptive ability across staple crops.

	Maize	Sorghum	Mahangu
Irrigation scheme	Rainfed and irrigated	Typically rainfed but could be irrigated	Typically rainfed but could be irrigated
Growing period	80-100 days	120-130 days	105-140 days
Amount of rain needed	500-800mm	500-700mm	250-700mm
Predicted yield under drought conditions	Decrease	Decrease	Increase
Predicted yield under increased temperatures	Decrease	Increase	Increase

The bean seeds were smaller than the ones traditionally planted and the sorghum plants had shorter stems than the traditional variety. The lack of cultural significance resulted in few farmers utilizing the more climate resilient seeds (Davies et al., 2020).

For farmers who are willing to change crops, this traditional status quo surrounding use of specific cultivars of crops could even be inertia to changing crops in tight communities.

There are also communities that have a strong religious belief that God will provide and are therefore unwilling to grow different crops or adapt their practices (Davies et al., 2020).

3.3. Irrigation Approaches

Through conversations with the UNAM faculty, a list of currently used strategies and technologies (referred to solely technologies throughout the study) was developed (Table 3.3.). These technologies span eight categories of farming practices: harvesting, irrigation, pest control, planting, power for transporting water, water storage, water sources, and weed control. The report focuses on irrigation, or water based, technologies (under the water sources, water storage, irrigation, and power for carrying water categories) because water is vital for growing crops and changes to precipitation are present under all four potential climate scenarios, thus making water scarcity another vulnerability that subsistence farmers face.

These local irrigation technologies have the ability to become climate smart approaches for decreasing farmers' vulnerabilities to and increasing their resilience to climate change.

3.3.1. Water Sources

Water sources refers to all of the locations where subsistence farmers could obtain water for watering their crops. There are four potential sources of water being used: boreholes, earth dams, rainwater and rivers.

Boreholes. These are holes drilled into the Earth with the intention of extracting water. These wells with small diameters, lack the storage area of an average well and therefore require a pumping system. Boreholes are touted for potential savings on water and for being outside of the jurisdiction of water utilities. They also provide more consistent water unlike alternative sources such as rainwater and rivers which are dependent on weather conditions (SA Boreholes, 2018).

Figure 3.4: Image of a borehole pumping station (Nandjato, 2017)

Earth Dams. These are dams made from natural materials rather than synthetic materials such as cement. They are also known as embankment dams. These dams are made from a mixture of clay, sand, silt, gravel, rock and combles; solid which is weak must be excluded so that the structure will be strong enough to withstand percolation and hold in water (Ratnayaka et al., 2009). Earthen dams are a commonly used solution for both water sources and storage throughout Namibia, and have been associated with similar Green Scheme projects in other regions of the country (allAfrica.com, 2020).

Rainwater. There are three methodologies for using rainfall as an irrigation source. First, rainfall can directly irrigate crops. Second, harvesting can be done in-situ, where water is trapped and held directly in the soil to continue to irrigate for longer durations than precipitation falls. Lastly, rainfall can be collected in manmade vessels (Section 2.2.2.) and stored for later use (Yosef & Asmamaw, 2015). This process can be as simple as leaving a bucket outside during rain or as complex as building catchment surfaces (i.e. roofs or ground surface) with specialized transport systems (i.e. surface drains or gutters) that drain directly into storage vessels (Sturm et al., 2009).

Table 3.3: Technologies being used in each of the eight parts of the agricultural process. Gray cells with "X" indicate the associated agricultural process for each technology.

	Harvesting	Irrigation	Pest Control	Planting	Power for carrying water	Water Storage	Water Sources	Weed Control
Animal power					X			
Biological								X
Borehole							X	
Broadcasting				X				
Canal						X		
Cutter	X							
Diesel/petrol engine					X			
Drip irrigation (above ground)		X						
Drip irrigation (below ground)		X						
Earth Dam						X	X	
Grid powerwed engine					X			
Hand hoe				X				X
Jab planter				X				
Knife	X							
Lights			X					
Manual	X	X		X	X			X
Mulching								X
Netting/tarp			X					
Noise (electronic e.g. drone)			X					
Noise (manual)			X					
Planting behind plough				X				
Plastic								X
Pond/pan						X		
Precision planter				X				
Rainfall							X	
River							X	
Seed drill				X				
Sickle	X							
Solar powered engine					X			
Sprinkler irrigation		X						
Surface irrigation (basin)		X						
Surface irrigation (flood)		X						
Surface irrigation (furrow)		X						
Synthetic pesticides								X
Tank						X		
Test aversion								X
Well						X		

Rivers. Many farmers live in close proximity to rivers, which they use to irrigate their crops. The Zambezi River is one of the largest sources of water in northeastern Namibia. The Okavango River also serves farmers in this region (Green Climate Fund, 2017). The amount of water in the rivers that is available for future irrigation is dependent on the climate scenarios. As the sources of both main rivers are outside of Namibian borders, future international water policy, especially as foreign governments adapt to climate impacts, could also impact the amount of water farmers have available for crops.

3.3.2. Water Storage

Water storage refers to the stockpiling of water in manmade or natural vessels for later use. With changing precipitation patterns under all four climate scenarios, increasing water storage will be vital for crop production. As there will likely be less precipitation, irrigation using stored water will be necessary to supplement plants' water needs.

There are four general water storage technologies: tanks, earth dams, canals, and wells.

Tanks. Tanks, including ponds and pans, are covered or uncovered cavities or cisterns built for individuals or communities to store water. They are typically associated with rainwater harvesting and only hold small amounts of water. One challenge of ponds or pans are that they are typically shallow and have a high surface area, which allows for high levels of water loss, with up to 90% of water to be lost to evaporation (McCartney et al., 2013).

Earth Dams. Earth dams face the same issues of small amounts of storage and loss of water due to evaporation.

Canals. Canals are man made waterways for draining or irrigating land (Davies & Marsh, 2019). These waterways could also experience lack of water due to decreasing precipitation and increasing evaporation.

Wells. The final type of water storage is (groundwater) wells, which function like boreholes but have a larger diameter and allow the water to pool for pumping USGS, n.d.). Wells could face similar issues related to lack of water and high rates of evaporation.

Other potential challenges for these water storage technologies as a result of climate change include:

- Reduced inflow with projected drought and extreme temperatures;
- Infrastructure damage as a result of extreme precipitation and weather events; and
- Increased risk of salinization and siltation with projected drought and extreme temperatures (McCartney et al., 2013).

3.3.3. Types of Irrigation

Farmers involved in the CRAVE project are divided into the two categories depending on their irrigation practices: rainfed and horticulture. Rainfed farmers rely entirely on precipitation for the growing of staple crops and horticulture farmers have more robust irrigation systems in order to grow produce and vegetables. The majority of farmers participating in the CRAVE project rely on rainfed systems, however one of the objectives of the project is to increase the number of horticulture farmers, and thus irrigated systems, in the region (Green Climate Fund, 2017).

There are four types of irrigation currently being used by horticulture farmers: manual watering, sprinklers, drip irrigation, and surface irrigation. There are three types of surface irrigation that will be discussed in this study.

Manual Watering. This type of irrigation refers to farmers who use their own strength to water their crops using some form of watering can or bucket.

Sprinkler Irrigation. Sprinklers refer to using a mechanized sprinkler system.

Drip Irrigation. Sometimes referred to as trickle irrigation or micro-irrigation, this is a method in which small quantities of water are applied directly to a plant's root zone through a series of perforated pipes so that the plant receives the exact amount of water needed (Venot, 2016). The drips to the root zone can be above ground at the base of the plant's stem or underground directly at the plant's roots.

This form of irrigation is highly touted because it has been documented to increase crop yields between 20-90% (Shamshery et al., 2017), with average reductions between 20-650% for crops including sugarcane and grapes which are grown by farmers in the CRAVE project (van der Kooij et al., 2013). Drip irrigation can also reduce water consumption by 30-60% and potentially even up to 70% in some cases (Shamshery et al., 2017; van der Kooij et al., 2013). Below ground installation also decreases water lost to increased evaporation under extreme heat scenarios (Ma et al., 2020). These water savings and crop yield increases could be crucial in preparing for changing precipitation patterns in all four projected climate scenarios and resulting decreases in crop yields.

Surface Irrigation. There are three types of surface irrigation: basin, flood and furrow. These types of irrigation work by physically flooding the land in order to water crops. The furrow method is the creation of small ditches along the crop line so that the flooding is strictly contained to the root areas (Bjorneberg & Sjoka, 2005). In basin irrigation, farmers create embankments around their fields and then flood within the embankments so that those barriers trap in water (Merriam-Webster, n.d.). These surface irrigation methods are more water intensive and less efficient than other forms of irrigation, and are also linked to soil degradation and erosion Bjorneberg & Sjoka, 2005; Hedley et al., 2014; Lehrsh et al., 2014).

3.3.4. Power for Carrying Water from the Source to Storage or to Use

For all sources of water, except for direct rainwater irrigation onto crops, transportation is necessary in order to carry water to storage vessels or directly to crops (2.2.1; 2.2.2.).

There are five types of power used to transport water in northeastern Namibia: animal power, diesel or petrol pumps, electric grid powered pumps, manual, and solar pumps. Animal power refers to animals that are used to carry buckets or containers of water from place to place, and manual refers to individuals who carry the water themselves.

Diesel, petrol, electric, and solar powered pumps are mechanical devices that siphon water from a source.

3.3.5. Barriers for Using Irrigation Technologies as an Adaptation Strategy

Modifying technological uses can be effective for minimizing vulnerabilities and increasing resilience to climate change under the four predicted scenarios. Considering that all four scenarios will impact precipitation, with three of the four scenarios resulting in less reliable precipitation and increased evaporation, and the fourth scenario resulting in an increase in extreme weather conditions, it is important to increase water collection and use efficiency.

Proximity to Water. Not all farmers live near water sources such as boreholes, wells and rivers. Farmers who live far from these sources might not easily be able to begin using these sources as a result of the distance and the resources necessary to carry water those distances.

Water Storage. With three out of four climate projections suggesting that there will be a decrease in precipitation, water storage is necessary. Under the drought it is likely that canals, earth dams, ponds and pans might not fill to capacity or the frequency with which they fill might be reduced, making them insufficient in providing enough water for irrigation (McCartney et al., 2013). Under the drought, extreme heat and shorter wet season scenarios, an additional change for water storage is increased evaporation. Even if farmers are able to store water, additional resources will be needed to ensure that storage vessels are covered to limit evaporation. Covering canals, earth dams, ponds and pans might not be possible, resulting in additional water strain (Klaassen et al., 1998; McCartney et al., 2013)

Runoff Collection. Harvesting runoff and draining water could help supplement water sources following extreme weather events and could help combat water shortage from increased evaporation under the other three scenarios (Molden et al., 2007). However, from interviews with UNAM faculty in the field, it is not clear if local farmers already have mechanisms in place to collect runoff and drainage water. Runoff and drainage waters are also more saline from interacting with soils, which makes it more difficult for irrigation as the salt levels could be harmful both to the irrigation system being used (e.g. sprinkler) or even to crops if the water contains too high of salt concentrations (Qadir et al., 2003).

Drip Irrigation. Drip irrigation is one of the most potentially effective climate smart agricultural technologies due to its ability to deliver the exact amount of water necessary directly to a crop's roots, limiting runoff and evaporation both of which are important under potential drought scenarios (Qadir et al., 2003; van der Kooij et al., 2013). Tech companies who have specifically marked drip irrigation systems for farmers in developing nations have created systems that are meant to be small yet infinitely expandable, and affordable. These "drip-kits" as they are known colloquially, are marketed for economic prosperity, transferability, and water efficiency, yet drip irrigation itself cannot guarantee these marketed impacts (Venot, 2016). There are therefore a number of barriers for drip irrigation to overcome to become a viable climate adaptation solution.

First, while drip irrigation is considered the most efficient irrigation method, the true water savings from drip irrigation compared to other methods such as surface methods may be inconclusive. Van der Kooij et al. and Venot argue that there are two reasons that efficiency statistics may not be accurate:

- Studies looking at the water savings from drip irrigation are so highly localized that they do not account for variances between farmers, their locations, the reasons that farmers are using drip irrigation, and their irrigation practices.

- There is no standard for calculating drip irrigation efficiency, as the term is used differently around the world, so the numbers articulated in studies can be misleading (van der Kooij et al., 2013; Venot, 2016)

This second point is further explained through the paradox of irrigation efficiency which shows that "crop per drop" systems that increase irrigation efficiency do not increase water availability. While this shows that drip irrigation can lead to higher yield per drop of water, this does not solve the issue of conserving water (Grafton et al. 2018). With water stocks expected to decrease under three of the four climate scenarios, should emphasis be placed on technologies that can increase water reserves, this question of efficiency could make drip irrigation take-up a less reliable adaptation strategy, if technologies are considered individually.

Second, climate smart agriculture is based on bolstering currently used technologies and strategies but according to survey data drip irrigation has not been widely adopted in the region with fewer than 10 of 205 farmers stating that they use drip irrigation.

Third, although drip irrigation systems were designed to be simple, affordable and infinitely expandable (Venot, 2016), drip irrigation is often expensive and can be difficult to install (Qadir et al., 2003).

Fourth, while drip irrigation is sometimes advertised as ensuring economic prosperity, this cannot be guaranteed as there are a number of other factors in selling sufficient crops. This marketing strategy assumes that small-scale farmers are able to adopt a market based approach and that they are focusing on earning more income rather than on other factors such as climate resilience and health challenges (Venot 2016). This marketing strategy alone can be a barrier for introducing drip irrigation as a climate-smart technology because drip irrigation will not solve the economic problems associated with decreased crop yields as a result of climate change.

Fifth, drip-kits are also designed to be expandable and transferable amongst farmers and farm sites. This however is not necessarily true as the companies selling these products sell drip-kits using assumptions about farmers, including gender and their environmental surroundings, which means that farmers have less autonomy in choosing the proper kit, and adds skepticism about the expandability and transferability of the kit. While this increases revenue for the technology company (Venot, 2016),, it creates additional monetary barriers to affording drip irrigation and increases the educational needs to understand drip irrigation systems for scalability.

Lastly, drip irrigation requires a number of pieces in order to be effective (pumps, drums, filter, pipes, microtubes, reducer tees, and caps), however pumps, which are needed to dole out the proper amounts of water to each plant, are not included in traditional drip-kits. This places additional logistical and financial burden on farmers to acquire a pump (Venot, 2016). Therefore in order to be effective, drip-kits would need to include all of the necessary parts including pumps.

Solar Pumps. The CRAVE project highlights solar pumps as a climate smart alternative to diesel, gas, and electric powered pumps to fill this gap (Green Climate Fund, 2017). UNAM also highlights the use of solar power in the agricultural process in their Concept Note for this study (Mupambwa et al., 2020). However, interviews with UNAM faculty and survey data show that solar pumps are not utilized in the region.

There are a number of barriers to utilizing solar pumps for irrigation. First, the photovoltaic (PV) system, pump and water distribution system must be well matched, meaning that all pieces are technologically compatible and that the PV power produced meets the power demand of the pump. (Shinde & Wandre, 2015). Second, PV pumping systems have low pumping yield in comparison to diesel and electric pumps, primarily due to inefficiencies in transferring power from solar panels or battery packs (if used - many solar pumps do not include batteries to make the system simpler and increase ease of use in subsistence farming communities) to pumps; the amount of water uptake is also variable based on the amount of sunlight available, as batteries are not typically used (Shinde & Wandre, 2015). PV pumping systems therefore might not be able to pump enough water to provide water for large scale communal water sources that are shared amongst many farms. And as these pumps work best when there is sunlight around noon, the hottest time of the day, it can be assumed that some farmers will likely be watering their crops while evaporation rates will be the highest; this could result in wasting water, which is predicted to become more scarce under three of the four climate scenarios.

In rare cases, the extreme weather scenario can also pose a threat to water infrastructure. Specifically more intense flooding could damage storage tanks and ponds ponds (McCartney et al., 2013). While unlikely, lightning or other events such as heavy rainstorms, hail or flooding could also damage other infrastructure such as irrigation systems or pumps (Shinde & Wandre, 2015).

3.4. Financial Flows

Overcoming the adaptation challenges for CSA approaches of growing resilient crops and technology implementation requires significant capital. Climate funds have been committed at the international level through Trust Funds (e.g., Special Climate Change Fund, Adaptation Fund) as well as through market-based mechanisms such as the Clean Development Mechanism (CDM). These funds help the government provide programs (e.g., CRAVE project) to increase adaptive capacity. The small fraction of total adaption funds that makes its way to subsistence farmers does so in the form of farmer assistance programs. The section below describes how funding flows from the international level to subsistence farmers.

Multilateral Climate Finance. Since 2001, Namibia has received just over US$625 million in multilateral climate funds. This is just a fraction of the country's estimated US $33 billion needed for mitigation and adaptation ($8 billion for mitigation and $25 billion for adaptation) (Republic of Namibia, 2015). Of the funds received, all come from the financial institutions within the UNFCCC; no funding has been received from Climate Investment Funds (Adaptation Fund, 2019; Global Environment Facility, 2016; Green Climate Fund, 2019). It is believed that the

World Bank's 2009 reclassification of Namibia as an Upper middle income country has hurt the country's ability to receive climate finance (van Rooij et al., 2013) as this reclassification has excluded Namibia from accessing funds from the Least Developed Climate Fund (Global Environment Facility, 2021).

Bilateral Climate Finance. Namibia has received bilateral funding for climate-related efforts from Denmark, the European Commission, Finland, Germany and Sweden. This money has been primarily for energy sector uses but not for subsistence agricultural adaptation efforts (van Rooij et al., 2013).

CRAVE Financing. In total, there are $10 million USD in funds for the CRAVE Project. $9.5 million is provided in grants by GCF and the other $500,000 is co-financed by the MAWF. There is no other co-financing or support from public or private entities.

There is little indication of how the funding flows from GCF to the CRAVE project to the farmers. The funding proposal specifically states that technologies will be initially granted freely to vulnerable farmers. There is however no further explanation of how vulnerable SSF are chosen, which technologies will be funded, or how those technologies will be funded (i.e. loans, grants, etc.). There is also no information in the funding proposal about the CRAVE project's exit strategy although it is specified that there is one (Green Climate Fund, 2017).

Environmental Investment Fund of Namibia. The Environmental Investment Fund of Namibia (EIF) aims to promote sustainable economic development in Namibia through investments in projects that protect the country's natural and environmental resources. The fund also serves as an accredited institution under the Green Climate Fund and is Namibia's implementing agency for compliance for international environmental commitments (Environmental Investment Fund, 2020).

EIF provides grants and loans, as well as sponsors and partners with organizations within Namibia. The grants and loans are available to individuals, the private sector and institutions and civil society. EIF offers two types of grants: seed grants up to N$10,000 ($687 USD) for institutions to invest in sustainable development, and project grants of between N$10,000-500,000 ($687-34,349.50 USD). EIF's Green Concessional Loans are soft lending, with lower than market interest rates, for individuals and companies for environmental enterprising. The loan has an interest rate of up to 4.27%, long repayment periods of up to 10 years and a grace period of up to 12 months (Environmental Investment Fund, 2020).

National Banks. There are two development banks and six commercial banks in Namibia that have the potential ability to provide finance for subsistence farmers. As of 2007, only 9.5% of lending in Namibia is allocated to agriculture, forestry and fishing (Amadhila & Ikhide, 2015). Of these banks, only 3 finance Small and Medium-scale farmers (SMEs): Agribank, First National Bank of Namibia and Bank Windhoek. Here it should be noted that subsistence farmers are sometimes separated out from SSF; here, subsistence farmers are included in SMEs.

The first, Agribank, is mandated to finance agriculture and related activities (Agribank, 2021). Agribank provides loans for everything from aquaculture to vehicles and tractors to brush encroachment; in total they have 17 categories for loans and work directly with two national projects (Agribank, 2021). Only their loans specifically for Green Scheme farmers are subsidized, and loans can only be issued as individual lending rather than group lending.

Because of Agribank's mandate, most farmers do not know that there are other possible avenues for finance. First National Bank, the largest and most expansive commercial bank in Namibia (First National Bank, 2021), will lend to commercial farmers but not subsistence farmers. Bank Windhoek does not provide monetary finance but can directly provide equipment or technology (Amadhila & Ikhide, 2015).

Microfinance. Microfinance is the idea of providing small loans or financial services to the poor so that they can grow their assets, start a business, and decrease their risks (Agrawala & Carraro, 2010). This financing strategy is defined by small loan amounts of less than $50 or $100 USD (Agrawala & Carraro, 2010; Hammill et al., 2008; Moser & Gonzalez, 2016), joint liability, frequent payments and the establishment of savings accounts by recipients (Agrawala & Carraro, 2010). Theoretically small loans with additional support from banks and potential middlemen, such as NGOs, will support the participant who might not have otherwise been able to receive the loan; this will allow the participant to slowly accrue enough assets to receive loans on their own while also decreasing their vulnerability to climate change.

Microfinance can include various types of assets including microcredit, microinsurance and microsavings (Hammill et al., 2008).

Microfinancing has been linked towards social empowerment of low-income communities (Fenton et al., 2015; Moser & Gonzalez, 2016) and women (Agrawala & Carraro, 2010), and reduction of social and physical vulnerabilities (Chirambo, 2017; Fenton et al., 2015; Milana & Ashta, 2020).. It has therefore been touted for its potential to fund climate change adaptation (Chirambo, 2017).

There is little evidence that microfinance is being used for agriculture and climate change adaptation in Namibia. FIDES, a well known microfinance bank, does not work in the realm of agriculture (Amadhila & Ikhide, 2015).

Compensation for Human-Wildlife Conflict. Human-wildlife Conflict (HWC), or interactions between humans and non-human animals that result in negative outcomes for one or both parties either directly or indirectly, is a key issue in northeastern Namibia (Republic of Namibia MEFT, 2018). For farmers, these interactions with megafauna can result in financial loss as a result of destroyed or lost crops (MET, 2018). Wildlife conservancies receive annual funding from the national government to compensate rural farmers for the losses they suffered due to HWC (Table 6.1). These compensation mechanisms are in place both to alleviate the financial burden that HWC has on Namibians, as well as to prevent retaliatory killings that may impact regional conservation goals (MET, 2018).

3.4.1. Financial Barriers

According to the survey, almost all farmers indicated that they require diversifying finances to become more climate resilient, but that there are significant financial barriers to adapting to climate change. Many farmers even indicated that financial challenges are the most difficult barrier to overcome in pursuing climate smart adaptation strategies. These barriers can be categorized as either supply-side or demand-side, in which the barrier stems from the banks or the farmers respectively.

Supply-Side Barriers. According to a study by Amadhila and Ikhide (2015), two common reasons that banks are not willing to fund subsistence farming is because of risk involved with agriculture and lack of institutional experience. In total they found 13 reasons that banks are unwilling to fund subsistence farmers (Figure 3.5).

Other notable barriers are that small scale farmers, especially subsistence farmers, often do not own their own land and share plots; for the banks this means that they do not have enough assets or collateral to qualify for a loan. Many of these farmers also do not have enough money for the large deposit fee (Amadhila & Ikhide, 2015).

The loans available to farmers often have high interest that could be a barrier to farmers obtaining and paying off these loans. As of May 2020, Agribank has loans with interest up to 9% (Agribank, 2021).

The application process for a grant or loan can also be a barrier. The EIF loan application process includes three rounds of assessment: 1) Fund Management Committee, 2) Technical Advisory Panel and 3) Board of Directors (Environmental Investment Fund, 2020). For farmers who are illiterate or do not know the language of the bank, the paperwork and various steps associated with this process could be a barrier for accessing the loan.

Table 3.1: The current amounts of compensation in Namibian dollars through the Human Wildlife Conflict Self Reliance Scheme adapted from the Republic of Namibia's MET. 1 Namibian dollar is the equivalent of 0.67 USD; N$100,000 = $6715.72 USD as of 2021 (MET, 2018).

Human death	
Funeral expenses and related costs	N$ 100,00
Injuries to persons	
Injury with no loss of body part	N$ 10,000
Injury with loss of body part	N$ 30,000
Disability	N$ 50,000
Loss of livestock	
Cattle	N$ 3,000
Goat	N$ 500
Sheep	N$ 700
Horse	N$ 800
Donkey	N$ 500
Pig	N$ 700
Crop damages	
¼ hectare	N$ 250
1 hectare	N$ 1000

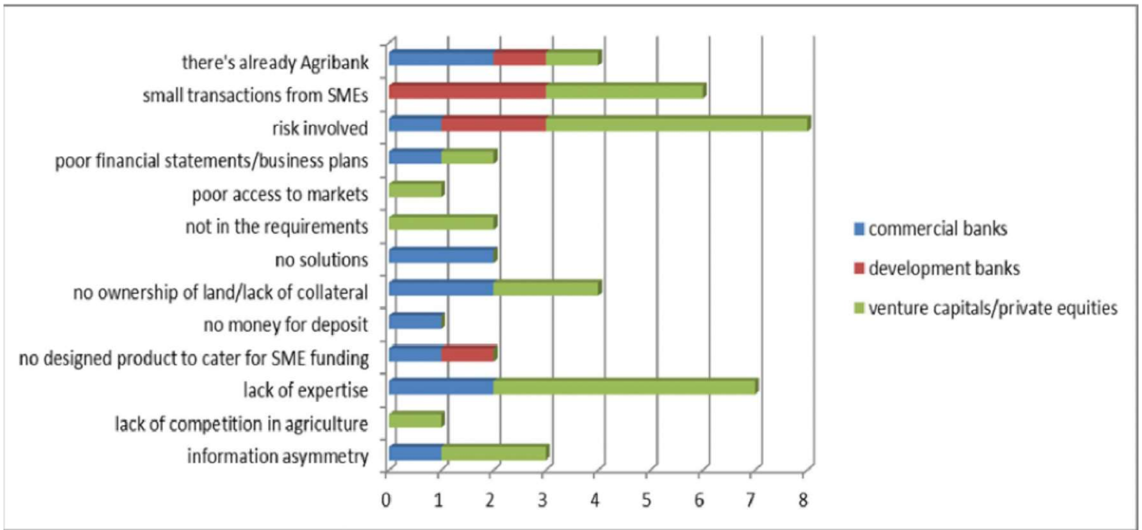


Figure 3.5: Graph showing reasons that banks would not provide loans for small scale farming (Amadhila & Ikhide, 2015).

Similar barriers exist for accessing financial compensation for loss of crop due to HWC. The process can be complicated and requires official documentation that could be inaccessible to farmers who do not read or know the language. The completion of this documentation also typically has a sunset clause for completion that could inhibit farmers from receiving their funds if the paperwork is not completed in time. In particular, this mechanism for receiving compensation has been critiqued as a barrier for women farmers (Khumalo & Yung, 2015).

The CRAVE project specifically includes provisions for providing farmers with technology. However ambiguity surrounding this aspect of the project could prevent farmers from accessing these resources. In particular, the wording is ambiguous in what is considered a technology, who is classified as vulnerable, the time length of 'initial', and the definition of 'freely'. As there is no defined exit strategy, it is unclear if farmers would be required to return the technologies or if they would have to pay the government back for them (Green Climate Fund, 2017). Without further details, this ambiguity could hinder a farmer's ability to utilize this specific feature of the program

Demand-Side Barriers. Many farmers are not familiar with other financial options outside of Agribank (Amadhila & Ikhide, 2015). A lack of transparency or dissemination about other financial institutions keeps farmers from accessing necessary resources to transition technologies.

Proximity to banks and HWC compensation sites can also be a challenge for subsistence farmers, as they are located in urban areas that might be far away from farms. Bank Windhoek only has locations in Windhoek (Bank Windhoek, 2021); Agribank has one branch in Rundu and one in Katima Mulilo (Agribank, 2021).

3.5. Gender-Based Vulnerabilities

Literature has shown that individuals belonging to groups of particular social identities are more vulnerable and therefore less resilient to climate changes within Namibia (Angula, 2012; Khatiwada & Silva, 2014; Khumalo & Yung, 2015). Increased social vulnerability may entail lower financial resilience, fewer opportunities to learn technical skills, or less decision-making power. These results in inequitable adaptation capacity.

While a number of identities can contribute to increased vulnerability (e.g., age, education), this study focuses on gender with the importance of gender disparities emphasized in both expert interviews and existing literature. Examining vulnerability with respect to gender allows for proposed adaptation solutions to address the unique vulnerabilities that female subsistence farmers face.

Financial Resilience. Gender has been shown to be one of the most challenging disparities in climate adaptation. Namibian women consistently have fewer job opportunities, less access to markets to sell products at, and fewer opportunities to own land (Angula, 2010; Khumalo & Yung, 2015). For example, consistent with survey results (Chapter 4), the production of timber and other forest goods, fishing, and trade, are predominantly conducted by men. Access to supplemental revenue sources outside of agriculture increases an individual's or household's resilience, allowing them to rely on other sources of income when agricultural yields are insufficient. These constraints decrease the options for supplemental income that female subsistence farmers have access to, placing them in a more vulnerable position than their male counterparts who have greater financial mobility (Angula, 2010; Angula & Kaundjua, 2016; Khatiwada & Silva, 2014). Having access to greater capital increases the likelihood of qualifying for a loan; these financial constraints lead female farmers to be less likely to obtain external funding than their male counterparts (Khumalo & Yung, 2015). Without these options large investments are not possible for most subsistence farmers, making land-ownership difficult to obtain.

Technical Skills. Even though Namibian women constitute around 75% of the workforce in natural resource sectors, they typically kept in non-technical positions, often working the jobs that do not require knowledge of technologies or machinery (Khumalo & Yung, 2015). This leaves women with fewer marketable job skills for employment purposes and without the experience and knowledge to implement new, adaptive technologies and strategies that require technical knowledge (Angula & Menjono, 2014; Khumalo & Yung, 2015).

Decision-Making. The impacts of climate change greatly affect female farmers' livelihoods, however, persisting gender biases result in a lack of participation by women in key decision-making processes (Angula, 2010; Angula & Kaundjua, 2016). In the context of subsistence agriculture, women are less likely to have financial decision-making capabilities within their own household and are less likely to access information regarding climate change (Angula, 2010; UNDP, 2012; Angula & Menjono, 2014; Khatiwada & Silva, 2014; Khumalo & Yung, 2015). These discrepancies are the result of traditional gender roles, lack of targeted outreach directed towards female farmers, and the additional familial responsibilities that women possess (Khumalo & Yung, 2015; Graham et al., 2016).

Single Women. Single women are particularly vulnerable to climate changes as they have the fewest financial opportunities of all marital status sub-groups (Angula & Menjono, 2014; Khatiwada & Silva, 2014). It is common practice for male farmers, both married and single, to sleep in their fields to protect their crops from wildlife and pests. However, single Namibian women report that this makes them feel unsafe and are less likely to do so, thus exposing their crops to predation, pests, or theft (Khumalo & Yung, 2015). If they do experience crop loss, single women have the lowest amount of available finances to recover from this (Khumalo & Yung, 2015).

3.5.1 Gender-Based Barriers to Climate Adaptation

The barriers facing female farmers in the agricultural sector are classified into three principal categories:

Inequitable Distribution of Resources. Resources such as finances, farming equipment, adaptive seeds, and transportation are not distributed evenly and female farmers, frequently have diminished access to these resources (Angula, 2010; Angula & Menjono, 2014; Khatiwada & Silva, 2014; Khumalo & Yung, 2015). Limited income opportunities also can lead to decreased access to collateral that would allow them to qualify for loans and fewer technical skills (Angula & Menjono, 2014; Khumalo & Yung, 2015).

Lack of Accessible Information and Education. Information and education regarding climate adaptation and climate smart agriculture (e.g., implementation of new strategies, scenario planning) is not always readily available. Women play a key role in agricultural processes, but rarely receive climate adaptation information or training targeted towards the roles that they occupy (Angula & Menjono, 2014; Khumalo & Yung, 2015). Limitations in information and instruction regarding CSA may prevent female farmers from utilizing them, thus increasing their vulnerability to climate impacts.

Lack of Assistance in Climate Adaptation. Female subsistence farmers are generally responsible for collecting water, firewood, and other necessities for their households and are the primary planters as shown in the survey data (Chapter 4; Graham et al., 2016). Working intimately with the natural environment means that women are more impacted by both short-term and long-term climate variance (Angula & Menjono, 2014; Khumalo & Yung, 2015). These impacts may include increased time spent collecting natural resources for their household, changing typical farming schedules based on variation in weather patterns, and increasing their ability to store and manage food supplies (Graham et al., 2016). Lack of assistance in learning, implementing, and maintaining climate smart technologies, as well as acquiring funds to do so, may limit female farmers' ability to implement CSA (Angula 2010; Angula & Menjono, 2014).

Other factors such as a women's traditional familial commitments as well as their concern for their safety as single female farmers, additionally limit the capacity of female subsistence farmers to adapt (Khumalo & Yung, 2015).

Chapter 4: A Survey of Subsistence Farmers in Northeastern Namibia

Subsistence farmers in northeastern Namibia are already experiencing the impacts of climate change. To evaluate the current conditions of subsistence farming, this study implemented a survey to collect data from three administrative regions of Namibia.

4.1. Methods

Survey Development. To assess the barriers faced by subsistence farmers preventing them from implementing climate smart technologies in their farming practices, a survey instrument was developed in collaboration with experts in local data collection, survey development, crop sciences, and environmental studies at the University of Namibia (Appendix A). The survey questions analyzed in this report were selected to address four areas of interest:

- Socioeconomic factors that may influence the ways in which subsistence farmers both perceive and adapt to climate changes in the context of subsistence agriculture
- Barriers identified by subsistence farmers that prevent them from taking adaptive building measures both past and present
- Farmers' perceptions of climate change
- Recommendations for improving resilience and adaptive capacity for subsistence farmers

This subset of data examines the hazards, vulnerabilities, barriers, overall perceptions of climate change, and recommendations for the future of climate adaptation to evaluate the current and future circumstances of climate adaptation in northeastern Namibia.

Study Area and Target Population. The CRAVE project is located in three regions that are particularly vulnerable to extremes in climatic variation. The study area consists of the three northeastern-most administrative regions within Namibia: Kavango West, Kavango East, and Zambezi (Figure 4.1).

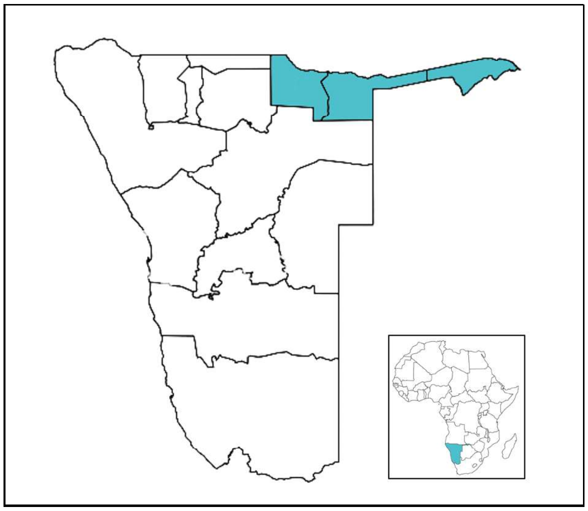


Figure 4.1: Map showing the country of Namibia with administrative regions delineated. The three regions included in the study are indicated in turquoise. Left to right, Kavango West, Kavango East, Zambezi. Inset indicates Namibia's location within the continent of Africa.

Of the 14 administrative regions that constitute Namibia, these regions are unique in their geography and environmental features. Receiving higher average rainfall than the rest of the country, the three study regions are categorized primarily as woodlands and grasslands. These conditions, as well as the presence of several large rivers in the regions, make agriculture particularly viable.

These regions were prioritized for two reasons; first, they are among the poorest in the country, with approximately 60-75% of the population in these regions living below the poverty line line (Green Climate Fund, 2017; National Planning Commission, 2015). Second, many communities in these regions rely on agriculture which is expected to be one of the sectors most impacted by climate change (Green Climate Fund, 2017).

Based on the most recent census data, *Kavango West* has a total population of 107,905 which is ranked 9th out of Namibia's 14 administrative regions. Kavango West covers a total area of 23,166 square kilometers, ranking 11th in size nationally (Namibia Statistics Agency, 2011).With a population of 115,447, *Kavango East* has the highest population (8th nationally) of the three study regions and at 25,576 square kilometers it is also the largest (10th nationally) (Namibia Statistics Agency, 2011). Kavango West and East were a single district (Kavango) until 2013 when the region was divided into two similar sized districts to ease administrative burdens. *Zambezi's* population of 90,596 (10th nationally) and total area of 14,785 square kilometers (12th nationally) make it both the smallest study region and least populated (Namibia Statistics Agency, 2011). In a unique geographical setting, the Zambezi district is famous for its water features including large gorges and canal networks. The Zambezi river, the largest of the regional rivers, now presents a flooding risk to inhabitants of the region (Namibia Statistics Agency, 2011).

Subsistence agriculture makes up approximately 43% of household primary income across Namibia and an average of 51% of household primary income in the study regions (Kavango West = 62%; Kavango East = 51%; Zambezi = 40%) (National Statistics Agency, 2011).

Sampling and Administration. To be accessible to a greater number of subsistence farmers, the survey was conducted in person. Farmers were convenience sampled from the target population of CRAVE farming plots in the three study regions. Upon receiving a statement of informed consent, the survey was administered by faculty, staff, and undergraduate students from the University of Namibia's Department of Crop Science and Integrated Environmental Science over a period of 12 days in February, 2021. Due to COVID-19 safety measures, all surveys were administered outside, maintaining social distancing protocols and wearing face masks.

Survey instruments were developed in English and were translated into local languages (Rukwangali in Kavango East and West, and Silozi in Zambezi) and administered by a researcher fluent in the local language. Responses were translated to English during the survey administration and the English versions were used for analysis.

Data Analysis. Data from the survey was analyzed using The Jamovi Project software, and the ggplot suite in R Studios (*Jamovi*, 2021; RStudio Team, 2020) Prior to analysis, data was cleaned and qualitative responses regarding climate change information sources and adaptation recommendations were coded according to a range of recurring themes. Comparisons were made between social identities, different perceptions of climate change, possible barriers to access climate smart technologies, and a variety of agricultural practices.

Limitations. The survey may have been biased by the researcher's pre-existing biases that marginalization and vulnerabilities were present in northeast Namibia. These could have impacted how farmers interpreted and responded to the questions. Though the

Table 4.1: Summary statistics of sample population (n=205). In several questions, one or more respondents declined to answer, the response was not recorded, or the response was considered 'other' and thus is not represented here.

Study Regions	Kavango West	Kavango East	Zambezi	Total
Number of Repondents				
Total	62	108	35	**205**
Female	42	71	18	**131 (64%)**
Male	20	37	17	**74 (36%)**
HOH Gender				
Female	19	40	10	**69 (34%)**
Male	42	66	25	**133 (66%)**
Education				
Total				
None	7	16	1	**24 (12%)**
Primary	14	28	6	**48 (24%)**
Secondary	32	52	21	**105 (53%)**
Tertiary	6	8	7	**21 (11%)**
Female				
None	5	13	1	**19 (15%)**
Primary	11	22	3	**36 (29%)**
Secondary	21	29	10	**60 (48%)**
Tertiary	4	3	4	**11 (9%)**
Male				
None	2	3	0	**5 (7%)**
Primary	3	6	3	**12 (17%)**
Secondary	11	23	11	**45 (63%)**
Tertiary	2	5	3	**10 (14%)**
Marital Status				
Total				
Single	15	36	5	**56 (27%)**
Married	30	44	24	**98 (48%)**
Widowed	5	10	4	**19 (9%)**
Cohabitating	11	16	1	**28 (14%)**
Divorced	1	1	1	**3 (1%)**
Female				
Single	11	28	3	**42 (32%)**
Married	18	23	10	**51 (39%)**
Widowed	5	10	4	**19 (15%)**
Cohabitating	7	8	0	**15 (12%)**
Divorced	1	1	1	**3 (2%)**
Male				
Single	4	8	2	**14 (19%)**
Married	12	21	14	**47 (64%)**
Widowed	0	0	0	**0 (0%)**
Cohabitating	4	8	1	**13 (18%)**
Divorced	0	0	0	**0 (0%)**

sample population was evenly distributed across the three study regions, these 205 respondents may not be representative of all subsistence farmers across Kavango West, Kavango East, and Zambezi. The respondents of the survey had a gender bias, with more women than men participating, which could have impacted the findings and interpretations of the data.

4.2. Results

Respondents. 205 subsistence farmers responded to the survey. Respondents were distributed relatively evenly per capita across the three study regions (Kavango West = 62; Kavango East = 108; Zambezi = 35). 131 (64%) of the respondents were female and 74 (36%) were male. Ages between 18 and 80 were represented in the sample (Table 4.1).

Crops. Respondents grew 35 different crops including the three staple crops and 32 horticulture crops. Of the three staple crops described in Chapter 3, maize and pearl millet were the two most commonly grown crops in the study population. However, the third staple crop, sorghum, was the seventh most grown crop (Figure 4.2). As sorghum is the most climate resilient staple crop, this may be an important point when considering crop selection as a CSA approach.

Awareness of Climate Changes. Respondents were asked to report the changes in climate events that they are already observing. The most commonly reported climate change impact was changes in rainfall patterns with 89% of respondents indicating that they have observed differences in rainfall frequency, intensity, or seasonality, followed by 58% for drought, 49% for temperature changes, and 47% for flooding (Figure 4.3).

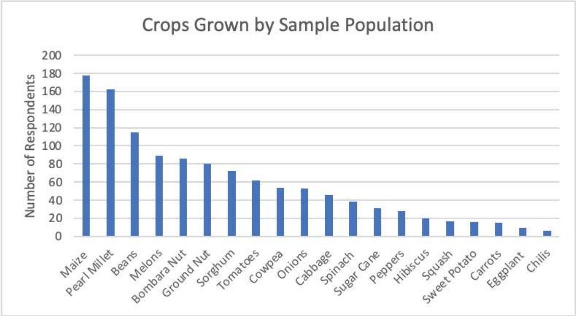


Figure 4.2: Crops grown by survey respondents (maize 86.2%, pearl millet 79.0%, sorghum 35.1%). Less than 1.5% of respondents reported growing beetroot, guava, mango, lemon, garlic, cucumber, grapes, oranges, okra, lettuce, kale, broccoli, cauliflower, zucchini, sweet corn, respectively.

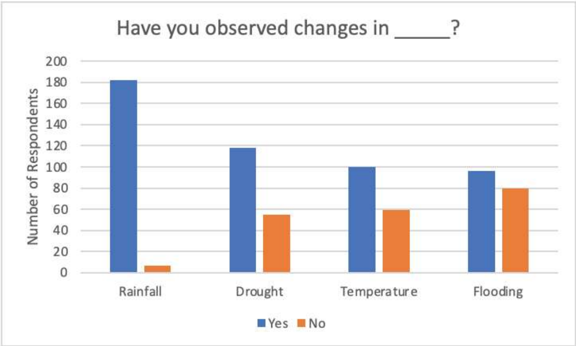


Figure 4.3: Respondents observation of changes in rainfall, drought, temperature, and flooding.

Of the observed changes in climate features, 70% were reported as having negative impacts on the respondent and their farm. Observations of climatic changes assist farmers in visualizing the impacts of climate change as well as understanding the need for adaptation. The majority of respondents are observing changes in rainfall, which may indicate a population that is both aware of and willing to prepare for the impacts of variable rainfall (e.g., implementing new irrigation techniques, increasing water storage). However, less frequently observed impacts such as flooding may be perceived as less important in climate preparation and may not be prioritized when planning for the future.

Current Adaptations. 42% of respondents reported that they had already or are currently implementing changes in their farming practices in order to adapt to climate change. The most common current adaptations are changing their planting schedule, differentiating livelihood (seeking out other economic opportunities, such as small businesses, part-time work), and utilizing new approaches or technologies in their farming (Figure 4.4).

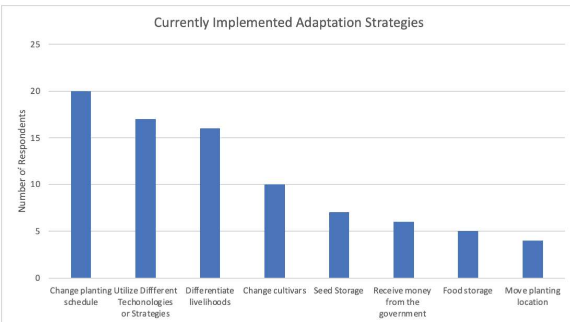


Figure 4.4: Adaptation measures that respondents are currently using to adapt to climate change

This information can be used to identify areas where CSA can bolster the adaptive practices that are already in practice and key areas where low-cost options are being underutilized. Farmers are already implementing changes in their planting schedule in response to the variances in the wet season. Education on CSA planting practices could increase the efficacy of this strategy. Conversely, adaptive food storage strategies are relatively underutilized. Since storage techniques allow surplus foodstuffs to last longer, this presents an area where simple, low-cost interventions could be particularly effective. Additionally, the most reported adaptation measures are also consistent with the most commonly observed climate change impacts as altering planting schedule is a response to inconsistent rain patterns that mark when planting should occur.

Perceived Barriers to Adaptation. Across the sample population, financial constraints were perceived to be the biggest challenge to climate adaptation, more so than constraints relating to time, awareness, difficulty of implementation, and cultural norms. 64% of climate adaptation, more so than constraints relating to time, awareness, difficulty of implementation, and cultural norms. 64% of respondents listed it as extremely challenging with an additional 6% listing it as very challenging, and only 2% of respondents listed it as slightly challenging (Figure 4.6). No significant differences were found between groups based on gender, gender of HOH, marital status, age, level of education, and number of household members and their reported level of challenges with each constraint. This is consistent with the recommendations that respondents provided to address these barriers. The most common response was to increase financial support of subsistence farmers, followed by increased farmer training, and increased access to tools and technologies (Figure 4.5).

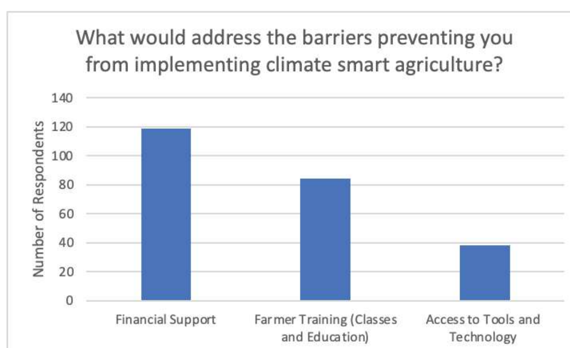


Figure 4.5: The three strategies that were most commonly recommended by respondents to address the various constraints they face in implementing climate adaptive farming practices on their farms.

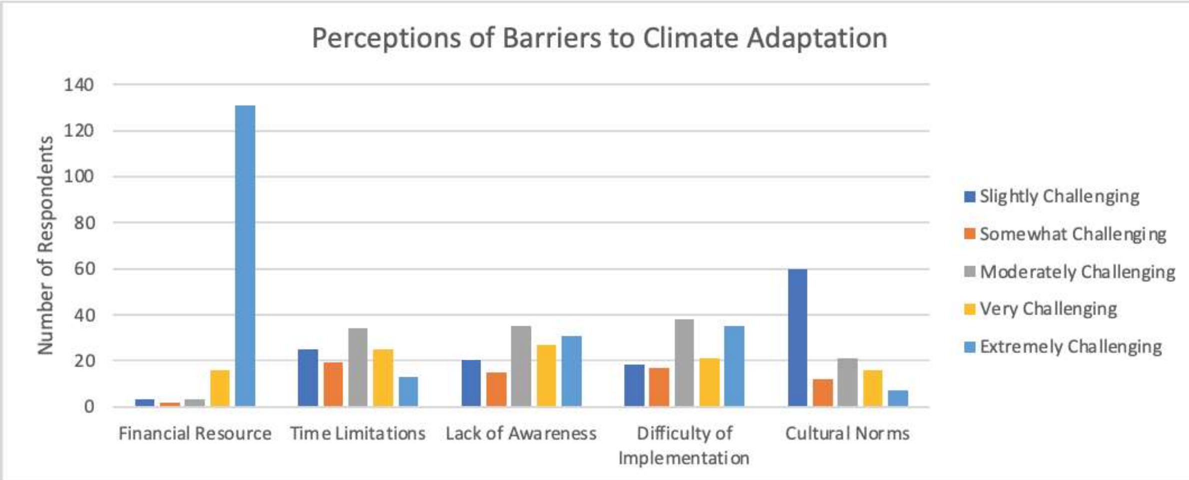


Figure 4.6: Severity of the financial constraints reported by sample populations (1 = slightly challenging; 2 = somewhat challenging; 3 = moderately challenging; 4 = very challenging; 5 = extremely challenging)

These responses are useful in identifying where CSA interventions might be most useful to farmers. Financial constraints are the most detrimental to farmers' adaptive capacities. Increasing financial support to address these challenges would alleviate many of the barriers that subsistence farmers face. Recommendations for farmer training activities and improved access to tools and technologies indicate additional gaps in adaptive capacity building and therefore two potential areas for the implementation of CSA and other capacity building interventions. potential areas for the implementation of CSA and other capacity building interventions.

Gender disparities. While men and women reported similar perceptions of climate change and adaptation, differences were found in their division of labor (Figure 4.7) and decision-making (Figure 4.8).

*Divisions of labor*are observed between the farm activities that men and women participate in. Men are primarily responsible for milking and feeding livestock, slaughtering, spraying pesticide, farm repairs, and fishing while women are the primary responsible for planting, and selling goods. Both men and women are charged with overseeing land preparation, weeding, bird scaring, and harvesting (Figure 4.7).

Women are the primary group responsible for the planting process which is the first step in the growing season, setting the schedule for the rest of the year. Altering when planting takes place is a commonly implemented climate adaptation technique and it is likely to be further utilized as climate conditions become more variable (Figure 4.3). Differentiated areas of labor on the farm allow targeted interventions at specific points in the agricultural calendar. Since women are primarily handling planting duties, providing information directly to them about altering planting schedules and growing resilient crops as adaptation measures could be helpful.

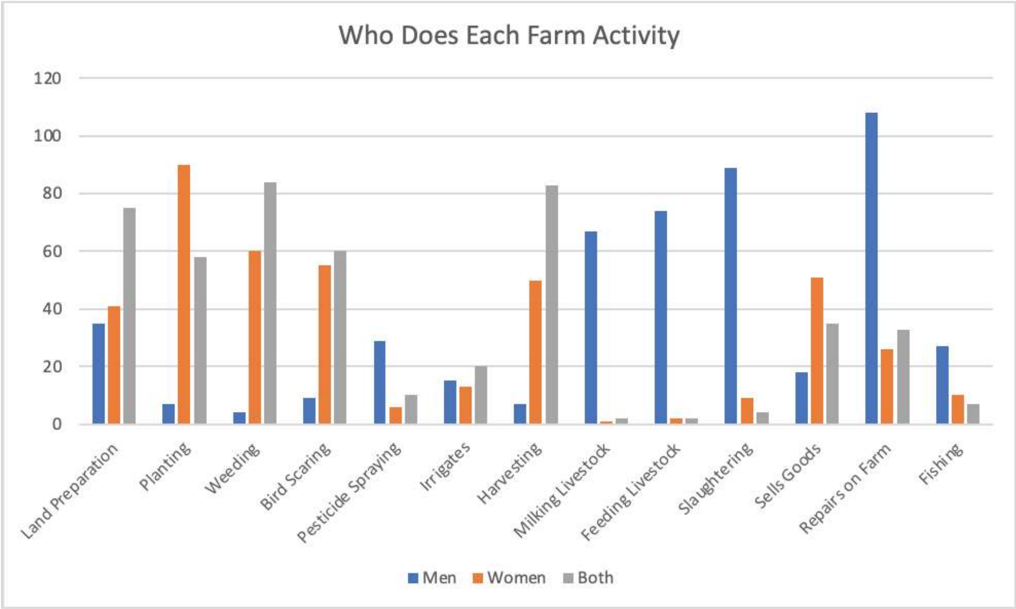


Figure 4.7: The distribution of farm activities between men, women, and both

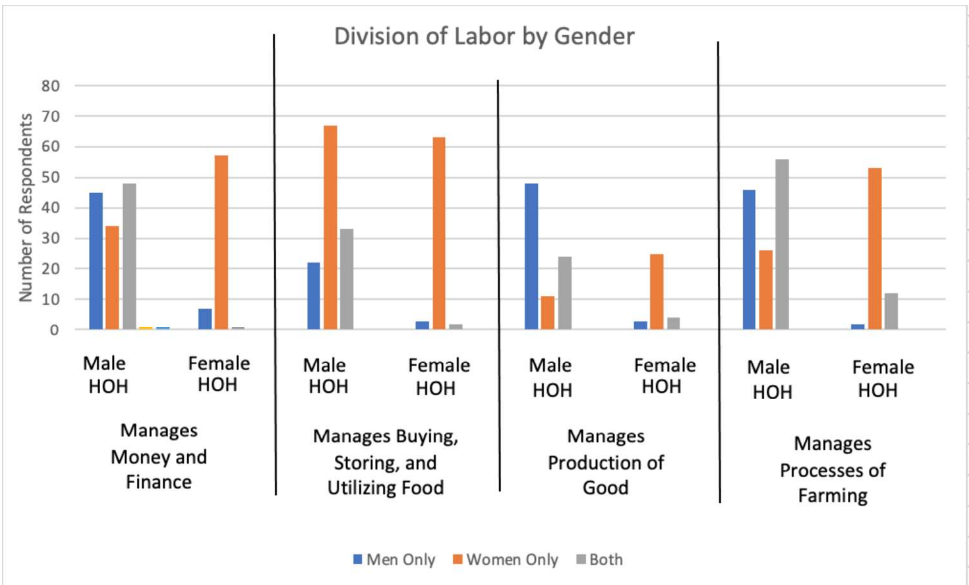


Figure 4.8: Indication of who possesses the primary decision-making power in four categories distinguished by the households with male HOHs and female HOHs. Information on HOH

Decision-making is the responsibility of the head of household. However, in male-headed households, women still make the decisions about managing, buying, storing, and utilizing food. Because of this, information about climate resilient food storage practices may be best directed towards women.

Information Sources. Respondents reported receiving information about climate change and farming practices from 15 different sources (Figure 4.9). These sources disseminate information about weather, farming techniques, and technologies. Radio was shown to be the most commonly utilized information source (70% of total respondents) followed by government ministries (57%), and traditional knowledge (55%). This indicates the informational sources that could be used to disseminate information regarding adaptive agricultural processes, climate hazards, and resources available to subsistence farmers. There were no differences between demographic groups in terms of where they sourced information.

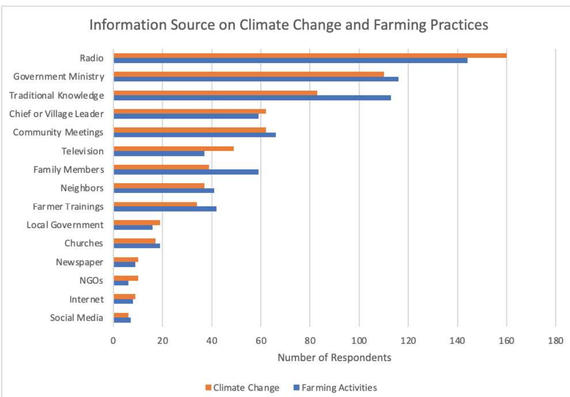


Figure 4.9: Identifies the sources subsistence farmers use to acquire information about farming practices by HOH gender.

Perceptions of Climate Change. The majority of respondents reported that climate change affects all people in the same region equally, regardless of the identities that they may hold (Figure 4.10). While the literature suggests that climate has differential impacts based on gender, this information offers insights into the relationships between subsistence farmers and their relationship to the environment. Farmers expressed a general sentiment that climate change does not discriminate in terms of who it impacts. In other words, respondents feel that climate change will impact everyone in their community equally. There is, however, a slight awareness that income disparities may lead to differentiated climate impacts. Perceptions of equally shared impacts may facilitate community-level resilience.

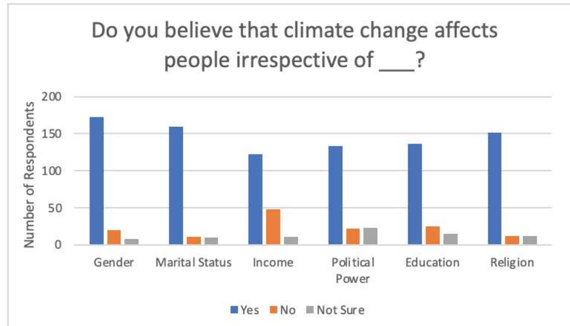


Figure 4.10: Perceptions of how climate change impacts farmers based on their different social identities.

Subsistence farmers reported on approaches to overcome inequities including resource distribution, education access, and financial support (Figure 4.11). The two most commonly reported approaches to address inequities were to increase access to seeds, technology, services, and benefits as well as to increase farmer training. This suggests a need for farmer trainings with more advanced information about resilient agricultural approaches.

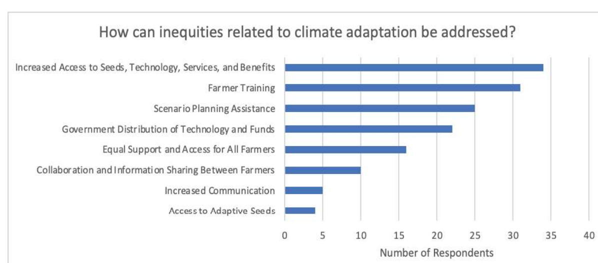


Figure 4.11: Recommendations identified by farmers regarding inequalities related to climate adaptation.

Future Adaptations. When presented with different approaches to climate adaptation, the majority of respondents reported that the proposed approaches would be helpful (Figure 4.12). However, when asked about their awareness of adaptation programs, respondents showed only moderate levels of awareness of existing programs (Figure 4.13). Only 31% of respondents were aware of climate change programs and 42% were aware of direct farmer assistance programs.

These findings once again point to the need for extension workers and farmer training centers to increase knowledge sharing on climate adaptation and to better design the resources for the needs of subsistence farmers.

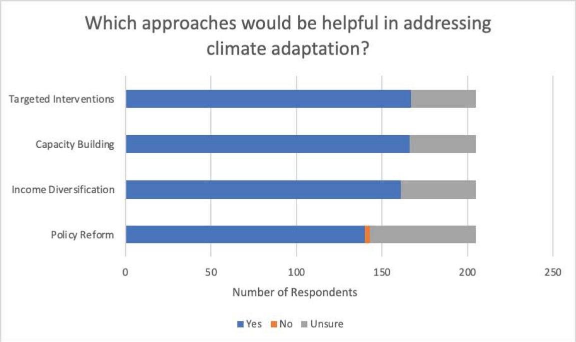


Figure 4.12: Amount of respondents whole believe that each proposed climate adaptation strategy will be helpful for addressing climate change and its impacts on subsistence farmers.

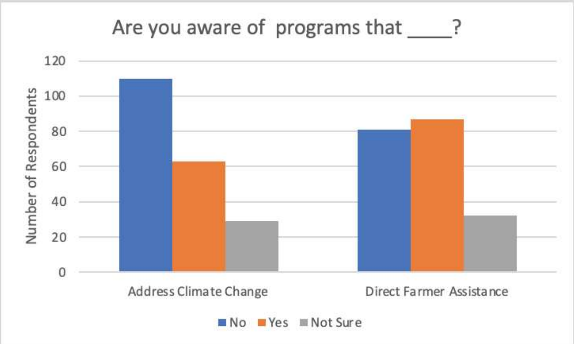


Figure 4.13: Awareness of programs that address climate change and provide direct assistance to help farmers receive equal access to resources needed to adapt.

4.3. Discussion

Survey results indicate that there are opportunities to adopt and improve climate resilient approaches for subsistence agriculture in northeastern Namibia. However, farmers face high levels of financial constraints that inhibit capacity building and increase vulnerability. In the future, targeted adaptation strategies may prove viable.

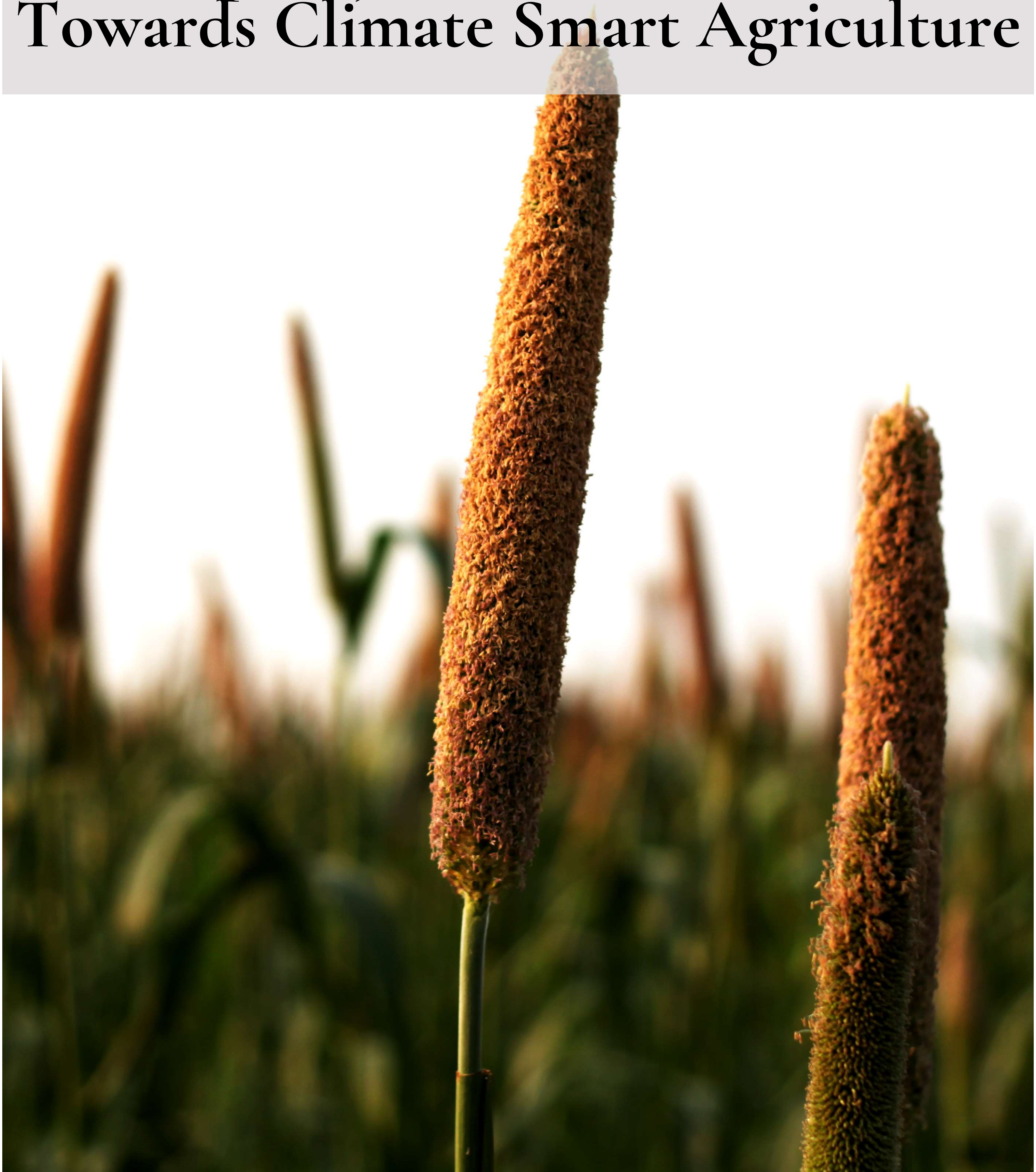
Financial Barriers. Farmers have a clear understanding of the financial barriers they face regarding climate adaptations as well as the need to address those barriers in order to implement adaptive practices. Financial resources or those that indirectly decrease financial difficulties are required to further climate adaptation in the region.

Information Sources. Future work in farmer education and information dissemination could be better addressed to the most relevant sub-groups of subsistence farmers. Gendered divisions of labor and decision-making processes may prompt targeted messaging regarding climate adaptation, while employing the most commonly utilized information sources would allow for training centers, extension workers, government ministries, or researchers to share relevant information with subsistence farmers.

Community-Led CSA. Improved food storage, growing more resilient crops, and efficient irrigation strategies all present opportunities to improve the resilience of subsistence farmers in the study region. Farmers also demonstrate a high willingness to adapt, with 97% of respondents reporting that would be willing to implement new technologies or practices if the barriers preventing them from doing so were alleviated.

In the subsistence farming community, there is widespread awareness of climate change impacts, high interest in better farmer training resources, and a willingness to adapt if provided the necessary resources. The consensus on these issues suggests community-level support for climate smart approaches as raises the possibility that community-led efforts may be an effective approach to adopting CSA.

Chapter 5: Recommendations Towards Climate Smart Agriculture



This study assessed how the climate hazards and vulnerabilities that affect subsistence farmers lead to an increased risk caused by climate change. The climate resilience of subsistence farmers can be improved by planning for multiple climate scenarios, building adaptive capacity, and implementing climate smart agriculture.

Recommendations were developed to address the barriers for helping subsistence farmers become more resilient. The recommendations are divided into three categories: Preparing for Climate Change, Implementing Climate Smart Agriculture, and Addressing Financial Barriers.

Target audiences were identified for each recommendation. Potential audiences range from international to local stakeholders. On the international scale are multi and bi-lateral organizations. The national level includes the Namibian government and financial entities like the Environmental Investment Fund of Namibia. Regional efforts are carried out by the CRAVE project and Extension Workers who work directly with subsistence farmers. Finally, research institutions within Namibia, such as UNAM, can study future climate conditions and resilience, possibly in collaboration with research institutions across the world.

5.1. Preparing for Climate Change

This set of recommendations offers suggestions to help prepare subsistence farmers for impending climate hazards.

1. Plan for all potential climate scenarios

Audience: Extension Workers, Farmers

Northeastern Namibia is at the intersection of numerous climate features leading to high climate variability. The region has experienced frequent opposing climate conditions (warm/dry and warm/wet) and extreme weather events (drought and flooding), and these variable weather events will increase in frequency and strength in the future due to climate change. All scenarios should therefore receive equal consideration when developing adaptation strategies and policies.

Planning for only one scenario could reduce adaptive capacity and potentially increase farmers' risk to climate change. For example, if drip irrigation is utilized in preparation for a drought and then a flood occurs, drip pipes could be washed away.

Planning is a thought process but it need not require allocation of financial or technical resources, which may be limited. For farmers, this planning could be considered in all parts of the farming process from preparing soils for planting all the way through harvesting. The Climate Scenario Planning Toolkit (Appendix B) could be used to help farmers engage in this planning process.

As the climate continues to change, iteratively updating plans is necessary to continuously improve adaptive capacity. This also necessitates increased monitoring of climate features, which is described below.

2. Increase monitoring of climate features and early warning systems

Audience: Namibian Government

As climate projections are continuously changing due to variability of climate features and uncertainties in modeling, it is important to continuously monitor climate conditions and features.

The government could continue to monitor current conditions in order to better understand and predict short-term weather conditions, long-term climate-patterns, and alignment with scenarios. Monitoring alignment with scenarios enables adapting of climate smart strategies with the changing climate. To best understand future climate scenarios, monitoring should not be limited to northeastern Namibia, but could include global and continental climate features that can impact the region such as the ITCZ or the Southeast African Monsoon system. This monitoring could utilize indigenous knowledge, and tools such as satellite data, geographic information systems (GIS), and remote sensing.

A number of early warning systems exist such as the Famine Early Warning Systems Network (FEWS NET) and the Monitoring for Environment Security in Africa (MESA), but they do not cover the full range of climate hazards (Nakanyete et al., 2020).

As this monitoring is targeted for government stakeholders with access to technical monitoring equipment, this process must also include knowledge sharing processes that are accessible to subsistence farmers. For example, early warning systems can utilize wireless emergency alerts through mobile phones and the radio to forecast and provide warnings of severe weather (FEMA, 2020). Farmers can use this information to implement climate smart strategies in preparation for climate hazards and scenarios.

5.2. Implementing Climate Smart Agriculture

These recommendations suggest ways to aid the implementation of climate smart strategies, such as growing resilient crops, improving irrigation, and researching novel adaptation approaches.

3. Facilitate the adoption of resilient crops

Audience: Namibian Government, Local Governments, and CRAVE Project

Helping farmers grow resilient crops could help them maintain their livelihoods under challenging climate scenarios.

First, the Government and CRAVE Project, two common seed sources, could provide farmers with seeds for adaptive crops. These seeds could either be for crops that are genetically modified to be more climate resilient or crops that are more likely to grow under various climate scenarios, such as Mahangu which does well under dry conditions.

Second, educational opportunities could be provided to help farmers increase their knowledge of climate resilient crops and overcome local inertia to grow new crops. Farmer trainings could utilize the Climate Scenario Planning Toolkit to help farmers explore which kinds of crops may grow better under each scenario. These trainings could take place in seed distribution centers so that the farmers have immediate access to both the seeds and the information needed to utilize them.

4. Improving on currently used technologies

Audience: National Government, Local Government, Extension Workers, Farmers

The CRAVE project emphasizes adaptive solutions such as drip irrigation and solar pumps. While these technologies could be effective tools for adaptation, they are infrequently used because they are not easily implemented by subsistence farmers due to high cost, maintenance, and availability.

Instead, it may be beneficial to implement climate smart solutions that improve on systems that farmers already have in place. One climate smart solution is to cover water storage vessels, especially tanks and other small scale storage containers. Water storage is vital under the three warm dry scenarios, however under these scenarios, it will be difficult for farmers to fill their storage tanks. Evaporation could also further deplete already limited water supply. Placing a simple covering, such as a lid or a tarp, over these containers could help to prevent evaporation and water loss.

This recommendation applies to many levels of stakeholders. The Namibian government could either provide capital for farmers to purchase storage lids or provide them direct access. For the latter, the CRAVE project could provide coverings in their technology assistance program. Extension workers and farmers could physically cover water storage containers using tarps, which may be readily available.

5. Foster Farmer Collaboration Networks

Audience: Extension Workers, Farmers

There is a heavy reliance on governmental organizations and programs such as CRAVE to support subsistence farmers. However, there are many circumstances in which government may not be able to provide the necessary support.

Traditional knowledge networks have helped many generations of farmers share useful agricultural practices. Extension workers could help strengthen existing farmer networks and utilize it to disseminate information. Farmers could then share information amongst themselves on seed varieties, farm equipment, instructional manuals, transportation, and funding programs that could help them adopt climate smart agricultural practices.

The reduced reliance on the government for such information would help farming communities communally weather climate change impacts.

6. Expand research on climate smart agriculture for subsistence farming communities

Audience: The University of Namibia

Although technologies like drip irrigation are not necessarily viable for use at the moment due to the significant challenges for implementation, these technologies may still be useful climate smart tools in the future. UNAM could therefore continue to pursue their research goals (Table 5.1) to develop novel technologies that increase farmer resilience.

UNAM could also research the viability of collecting water runoff as an additional water source in the future. As water becomes increasingly scarce under three of the four climate scenarios, additional water sources will be necessary. While there is little evidence that surface runoff is being collected in subsistence farming communities in northeastern Namibia, techniques for collecting surface runoff exist around the world and could be considered for this region (Molden et al., 2007; Qadir, 2003). This research could also study how runoff water salinity impacts local plants and irrigation strategies.

Table 5.1: Technologies and their corresponding climate-smart strategy for additional research at UNAM (Mupambwa).

Technology	**Targeted Vulnerability**
Planter and weeder	Conservation agriculture
Grain thresher/cleaner	Food security
Hydroponics	Water conservation
Drip irrigation	Water conservation
Bird scaring	Reduce crop losses
Biogas	Renewable energy
Mushroom production	Food security

UNAM has been engaged in research on climate smart agriculture, but could be aided through collaboration with the national government, the CRAVE project, farmers, and international research institutions.

5.3. Addressing Financial Barriers

As northeastern Namibian farmers identified lack of financial resources as a major constraint, these recommendations span international, national, and local financing options that may provide farmers with access to much-needed capital.

7. Focus Namibia's NDC on Climate Smart Agriculture

Audience: International Organizations and Government of Namibia

Namibia voluntarily submitted an Intended Nationally Determined Contribution (INDC; Republic of Namibia, 2015) but has yet to submit a revised NDC. Their INDC indicates that the country needs financial assistance to meet both its mitigation and adaptation needs, with two-thirds of requested funds intended for adaptation. Requested funding is intended, in part, to improve the coordination between different adaptation assistance programs that sometimes independently work to disseminate hazard and adaptation information, develop institutional capacity at local levels, and plan for the future climate change.

While funding is also requested to implement climate smart agriculture, little detail is provided as to how it would be used. Providing greater detail in an updated NDC could help fund climate smart agriculture projects. Details that could be provided include a list of specific climate smart technologies that are needed (e.g., irrigation systems) and agricultural challenges facing regions with different climate scenarios. Making these details explicit in the NDC could help Namibia receive multilateral and bilateral funding specifically for climate change adaptation.

8. Conduct research on new financial mechanisms for CSA

Audience: UNAM

Market-based mechanisms, such as CDM and Carbon Africa, incentivize developed nations to support climate adaptation in developing nations. This could have the potential to be scaled down for use in subsistence farming communities but additional research is needed to develop such a mechanism.

Payments for Ecosystem Services (PES), a system in which farmers are paid to utilize CSA strategies, is a market-based mechanism that has been used in subsistence farming communities in South America, Asia, and other parts of Africa (Deng et al., 2016; Wang et al., 2017).

PES not only helps farmers get capital, but also helps them reap environmental benefits. For example, in soil restoration programs, using cover crops can strengthen the soil, improve water flow, and increase crop yield.

Therefore, PES could be an effective tool for improving the sustainability of the Namibian ecosystem and subsistence agriculture while improving the current livelihoods of Namibian farmers. (Börner et al., 2017; Grima et al., 2016; Narloch et al., 2017; Wells et al., 2017).

UNAM could work with the government to study PES viability as part of their study on market-based financial mechanisms for subsistence farming.

Research could also be conducted on the viability of microfinance. Currently, microfinance is not used to support subsistence farmers in Namibia yet may provide them with much needed capital. In microfinance approach, banks provide tiny loans to farmers for whom small amounts of capital go a long way. These loans also reduce risk for banks because loan amounts are small.

One of the challenges with microfinance is that farmers often do not have the collateral necessary to get a loan. Thus, research on microfinance approaches could identify potential 3rd parties that might provide farmers with the necessary collateral.

Developing viable microfinance schemes that require less or no collateral could also be an area of research.

9. Provide assistance to farmers applying for financial resources

Audience: Regional Government, Extension Workers, Financial Institutions

Farmers need capital in order to implement CSA. Barriers to getting capital are well established, but may be overcome using some practical approaches.

Applying for loans or crop loss compensation is a complex process. Farmers may find it difficult to navigate the timelines, language, and literacy issues. To address this, banks or government institutions could improve translation services across the many languages spoken in Namibia. They could also provide individual assistance to illiterate farmers who are trying to complete an application. Transportation could also be provided to help farmers get to the bank.

To simplify the crop loss compensation, the window for reporting Human Wildlife Conflicts incidents could be extended. This might help farmers deal with paperwork during busy agricultural periods.

The government and CRAVE project could also provide educational resources to help farmers learn about the various financial mechanisms at their disposal. As part of farmer trainings, information could be shared on existing financial opportunities, qualification requirements, and application processes. Trainings could go further by having extension workers directly assist farmers in completing loan and program applications.

5.4. Towards Climate Smart Agriculture

Subsistence farmers in northeastern Namibia are susceptible to the future impacts of climate change. This study assessed some of the barriers that prevent subsistence farmers from adapting their agricultural practices.

Planning for different climate scenarios provides one path to more resilient practices. Because a range of future climate scenarios are possible, each must be considered. This is an uncommon approach in climate planning but offers a way to hedge against the uncertainties associated with climate predictions.

Namibian subsistence farmers are motivated to plan for their futures. They are aware of the risks climate change presents to their livelihoods. Their current agricultural practices are partially based on knowledge passed down through generations of farmers. Climate smart agriculture may need to both build on and deviate from culturally ingrained practices.

When planning for the future, farmers often rely on agricultural approaches that have not been designed or implemented with them in mind. Resilient agricultural approaches that incorporate farmer needs may ultimately be more successful. Predicting this with certainty is not possible, but it has been the underlying assumption driving this study namely that, with the right resources, subsistence farmers can indeed become more climate resilient.

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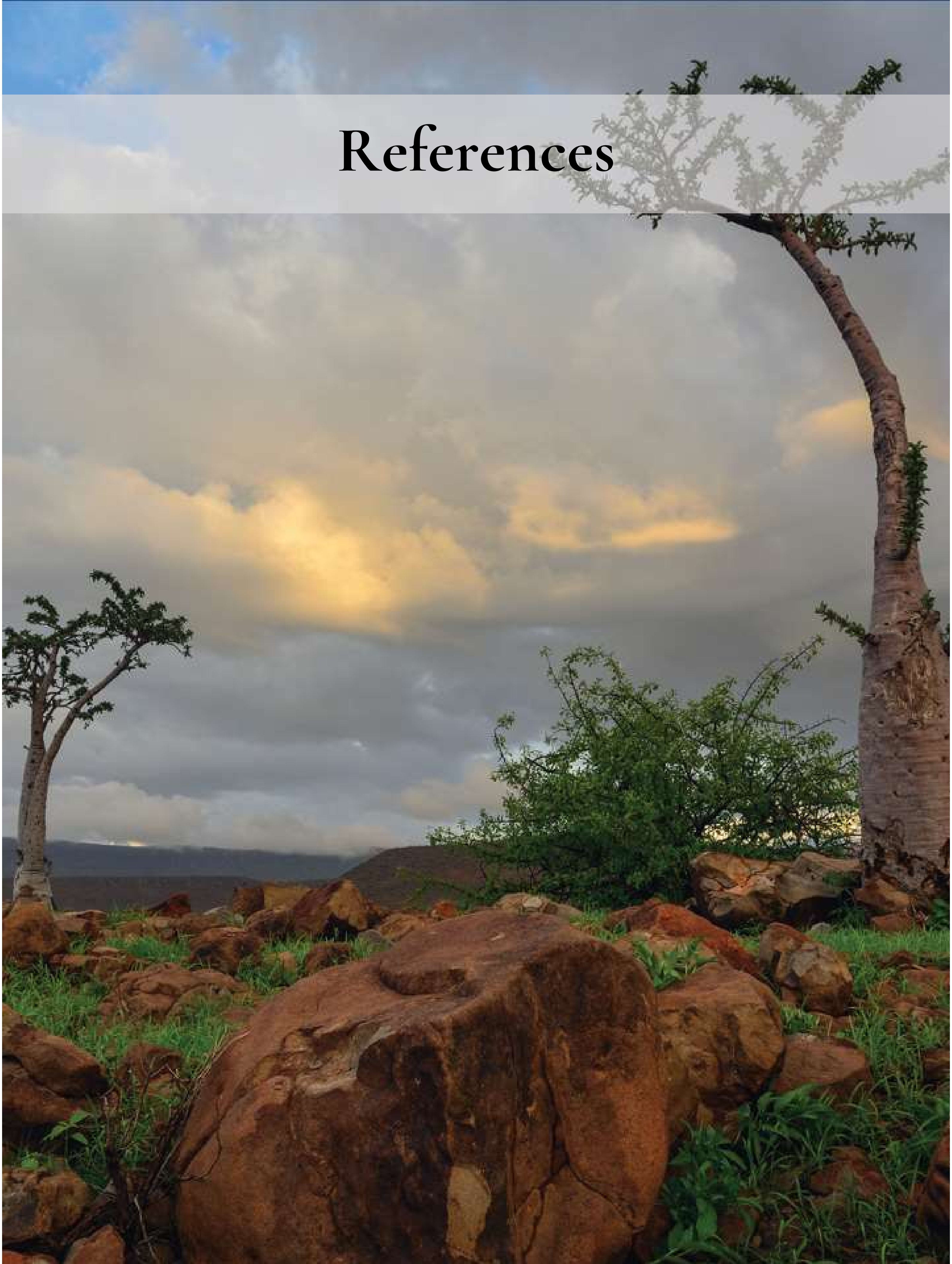

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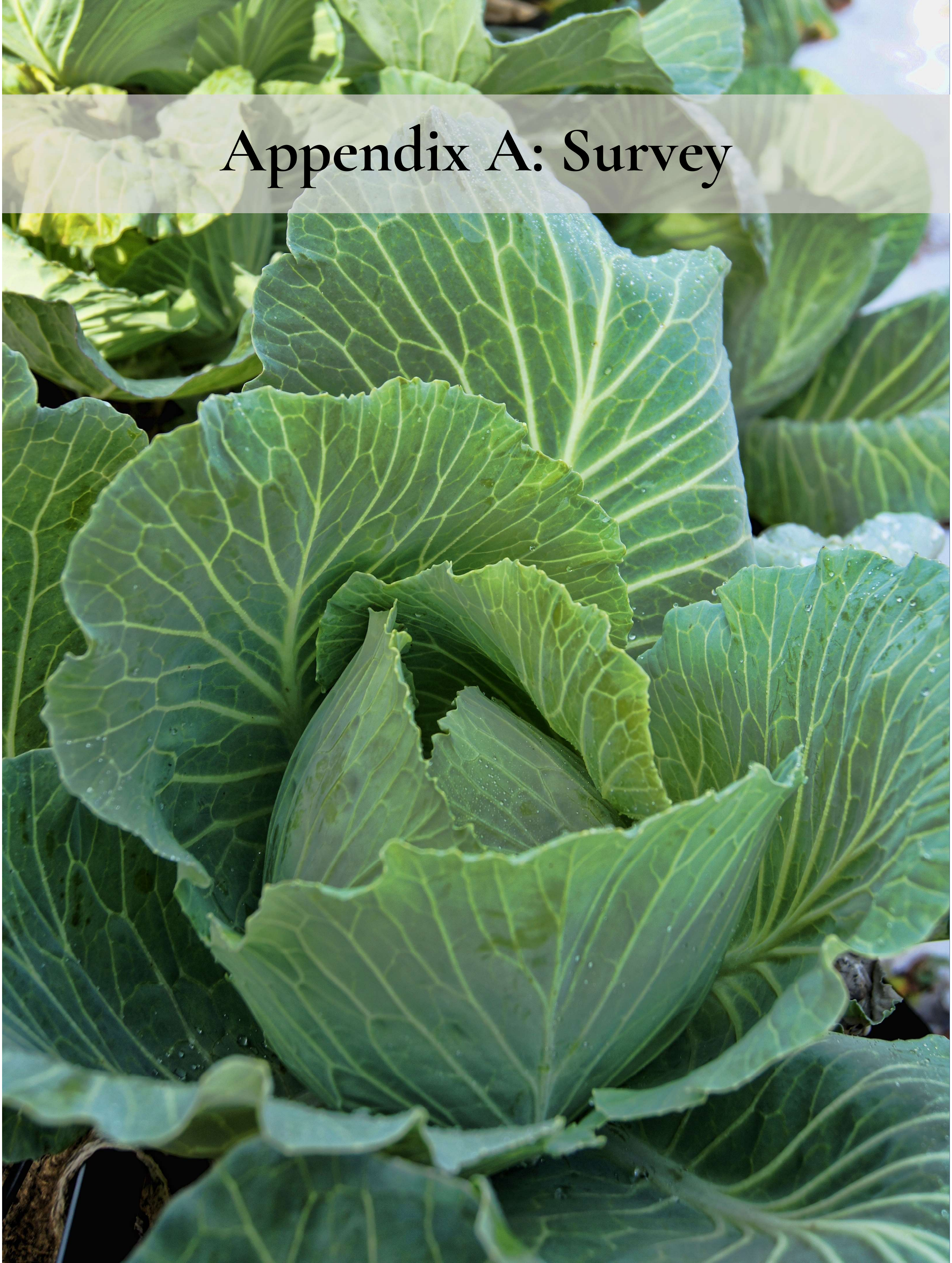
Appendix A: Survey



	(Please print below)
QUESTIONNAIRE NUMBER	

University of Namibia
Departments of Crop Science and Integrated Environmental Science
Ogongo Campus

Questionnaire

This questionnaire intends to collect information needed to implement the following research sub-themes under CRAVE project:

1. Effects of climate change on human well-being of vulnerable and marginalized communities in Northeastern Namibia
2. Identifying and demonstrating locally adaptable climate smart technologies effective in improving the adaptability of local communities in the face of climate change in Namibia
3. Strengthening sustainable land management and suitable land use practices in Northeastern Namibia
4. Effect of four tillage systems, intercrop, organic and inorganic fertilizer treatments on productivity of the various intercropped crops under conservation agriculture in Kavango and Zambezi regions

Introduction

This is a request for you to participate in this survey. The purpose of the survey is to determine farmers' perceptions on the 1) "effects of climate on human well-being of vulnerable and marginalized communities, 2) identify locally adaptable smart technologies and sustainable land management and use practices, 3) Identify sustainable land management and suitable land use practices 4. Identify conservation agriculture, organic and inorganic fertilizer practices in Kavango and Zambezi regions". The survey will be conducted by University of Namibia in collaboration with CRAVE project. It will take about 1 hour to complete the questionnaire.

Statement of Informed Consent:

1. This survey is part of a study to be conducted by the University of Namibia and the University of Michigan in partnership with the United Nations Framework Convention on Climate Change (UNFCCC), the Global Water Partnership (GWP) and the Climate Resilient Agriculture in three of the Vulnerable Extreme northern crop-growing regions (CRAVE) Project. It has been approved by the University of Namibia Centre for Research and Publication.
2. This survey will ask questions approved by the International Review Board relating to your personal demographic information, several examples of technologies and strategies, challenges to adapting these technologies or implementing the strategies, and risks and hazards associated with climate adaptation.
3. Your participation is free and voluntary, and you may withdraw at any time. If you choose to withdraw your response will not be recorded.
4. The information provided will be kept confidential and anonymous.
5. There is no risk involved in taking part in this survey.
6. The data collected may be reviewed by the ethical committee.
7. No incentives or personal benefit will be obtained from your involvement.
8. The survey results may assist in addressing disproportionate impacts of climate change on human-well beings of marginalized and vulnerable farmers to inform future policy interventions.

Please sign this consent form if you have agreed to participate in this survey, a copy will be provided

Signature: ____

Date: ________________________

	(Please print below)
QUESTIONNAIRE NUMBER	

PRELIMINARY SECTION

	TEST ITEMS	RESPONSES	TEST ITEMS	RESPONSES
P.1	Interview date **(dd/mm/yyyy)**		P.7 GPS Coord	
P.2	Interview start time (*24hr*)		P.8 Type of farm holding	
P.3	Name of the interviewer			
P.4	Name of the Village			
P.5	Name of the constituency			
P.6	Name of the region			

SECTION A: SOCIO-DEMOGRAPHIC INFORMATION

Please complete the following questions by ticking the appropriate box.

A1.Age (tick appropritely)	18-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81+
A2. Gender	M		F		other								
A3. Tribe/ethnicity													
A4. Marital status	Single												
	Married												
	Widowed												
	Cohabiting												
	Divorced												
A5. Gender of household head	M		F		other								
A6. Highest education (HH)	None		Pry		Sec		Ter						
A7. Household size					*(Total number of people staying in the house)*								

A8. Does the head of the household have any disability or condition that is likely to hinder his/her full participation in the daily agricultural activities? Yes ☐ No ☐

A9. If your answer to A8 is yes, what disabilities does the head of household have?			
Hearing impairment	☐	Speech impairment	☐
Learning disability	☐	Visual impairment	☐
Mobility impairment	☐	Other (Please specify)	☐ ________

A10. If your response to (A8.) is yes, does the household head receive any form of assistance from the Government/organization?
Please specify:

____

A11. What are the main sources of livelihood in your household? List them in order of decreasing importance using the list provided below.

Most important____

____ **(Least important)**

1. Agriculture 2. Fishing 3. Formal employment 4. Trade
5. Forest products 6. Non-timber forest product 7. Other

	(Please print below)
QUESTIONNAIRE NUMBER	

A12a. Do you have any supplementary livelihood sources? Yes ☐ No ☐

A12b. If you responded yes to A12a, complete the table below:

No.	During the last 12 months, have you or any other household member received any of the following assistance?	Received 1=Yes 2= No
1.	Remittances (Within Namibia)	
2.	Remittances (From outside Namibia)	
3.	Retirement Pension/ pension grant	
4.	Social security (e.g., childcare grants, disability grants etc.,)	
5.	Food for work programmes	
6.	Relying on social safety nets (kinship)	
7.	Investment income	
8.	Veteran social grants	
9.	Other (Specify)	

A13. Who in the household is primarily responsible for the following activities (Tick appropriately)?

Managing:	Men (M) only	Women (W) only	M and W 50/50	Mostly M	Mostly W	Not applicable
The money and finances						
The buying, storing, and utilizing of food						
The production of goods (handicrafts, animal products, foodstuffs, etc.)?						
The processes of farming (deciding how land is used, deciding the schedules for planting and harvesting, etc.)?						

A14. Where do you receive the information that you use to inform your farming practices? Select all applicable information sources.

Radio	☐	Chief or other village leader	☐
Television	☐	Family members	☐
Community meetings	☐	Neingbors	☐
Farmer training	☐	Traditional knowledge	☐
Governmnt Ministry	☐	The internet	☐
NGOs	☐	Social media	☐
Churches	☐	The local Government	☐
Print media (News paper)	☐		

	(Please print below)
QUESTIONNAIRE NUMBER	

A16. For each of the following activities, please indicate if the activity is primarily done by men (M), women (W), both men and women (B) or children (C), not applicable (NA)

Activities	M	W	B	C	NA
Land Preparation					
Planting					
Weeding					
Bird scaring					
Spaying pesticides					
Irrigating					
Harvesting					
Milking livestock					
Feeding livestock					
Slaughtering					
Selling goods					
Doing repairs on the farm					
Fishing					

SECTION B: CLIMATE CHANGE EFFECT ON HUMAN WELL-BEING

B1. Have you observed any changes to the following in your lifetime?

Weather patterns		Changed	No change	If changed			
	Climate Change			Negatively	positively		
Rainfall							
Floods							
Drought							
Temperature							
	For the changes specified above, what in your opinion are the possible causes?						
Climate Change							

For the changes identified in (B1.) above, state how the changes affected the activities below using the provided words below:

Activities	Rainfall	floods	Drought	Temperature
Economic activities				
Social activities				
Infrastructure				
Trade				
Social activities				

4. Severely 3. Somewhat severe 2. Not sure 1. None

B2. Provide specific details on the specific effects e.g., if you lost a building due to flood, children unable to go to school.

Activities	Details
Economic activities	
Social activities	
Infrastructure	
Trade	
Social activities	

B3. Where do you receive information about climate change? Select all the applicable sources.

Radio	☐	Chief or other village leader	☐
Television	☐	Family members	☐
Community meetings	☐	Neingbors	☐
Farmer training	☐	Traditional knowledge	☐
Governmnt Ministry	☐	The internet	☐
NGOs	☐	Social media	☐
Churches	☐	The local Government	☐
Print media (News paper)	☐		

SECTION C. COPING STRATEGIES AND ADAPTATION MECHANISMS

C1. How have you adapted to climate change effects in the past, if at all?

____

____

____

C2. Are you aware of any technologies/strategies that can be adopted to lessen the impact of climate change? Yes ☐ No ☐

C3. If you responded Yes to C2. Above, what strategies or technologies are you aware of (list them according to priority)?

____

____

	(Please print below)
QUESTIONNAIRE NUMBER	

C4a. For the following technologies and strategies, indicate whether

a. The respondent is aware of the technology/strategy and using it, aware but not using it or used it in the past (stopped using it).
b. Constraints that are preventing the respondent from using the technology/strategy

Technology/Strategy	**Responses**				**Constraints to use of the Technology**			
	Currently in use	**Aware but not using**	**Used in the past**	**Not aware**	**Financial resources**			
					Lack of funds	**Affordability / Too expensive**	**Not profitable**	**Others**
Drip irrigation								
Hydroponics								
Seeder								
Drone								
No-till								
Ridge till								
Seed storage								
Rip and furrow								
Crop Rotation/ Intercropping								
Mulching								
Use of cover crops								
Use of organic fertilizers								
Rain water harvesting								
Surface runoff harvesting								
Soil conservation structures								
Vegetation management								
In-field water harvesting								
Weed control								
Planting								
Harvesting								
Threshing								
Biogas								
Solar								
Others (specify)								

Specific for other (C.4)……………………………………………………………………………….

	(Please print below)
QUESTIONNAIRE NUMBER	

C4b. For the following technologies and strategies, indicate whether

a. The respondent is aware of the technology/strategy and using it, aware but not using it or used it in the past (stopped using it).
b. Constraints that the respondent is experiencing in use of the current technology/strategy.

Technology/Strategy	**Constraints to use of technology (Tick appropriately)**						
	Time consuming	**Lack of awareness**	**Difficult to implement**		**Lack of support**	**Others (specify)**	**Others (specify)**
			Cultural norms	**Cumbersome practices**			
Drip irrigation							
Hydroponics							
Seeder							
Drone							
No-till							
Ridge till							
Seed storage							
Rip and furrow							
Crop Rotation/ Intercropping							
Mulching							
Use of cover crops							
Use of organic fertilizers							
Rain water harvesting							
Surface runoff harvesting							
Soil conservation structures							
Vegetation management							
In-field water harvesting							
Weed control							
Planting							
Harvesting							
Threshing							
Biogas							
Solar							
Others (specify)							

C5. Of the technologies/strategies indicated in 26, rate how useful each one is on a scale 1-5

Technology/strategy	Not useful at all 1	Useful in a few contexts 2	Neither useful nor useless 3	Useful 4	Very Useful 5

C6. Of the constraints indicated in 26, rate how challenging each one is on the scale 1-5

Constraints	Slightly challenging 1	Somewhat challenging 2	Moderately challenging 3	Very challenging 4	Extremely challenging 5
Financial resources/lack of funds/affordability					
Time consuming					
Lack of awareness					
Difficult to implement					
Cultural norms/practices (resistance to change)					
Other (same as above)					

C7. What specific programs, tools, support systems, information, etc. would address these constraints for you? (i.e., childcare, transportation, finances, instruction manuals, classes, etc.) (List according to priority)

___

___

___

C8. If the constraints you indicated are addressed, will you be willing to adopt these technologies in the future?

Yes ☐ No ☐

C9. If response to C.8 is No, provide the reason for the unwillingness to adopt the technology/strategy?

___

SECTION D: CLIMATE-SMART TECHNOLOGIES

D1. What crops do you grow? Select all the applicable crops.

Pearl millet	☐	Groundnut	☐
Sorghum	☐	Melons	☐
Maize	☐	Tomatoes	☐
Beans	☐	Cabbages	☐
Cowpea	☐	Onions	☐
Bambara nut	☐	Spinach	☐

D2. Other (list all) if any, ……………………………………………………………………………..

D3. What are the sources of water for your farming? Select all the applicable water sources

Rainfall		Borehole		
River		Earth dam		
Maize		Other		Specify

D4. Do you store any water from the source specified in D3? for farming purposes?

Yes ☐ No ☐

D5. Which water storage technologies/strategies have you adopted? Select the appropriate choices.

Pond/pan		Earth dam		
Tank		Well		
Canal		Other		Specify

D6. What type of irrigation are you using? Select all that is applicable.

None		Sprinkler irrigation		
Surface irrigation (flood, furrow, basin)		Drip irrigation (above ground)		
Manual irrigation (Watering can)		Drip irrigation (below ground)		
		Other (specify after check box)		

D7. If you are using irrigation to grow your crops, where do you get power to bring water from the main source to the storage or point of use?

Buckects are used, drawn and carried manually		Solar powered engine pumps	
Animal power used to transport water in containers		Grid powered engine pumps	
Diesel/petrol engine pumps		Other	
Specify (If other is selected)			

D8. What do you use to control weeds? Select the appropriate ones.

NA/None		Mulching	
Manual weed pulling		Plastic	
Hand hoe		Other pesticides	
Biological		Synthetic pesticides	
Other (Specify after check box)			

D9. Which method do you use for planting? Select all that apply.

Manual (heel)		Planting behind the plough	
Boadcasting		Precision planter	
hand hoe		Seed drill	
Jab planter			
Other (Specify after check box)			

(Please print below)

QUESTIONNAIRE NUMBER	

D10. Which methods do you use for harvesting? Select the appropriate choices.			
Manual		Cutter	
Sickle		Knife	
Other (Specify after check box)			

D11. What types of pests do your crops face?			
Birds		Insects	
Rodents		Knife	
Other (Specify after check box)			

D12. Which pest control methods do you use for protecting your crops? Select appropriate choices.			
NA/None		Noise (electronic ie drone)	
Netting/tarp		Test aversion covering (Like a hot sauce spray)	
Noise (Manual)		Scare crow	
Lights			
Other (Specify after check box)			

D13. Where do you obtain your seeds? Select appropriate choices.			
Neighbors and other farms		Self (seed-serving)	
Store		Seed co-operative	
CRAVE			
Government			
Other (Specify after check box)			

D14. Do you have plans to try:	Yes	No
New type of irrigation in the future		
New weed control methods in the future		
New planting methods in the future		
New harvesting methods in the future		
Any pest control methods in the future		

If yes to any of the responses on the left, specify	
Irrigation types to be tried in the future	
Weed methods to be tried in the future	
New planting methods to be tried in the future	
New harvesting methods to be tried in the future	
Any pest control methods to be tried in the future	

D15. Which farm implements do you own for the different categories of uses and what is their cost and working efficiency?

Name of equipment/tool owned by the household	Category of use	Level of sophistication	Cost range	Improvements needed to increase efficiency
	C1. Land preparation C2. Water pumps C3. Weeding C4. Spraying crop C5. Birds scaring on crop C6. Harvesting crops C7. Grain threshing C8. Grain storage C9. Energy supply	L1. Home made and manually L2. purchased and manually operated L3. puchased and driven by oxen L4. Purchased and motorized (powered by petrol diesel or electricity)	Ct1. Low(<N$1 000) Ct2. moderate (N$1 001 - N$10 00 Ct3. High ($N10001-N$ 20 000) Ct4. Very high(> N$ 20 000)	IM1. No need for improvements IM2. There is need for modelling to increase efficieny

SECTION E: SOCIAL VULNERABILITIES AND INEQUALITY WITH REGARDS TO CLIMATE CHANGE COPING MECHANISMS AND ADAPTATION STRATEGIES

E1. Do you think you are more vulnerable to climate change than other farmers?

Yes ☐ No ☐ Not sure ☐

E2. If your response is Yes to E1 above, why do you think you are more vulnerable to the effect of climate change than others?

____

____

____

____

E4. Do you think climate change affect people equally irrespective of:

	Yes	No	Not sure
Gender			
Marital status			
Income			
Political power			
Education			
Religion			
Other			
If other (specify)			

E5. For the group indicated as **No** in E4, why in your opinion are they not impacted by climate change?

____

____

____

E6. For the group indicated as Yes in E4, why in your opinion are they impacted by climate change?

____

____

____

SECTION F: SUPPORT TO ENSURE INCLUSIVITY AND SOCIAL JUSTICE

F1: Are you aware of any Government policy/programme(s) that addresses climate change?

Yes ☐ No ☐ Not sure ☐

F2: Are there any Government/civil society policy/programmes that help farmers to have equal access to resources and technologies that address climate change impacts?

Yes ☐ No ☐ Not sure ☐

F3: If yes, can you please specify the type of support/assistance provided and from whom?

____

____

____

____

	(Please print below)
QUESTIONNAIRE NUMBER	

F4: In your opinion, how can inequality gaps (If any) be addressed to ensure that there is equality for all farmers facing climate change?

____

____

____

____

F5: Do you think any of the following interventions from the government (national or local) or the private sector would be helpful in addressing inequality of farmers facing climate change?

Intervention	**Please tick**
Targeted interventions e.g., technology transfer	
Capacity building and information dissemination	
Promotion of income diversification	
Policy reforms	
Other (specify):	

F7: Following this survey, is there anything else you would like to add or ask regarding equality and social justice with regards to climate change? Anything you think is relevant to the study?

____

____

____

____

We thank you for your participation.

INTERVIEW END TIME	

Appendix B: Climate Scenario Planning Toolkit

Climate Scenario Planning Toolkit

SCHOOL FOR ENVIRONMENT AND SUSTAINABILITY
UNIVERSITY OF MICHIGAN

UNAM
UNIVERSITY OF NAMIBIA

Why use a Climate Scenario Planning Toolkit?

The purpose of this toolkit is to assist farmers and CRAVE extension workers to envision climate scenarios and better plan for a future that will vary with climate patterns and extreme events. This approach, developed by the Great Lakes Integrated Sciences and Assessments (GLISA), has helped local communities prepare for changing climatic conditions. The information in this toolkit has been developed specifically for northeastern Namibia.

The aims of this toolkit are to:

- Contextualize local climate trends, features and future scenarios for sharing across farming communities
- Provide a set of climate scenarios tailored to the agricultural needs of northeastern Namibia
- Help farmers better understand scenario planning in order to adapt agricultural activities to align with scenarios
- Allow extension workers and farmers to more clearly picture how northeastern Namibian agricultural activities are impacted by climate and extreme events

What are Climate Scenarios?

A climate scenario describes changes to climate conditions of temperature and precipitation, extreme events like droughts and floods, and impacts to ecosystems and humans. Climate scenarios are developed by examining the different ways that climate change can alter atmospheric and atmospheric-oceanic climate processes, their interactions, and subsequent climate outcomes. These climate outcomes, in turn, have impacts on subsistence farmers in northeastern Namibia. By accounting for a range of possible outcomes, climate scenarios foster decision-making under conditions of uncertainty.

Using the Climate Scenario Planning Toolkit

The goal of the Climate Scenario Planning Toolkit is to help subsistence farmers plan for all possible climate scenarios. In addition to the Climate Scenario Planning Toolkit, supplemental resources to be utilized in workshops include: instruction manuals for farming technologies and approaches, assistance in completing financial paperwork, increased training on climate adaptation, and information regarding financial programs aimed at subsistence farmers.

Step 1: Assess Barriers

1. Identify how challenging each barrier is to the implementation of new technologies or approaches that are more climate resilient.
2. What are specific ideas for how to address these barriers? What do farmers need in order to address these barriers and implement these approaches?
3. Who is responsible for conducting the activities on the farm? Men, women, or both?

Step 2: Learn the Climate Scenarios

Warm and wet scenario:

Scenario 1: Extreme Rainfall and Flooding

Warm and dry scenarios:

Scenario 2: Extreme Heat

Scenario 3: Drought

Scenario 4: Shortened Wet Season

Step 3: Identify Impacts on Farming

Identify how each of the activities that occurs on a farm will be impacted by climate change in each of the 4 scenarios (i.e., ground preparation, planting, growing, harvesting, irrigation, water storage).

Step 4: Develop Adaptation Goals

Bringing it all together, develop at least one personal adaptation goal per scenario, make plans for implementing these goals, and identify the specific challenges you might face in implementing them.

Step 1: Assess Barriers

1 How challenging are each of these barriers to implementing new, adaptive agricultural practices? Indicate the level of challenge on a scale from 1 (slightly challenging) to 5 (extremely challenging) in the chart below.

Barriers	*Slightly challenging 1*	*Somewhat challenging 2*	*Moderately challenging 3*	*Very challenging 4*	*Extremely challenging 5*
Financial resources/lack of funds/affordability					
Time consuming					
Lack of awareness					
Difficult to implement					
Cultural norms/ traditional practices					
Other:					
Other:					
Other:					

2 What would help remove these barriers (e.g., childcare, transportation, finances, tools, manuals, classes, trainings)?

____

____

____

3 Mark who is responsible for the activities done on the farm—men, women, or both?

Farming Activity	*Men*	*Women*	*Men & Women*
Ground Preparation			
Planting			
Growing			
Harvesting			
Irrigation			
Water Storage			
Other:			
Other:			

Step 2: Learn the Climate Scenarios

	Causes	Changes	Impacts
Extreme Rainfall and Flooding	↑ Strength of La Niña, +IOD, +SIOD or SE African Monsoon ↑ +IOD/+SIOD frequency ↑ ITCZ rainfall intensity	↑ Rainfall intensity ↑ Total rainfall ↑ River & field flooding	• Soil over-saturation • Water runoff and soil erosion, especially following a dry period • Crop degradation or loss
Extreme Heat	↑ Global temperature [1] ↑ Namibia's land surface temperature [2]	↑ Evaporation rate from water sources ↑ Evapotranspiration from crops ↓ Soil moisture	• Human and crop heat stress • Crop degradation and loss
Drought	↑ Temperature ↑ Strength/frequency of El Niño relative to La Niña ↑ -IOD/-SIOD events • ITCZ narrowed, shifted N • STH moves closer to land	• All changes from Extreme Heat Scenario changes • Longer term, multi-year droughts ↓ Total rainfall ↓ Moisture transport and relative humidity from northern Africa • Shortened wet season	• Some crops prevented from reaching maturity • Groundwater depletion • Crop degradation or loss • Water scarcity for humans and crops
Shortened Wet Season	↑ Strength of West African Monsoon delays ITCZ migration • Earlier end to wet season	• Shortened wet season ↓ Total rainfall ↓ River water	• Some crops prevented from reaching maturity • Shorter growing season for agriculture without irrigation

1. Global mean surface temperature predicted to increase an average 2.0°C (likely range: 1.4 to 2.6°C) by 2046– 2065 and 3.7°C (likely range: 2.6 to 4.8°C) by 2081–2100 under RCP8.5 (IPCC, 2013).
2. Country-wide temperature increases by 2046-2065: 1 to 3.5°C in austral summer and 1 to 4°C in winter (Republic of Namibia Ministry of Environment & Tourism, 2015).

Step 3: Identify Impacts on Farming

Using the table below, indicate the impact of each climate scenario on each farming activity for each crop grown on your farm (use multiple sheets if necessary) . Additional activities can be added in the rows labeled *other*.

Crop: ______________________________

Farming Activity	*Extreme Rainfall and Flooding*	*Extreme Heat*	*Drought*	*Shortened Wet Season*
Ground Preparation				
Planting				
Growing				
Harvesting				
Irrigation				
Water Storage				
Other (specify):				
Other (specify):				

Step 4: Develop Adaptation Goals

For each of the four climate scenarios, what are your goals for adapting to the projected climate scenarios? What steps are needed to achieve each goal? What barriers must be overcome in each scenario to achieve the adaptation goals?

Climate Scenarios	*Extreme Rainfall and Flooding*	*Extreme Heat*	*Drought*	*Shortened Wet Season*
Set a goal: How can you adapt to each climate scenario?				
Examples of adaptation goals	Protect seeds and seedlings from washing away during flooding	Prevent moisture loss from soil	Store more water for irrigation	Conserve water for end of growing period
Make a plan: What technologies and strategies will help you achieve their adaptation goals? When should these steps be completed?				
Examples of plans	Use tarp to cover sprouts during a heavy rain	Lay mulch to prevent evaporation	Implement drip irrigation to save water	Aquire water tanks for water storage
Explore challenges: What challenges do you foresee arising in each climate scenario?				
Examples of challenges	Will be difficult to prepare for extreme rain events	Heat negatively impacts human ability to do manual labor	Lack of water threatens plant growth	Plants might not reach maturity before end of wet season