

# Developing a conceptual model of resilience of communities to climate change in the Cuvelai Etosha Basin

**BF Mpofu**

 [orcid.org 0000-0002-6906-506X](https://orcid.org/0000-0002-6906-506X)

Thesis accepted in fulfilment of the requirements for the degree *Doctor of Philosophy in Science with Environmental Sciences* at the North-West University

Promoter: Prof NA Kgabi

Co-promoter: Prof SJ Piketh

Graduation May 2024

33640599

## **Abstract**

Research on vulnerability and adaptation to climate change have increased because of the growing realisation that the response determines resilience. Societal capacity to adapt is linked to both severity of impacts and societal readiness and preparation. The aim of this study was to identify the factors that make communities vulnerable to floods in the Cuvelai-Etoshia Basin in Namibia. To achieve this aim, 50-year historical precipitation patterns from the Oshakati weather station were examined and the time series was analysed using statistical package for social science (SPSS) version 29. Since the precipitation data was over a 50-year period, it was expected that data quality issues might arise and, therefore, the research incorporated data wrangling steps to address them. The wrangling steps involved treating missing data, conducting reliability testing, and shaping the data to ensure it is suitable for its intended use. Besides the precipitation data, a hazard risk analysis was conducted in the study area to determine if there were any predisposing factors that could possibly induce flooding during the rainy season. An indicator-based approach was used in the ground truthing exercise, and it allowed for a holistic assessment of risk factors such as physical, environmental, and social that could be linked to the community's vulnerability. The results of the hazard analysis were used to identify areas which had the highest risk to flooding, and these were used to map out areas of high, moderate, and minimal risk. The areas at risk to flooding were delineated using geodata derived from satellite imagery and various shapefiles and geographic information system software was used to create flood hazard maps. The overall purpose of the study was to develop a conceptual model that will be used to explain the various components, interactions and dynamics involved in building resilience to the impacts of climate change in the in the Cuvelai Etoshia Basin. The results revealed that significant precipitation fell only during the months of November through to April, with notable intensity in the first three months of the year. Further analysis revealed that the rainfall amounts, and rain season had significantly shortened over the last 10 years however, the rainfall intensity had also increased during the usual rainfall months but were not enough to warrant extensive flooding. The study also revealed that floods experienced in Ehenye community in Oshakati, especially in the years 2008; 2010; 2011 and 2014 were also induced by the geography of the area which played a significant role in determining susceptibility to flooding. Factors such as presence of depressions/Oshana's and proximity to the Okatana river contributed to the size and characteristics of the watershed.

The main non-climatic reasons for flooding were the absence of critical flood infrastructure such as municipal constructed storm water drainages. The town's disaster management was found to primarily focus on rescue and relief and the government interventions are limited to financial and early warning systems. Overall, the flooding was attributed to a combination of identified irregularities in town planning, inadequacy in flood infrastructure and shortened but intensified rainy season. The results also revealed that the study area had a good legal environment on paper, but implementation was lacking. Possible areas of opportunities to leverage adaptation were identified and resilience strategies were recommended. Using the results obtained as well as literature search, a conceptual model of resilience to climate change was developed. The model was developed to understand the multidimensional nature of resilience through measuring pre-event characteristics that contribute to a community's capacity to reduce existing risk, prepare for, and recover better from a flood event. The model also considered all critical factors that must be prioritized when planning for settlement in areas that are prone to climatic hazards. The holistic comprehensive approach of the model can guide the planning authority into building climate resilient communities. The study recommends implementation of policies, plans and fostering horizontal communication and coordination between line town authority, line departments and communities to reduce further flood vulnerabilities and thus strengthening resilience.

**KEY WORDS:** Climate change, flooding, resilience, rainfall, vulnerability, climate risk.

**Declaration**

I, Buhlebenkosi Fiona Fuyane-Mpofu hereby declare that this research titled “Developing a conceptual model of resilience of communities to climate change in the Cuvelai-Etosha Basin”, is my own work undertaken at the North-West University (Republic of South Africa). This work has not been submitted in any form to be awarded a degree at any other institution, nor has it been previously published. All the resources that were consulted in the preparation of this work have been cited and acknowledged.

Signature:..... Date.....

## **Acknowledgements**

This research would not have been possible without the patience and guidance of my supervisors Professor Nnenedi Kgabi and Professor Stuart Piketh; North-West University (NWU) Department of Agriculture and Environmental Science for the study bursary, Oshakati Town Council for assisting and accommodating me in between their busy schedules and responding timeously to my questions.

My gratitude also goes to the Namibia University of Science and Technology (NUST) geomatics team for the technical support, the National Commission of Science and Technology (NCRST) and the Southern African Regional Universities Association for the review of the developed conceptual model and rating tools. Sincere gratitude to my husband Nkosinathi for the patience and encouragement and dedicated to my parents Cee and J.R.

## List of Abbreviations

AFDB	African Development Bank
COP	Conference of Parties
GEF/SGP	Global Environmental Facility/ Small Grants Programme
GDP	Gross Domestic Product
GIS	Geographic Information Systems
FDI	Foreign Direct Investment
IPCC	Intergovernmental Panel on Climate Change
NCRST	National Commission of Research, Science and Technology
NMS	National Meteorological Service
NSA	National Statistics Agency
NUST	Namibia University of Science and Technology
SARUA	Southern African Regional Universities Association
UNDP	United National Development Programmes
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organisation

## List of local terms

Efundja:

Irregular large flood event from higher up the Cuvelai bringing many different fish species.

Oshana

A depression usually filled with water during the rainy season.

Li shana

Plural for oshana. Meaning connected grassed depressions in the Cuvelai river system filled regularly with rainwater.

Ondombe

Deeper open water pools that hold water for longer.

## Table of contents

<b>ABSTRACT</b> .....	<b>II</b>
<b>DECLARATION</b> .....	<b>IV</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>V</b>
<b>LIST OF ABBREVIATIONS</b> .....	<b>VI</b>
<b>LIST OF LOCAL TERMS</b> .....	<b>VII</b>
<b>CHAPTER 1: INTRODUCTION AND BACKGROUND TO THE STUDY</b> .....	<b>1</b>
1.1 INTRODUCTION .....	1
1.1.1 DEFINING CLIMATE CHANGE .....	2
1.1.2 <i>Climate as a risk</i> .....	3
1.2 CLIMATE IMPACTS .....	3
1.3 PROBLEM STATEMENT .....	4
1.4 RESEARCH AIM AND OBJECTIVES .....	6
1.4.1 <i>Research aim</i> .....	6
1.4.2 <i>Research objectives</i> .....	6
1.4.3 <i>Research questions</i> .....	7
1.5 JUSTIFICATION.....	7
<b>CHAPTER 2: LITERATURE REVIEW</b> .....	<b>9</b>
2.0 INTRODUCTION .....	9
2.1 BACKGROUND TO THE STUDY .....	9
2.2 NAMIBIA AND CLIMATE CHANGE.....	10
2.3 THE SETTING: CUVELAI-ETOSHA BASIN.....	11
2.4 CLIMATE CHANGE AND ITS EFFECTS ON COMMUNITIES .....	13
2.5 CLIMATE VARIABLES .....	14
<b>2.5.1 Rainfall</b> .....	<b>15</b>
2.5.2 CHALLENGES WITH RAINFALL MEASUREMENT .....	16
2.6 UNDERSTANDING FLOODS.....	19
2.6.1 <i>Types of floods</i> .....	19
2.6.2 <i>Impacts of floods</i> .....	21
2.6.3 <i>Long term impacts</i> .....	22
2.7 FLOOD MANAGEMENT .....	23
2.7.1 <i>Non-structural flood management practices</i> .....	24
2.8 FLOOD MAPPING .....	25
2.8.1 <i>Flood data techniques</i> .....	26
2.9 VULNERABILITY, ADAPTIVE CAPACITY, AND RESILIENCE .....	26
2.10 <i>Adaptive capacity and resilience</i> .....	31

2.11 Steps to building resilience .....	33
2.12 CONCEPTUAL MODEL IN RESEARCH .....	35
2.13 CONCEPTUAL APPROACHES OF RESILIENCE .....	35
2.13.1 Engineering resilience .....	36
2.13.2 Ecological resilience .....	36
2.13.3 Socio-ecological resilience .....	37
2.14 COMPARISON OF THE THREE APPROACHES .....	37
2.15 REVIEW OF FRAMEWORKS .....	37
2.15.1 Climate resilient cities framework .....	38
2.15.2 PEOPLES resilience framework .....	38
2.15.3 Disaster resilience framework .....	39
2.15.4 Building resilience against climate effects (BRACE) .....	39
2.16 GAPS IN EXISTING FRAMEWORKS .....	40
<b>CHAPTER 3: MATERIALS AND METHODS .....</b>	<b>43</b>
3.1 INTRODUCTION .....	43
3.2 MATERIAL AND METHODS .....	43
3.2.1 Sampling .....	43
3.3 DATA COLLECTION AND ANALYTICAL TECHNIQUES .....	43
3.3.1 Climate variability- objective 1: .....	43
3.3.2 Data acquisition: .....	45
3.3.3 Data wrangling .....	46
3.3.3.1 Pruning the attribute set .....	46
3.3.3.2 Decomposing the composite attributes .....	47
3.3.3.3 Data cleaning .....	49
3.4 ANALYSIS OF DATA .....	51
3.5 DATA SOURCES .....	51
3.6 VULNERABILITY RISK FACTORS OF COMMUNITIES- OBJECTIVE 2 .....	52
3.6.1 Hazard identification .....	52
3.6.2 Hazard analysis .....	53
3.6.3 Societal and legal analysis .....	53
3.6.4 Environmental and physical analysis .....	53
3.6.5 Critical facility analysis .....	54
3.7 RISK MAPPING – OBJECTIVE 3 .....	55
3.8 SECONDARY DATA ANALYSIS .....	58
3.9 DEVELOPMENT OF THE MODEL .....	59
3.10 MODEL EVALUATION .....	59
3.11 MODEL VALIDATION .....	60
<b>CHAPTER 4: RESULTS AND DISCUSSION .....</b>	<b>62</b>
4.1 OBJECTIVE 1- ANALYSIS OF HISTORICAL RAINFALL TRENDS .....	62

4.1.2 DATA ACCESS .....	64
4.1.3 DATA QUALITY .....	64
4.1.3.1 <i>Treatment of missing data</i> .....	65
4.1.3.2 <i>Reliability of data</i> .....	67
4.1.4 ANALYSIS OF PRECIPITATION DATA.....	72
4.1.4.1 <i>Rainfall intensity/concentration</i> .....	78
4.1.4.2 <i>Precipitation trend analysis</i> .....	80
<b>4.1.5 Conclusion for Objective 1</b> .....	81
4.2 OBJECTIVE 2 RISK VULNERABILITY FACTORS .....	82
4.2.1 <i>The general landscape</i> .....	82
4.2.2 <i>Physical analysis</i> .....	86
4.2.3 <i>Risk Mapping</i> .....	89
4.2.4 <i>Conclusion</i> .....	94
4.3 OBJECTIVE 3- ASSESSING VULNERABILITY RISK FACTORS .....	95
4.3.1 <i>History of Ehenye</i> .....	95
4.3.2 <i>Oshakati Migration Patterns</i> .....	96
4.3.4 <i>The legal environment</i> .....	96
4.3.5 <i>Disaster Risk Management</i> .....	98
4.3.6 <i>Town strategic plans</i> .....	99
4.3.7 <i>Critical Support Factors</i> .....	100
4.3.8 <i>Summary causes of flooding</i> .....	101
4.3.9 <i>Solutions</i> .....	102
4.3.9.1 <i>Immediate Solutions</i> .....	102
4.3.9.2 <i>Long term Solutions</i> .....	104
4.4 OPPORTUNITIES FOR RESILIENCE .....	105
4.5 OBJECTIVE 4- CONCEPTUAL MODEL.....	108
4.5.1 <i>Enablers of resilience</i> .....	108
4.5.2 <i>Model Context</i> .....	114
4.5.2.1 <i>Conceptual model goals and objectives</i> .....	114
4.6. EXPLANATION OF THE CONCEPTUAL MODEL .....	117
4.6.1 <i>Flood hazard management</i> .....	119
4.6.2 <i>Determining resilience</i> .....	120
4.7 MODEL EVALUATION.....	124
4.7.1 <i>Pilot Test</i> .....	126
4.7.2 <i>Strengths and weaknesses of the developed tools</i> .....	128
4.8 <i>Conceptual Model Validation</i> .....	130
<b>CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS.....</b>	<b>131</b>
5.1 SUMMARY AND CONCLUSIONS .....	131
5.2 RECOMMENDATIONS .....	135
5.3 LIMITATIONS.....	137

5.4 FUTURE RESEARCH.....	137
APPENDIX 1- PERMISSION LETTERS.....	163
APPENDIX 4 – FLOODING VARIABLES.....	172
APPENDIX 5 IMAGES OF EHENYE.....	176

**List of Tables**

Table 2 1:Risk key ..... 27

Table 3. 1 Environmental and physical parameters ..... 53

Table 3. 2 : Critical factor analysis ..... 55

Table 3. 3: Risk key ..... 56

Table 3. 4 List of shapefiles used to create risk maps..... 57

Table 4. 1 Aggregate number of precipitation days per month and per year. .... 66

Table 4. 2 Normal test statistic for precipitation days ..... 67

Table 4. 3 Data after treatment of missing values, organized in seasons..... 70

Table 4. 4 Summary of precipitation data organized in seasons. .... 75

Table 4. 5 Average precipitation per day of the month..... 77

Table 4. 6 Highest rainfall record given in mm/month. .... 79

Table 4. 7 List of shapefiles used in map creation of Ehenye ..... 89

Table 4. 8: Flood classification levels ..... 119

Table 4. 9 Asset base weights - TOOL A..... 120

Table 4. 10 Vulnerability and resilience scale - TOOL B..... 122

Table 4. 11 Resilience scale -TOOL C ..... 123

Table 4. 12 Testing of tool A..... 126

## List of figures

Figure 2. 1 Map of study area in relation to Namibia.....	9
Figure 2. 2 Hydrological map of the Cuvelai Etosha Basin. ....	13
Figure 2. 3 Conceptual model on vulnerability. ....	30
Figure 3. 1 Data handling process to evaluate the climate variability. ....	44
Figure 3. 2 Precipitation data format.....	45
Figure 3. 3 Snapshot of OSH data set after eliminating some columns.....	47
Figure 3. 4 Snapshot of OSH dataset. ....	48
Figure 4. 1 Box and Whisker plot for the number of precipitation days .....	68
Figure 4. 2 Histogram for number of precipitation days organized in months .....	71
Figure 4. 3 Data normality test results for precipitation data .....	72
Figure 4. 4 Normal probability plot and curve for precipitation data.....	73
Figure 4. 5 Monthly average precipitation .....	77
Figure 4. 6 Precipitation trend line .....	80
Figure 4. 7 Map of Ehenye in relation to Oshakati Town.....	83
Figure 4. 8 The Cuvelai drainage system depicting concentration of waterways around Oshakati Town. ....	84
Figure 4. 9 Image of oshana/depression during the 2023 rainfall season .....	85
Figure 4. 10 (a) and (b): Ongoing construction of the embankment. ....	87
Figure 4. 11 Images depicting flooded Ehenye .....	88
Figure 4. 12 Map of Ehenye showing natural and manmade water features. ....	90

Figure 4. 13 Superimposed map showing water features and landuse in Ehenye. .... 92

Figure 4. 14 Enablers of community resilience. .... 109

Figure 4. 15 Conceptual model for building climate resilient basin communities' ..... 115

## **CHAPTER 1: INTRODUCTION AND BACKGROUND TO THE STUDY**

### **1.1 Introduction**

Scientific evidence gathered around the world including assumptions and findings about climate change are continually assessed and evaluated to understand the real causes and effects (Hegerl et al., 2019). While evidence is clear that indeed the climate is changing, not every detail settled or completely certain and not every pertinent question has yet been answered (National Academy of Science, 2011). Research on climate change indicates that the poorest and most vulnerable people in society are affected the most by climate change as they often reside in areas more susceptible to hazards such as floodplains and coastal regions (Madden, 2017). While mitigation and adaption talks are ongoing through many platforms such as the annual Conference of Parties (COP) (Akbas, 2016), the affected, especially in the third world countries, seldomly get information timeously. Even when information does reach the underdeveloped communities, it is seldom correctly contextualised or helpful. There are many reasons for this and one such is the fact that, climate change is diverse, complex, and bridled with scientific uncertainty which may make it challenging to predict future climate projections (Huddleston, 2016). This has left many communities exposed to extreme climate hazards and subsequent consequences much to the confusion of the general communities and governments at large (Awojobi, 2017)

The International Panel on Climate Change (IPCC) recognises Africa in its totality as the most vulnerable continent due to the multiple stresses that it already faces. Stressors like food scarcity, poverty, and burden of disease such as HIV/AIDS and malaria have a bearing on the adaptive capacity of some of the countries affected (African Climate Policy Centre, 2013; Sherbinin, 2014)

### **1.1.1 Defining climate change**

Climate is defined in terms of average weather over a long period of time, and it evolves under its own internal dynamics and due to external influences, such as human induced changes in the atmosphere (Molua et al., 2020). Climate change is described as an alteration in the condition of the climate that can be recognised by modifications in the known normal characteristics typically extending for longer periods longer than 30 years (Bernstein et al., 2007; Lavell et al., 2012). Climate change poses a threat to humans and ecosystems. Science scholars believe that climate change is not a naturally occurring phenomenon, but one that is human induced. According to Shukla et al., (2022) scientific studies increasingly demonstrate that anthropogenic activities that release greenhouse gas emissions are contributing to climate change as through trapping of the heat and causing the earth's temperature to rise. The IPCC reports that since the Industrial Revolution, the carbon dioxide abundance has risen by 375 ppm and continues to rise (IPCC, 2018) Research suggests that most of the observed global warming of the last 50 years, can be attributed to human activities such as, burning of fossil fuels, pollution, deforestation due to the need for urban land development amongst others (Lavell et al., 2012). In response to this, the United Nations Framework for Climate Change (UNFCCC) and the Kyoto Protocol as well as the Paris Agreement in 2015, recommend reducing greenhouse gas emissions and limiting global warming to below 2 degrees of preindustrial level and also documenting and reporting, emissions so that there is accountability (UNFCCC, 2015).

Rahman (2013) emphasises that human beings should note that any small changes in average temperature can translate to big changes across the planet, and these changes may bring about significant impacts across the different environmental, developmental, and economic sectors in society. Climate change cannot be ignored, because living things (plants, animals, and humans) and communities have previously developed in a climate that varied only a little, and now all living things must learn to adapt and cope with rapid

climate change, making life a little hard and the earth much harder to live in (Langsdorf et al., 2022).

### **1.1.2 Climate as a risk**

Climate risk is defined by the World Bank as the likelihood of the occurrence of a hazard and this may result from extreme climate, which affects natural and human systems (Eckstein et al., 2019). According to Serdeczny et al (2016), an extreme change in climate is likely to aggravate the already fragile ecosystems that are especially found around the world. Any country in that region that relies on sectors that are sensitive to climate for example rainfed agriculture may suffer because of the uncertain changes in climate. For any country or community to be resilient, there first must be an understanding of the threats and vulnerabilities affecting it. According to Silva-Villanueva (2019), climate resilience refers to the capacity of individuals and communities to withstand, adapt to and recover from the adverse effects of climate change. For this to happen, climate risks need to be understood. Once threats and vulnerabilities are known, then resilience programs may be instituted in communities to enable them to recover (Harrison et al., 2019). The risks brought by climate change vary according to location and this variation occurs due to several factors, including the local climate, geography, socio-economic conditions, and adaptive capacity. In Southern Africa, the most common are extreme weather patterns such as temperature and precipitation and they both affect communities mainly through flooding and drought.

### **1.2 Climate impacts**

The consequential effects of climate change on communities are exhibited differently. Climate scholars, put forward the notion that the most important characteristic in addressing emerging climate risk is the ability to adapt (Füssel, 2010; Kropp & Scholze, 2009; Pearce et al., 2015). Communities that are dependent on natural resources for sustenance as those that have been highlighted as needing to quickly adapt as the

impacts affect both social and economic systems that support them. Most of these communities are found in developing countries. (Bernstein et al., 2007; Hooli, 2016).

Namibia is one of the driest countries in sub-Saharan Africa with a climate that is characterised by hot temperatures, persistent droughts and unpredictable rainfall which contribute to water scarcity crop failure, food insecurity and ecosystem degradation amongst others (Mendelsohn & Beat, 2011). Namibia's economy is supported by various industries such as mining, agriculture and fishing but the water scarcity has affected each one of these sectors as they required water for sustenance. , However, despite the various options in economic support, agriculture is the most prominent as at least 70 % of the population relies on it to support their livelihoods (National Policy on Climate Change for Namibia, 2010; Van Zyl et al., 2012).

The unpredictable weather patterns in the country makes the ecosystem fragile and the high reliance of the Namibian people on the natural environment for their livelihoods, exacerbates their vulnerability to climate change (Niipare et al., 2020; Shaamhula & van Rooy, 2019). The evident vulnerability has prompted the Government of Namibia to continuously address climate change through firstly ratifying; the United Nations Framework Convention on Climate Change (UNFCCC) in 1995 and through passing various policies and programmes such as: the National Climate Change Strategy and Action Plan (2013-2020), Disaster Management Act 2012, Climate Change Policy 2011, the appointment of a National Climate Change Committee (NCCC). Furthermore, the Government of Namibia, through its Ministry of Environment supports climate change adaptation programmes through various financing mechanisms channelled to the affected communities.

### **1.3 Problem statement**

Climate change is a global occurrence that impacts communities differently. The change in climate has consequences on different aspects of society such as the economy, the environment, and politics (Wolff et al., 2014). Namibia's rainfall patterns have become

increasingly erratic and have led to prolonged droughts and unpredictable precipitation. Analysed information on climate variables such as precipitation and how they affect the communities in the Cuvelai-Etosa River Basin are important as this will allow adaptive and resilience measures to be instituted. So far, evidence produced by the Namibia Meteorological Department (2017), has not indicated that rainfall has varied spatially but have acknowledged that there have been more incidents of flooding annually especially in the Ehenye community of Oshakati Town (Hango, 2017). Highlighted years of flooding include 2010; 2011; 2014 and 2018 and the floods have impacted the community through damage of property and infrastructure, loss of lives and livelihoods such as farming and consequently, critical areas such as schools and businesses must shut down temporarily. Due to flooding, various social determinants of health are impacted such as housing, water, and sanitation requiring relocation of displaced residents to emergency shelters. Health risks emanating from contaminated drinking water sources increase the risk of waterborne diseases such as cholera and diseases such as malaria resurface due to stagnant water and unfortunately, health care facilities are not always accessible as they too, are affected or have become inaccessible due to flooded roads and pathways.

The amount and type of damage within the town, is not adequately recorded in any inventory because the origins and various dimensions of the flooding disasters are difficult to record and evaluate as the priority during the event is to save lives (Shaamhula & van Rooy, 2019). What is lacking for the study area is detailed analysis of rainfall trends as well as information on why and how these floods occur whilst also exploring upstream approaches that could be considered in finding risk reduction and resilience measures (Niipare et al., 2020). This lack of data at localised scales, invariably forces communities and governments into a reactive rather than a proactive mode, thus reducing the chance to enable institutions to co-ordinate risk reduction measures effectively (Kuliwoye, 2010). Through science and technology, climate predictions are possible but sometimes not accurate, however preparation is done for any change through early warning systems and operational models. The analysis of the flood events and the

consequential damage are important requirements for developing risk prevention mechanisms. These measures will ensure that communities become resilient.

Although statutory requirements that govern and guide issues surrounding climate change are in place in Namibia, such as the Climate Change Policy of 2011, Disaster Management Act, 2012 as well as the National Climate Change Strategy and Action Plan 2013-2020, these have fallen short in managing floods, reducing damage and community vulnerability likely due to missing localised data on climate change from the community. Analysed information on climate variables such as precipitation and how they affect the communities in the Cuvelai-Etосha River Basin are important as this will allow adaptive and resilience measures to be instituted. The problem at hand is that the communities of the Cuvelai are failing to adapt to climate change due to lack of established coping strategies/mechanisms beforehand and guiding protocols because of lack of risk assessments before settlement. The purpose of the study was to identify factors that put the community at risk to flooding whilst exploring possibilities of adaptation and resilience.

## **1.4 Research aim and objectives**

### **1.4.1 Research aim**

The aim of the study was to develop a conceptual model that provides a systematic approach to understanding, assessing, and implementing measures that will ensure resilience in communities affected by flooding in the Cuvelai Etosha Basin.

### **1.4.2 Research objectives**

: The specific objectives of the study were to:

1. To analyse historical trends of precipitation in the Cuvelai-Etосha Basin in Namibia.
2. To characterise the study area into risk zones (affected and potentially affected areas to identify hotspots).

3. To assess the vulnerability risk factors of communities in the basin.
4. To develop and validate a conceptual model for resilience in the Cuvelai-Etosha Basin.

### **1.4.3 Research questions**

1. What precipitation patterns have been experienced over the last 50 years?
2. What makes the area vulnerable to flooding? What are the risk factors associated with change in climate?
3. What are the vulnerability factors of communities in the Cuvelai Etosha Basin
4. What are the pertinent components of a framework for resilience within the context of the Cuvelai- Etosha Basin?

### **1.5 Justification**

Climate change research helps improve understanding of the drivers, impacts, risks, and vulnerabilities associated with changing climatic conditions. This will inform policy and decision making, while guiding adaption and resilience strategies aimed at reducing vulnerability. By identifying adaption options, innovative solutions in building resilience can adopted to protect livelihoods, safeguard ecosystems. This research is important because the climate trend analysis output was used to determine long term trends of precipitation in the Cuvelai Etosha Basin. The output allowed assessment to determine seasonal shift, intensity, and frequency to understand extreme precipitation events and associated risks. Furthermore, interpretation of trends revealed limitations associated with historical data including data capturing errors. The trend analysis output can also be manipulated further for climate forecasting as well as input in the development and improvement of the early warning systems. The risk zones identified by this research can be adopted by Oshakati Town Authority to settlement planning, zoning, regulations, and development policies. The flood risk characterization will inform authorities so they can

avoid high risk areas that have a high probability of flooding thus promoting sustainable development.



economy due to its significant contribution to export earnings and government revenue (Namibia Statistics Agency, 2011) . Agriculture is limited to arable land, most subsistence farmers tend to focus on livestock and dry land crop production of sorghum, millet, and fruits (GIZ, 2020). Namibia is a water stressed country as it experiences erratic rainfall with annual average rainfall ranging from 700 mm in the north and 25 mm or less in the south of the country (Ministry of Environment & Tourism, 2015). According to Hooli (2016), lack of water and frequent droughts are one of the impediments of development in Namibia thus as a way forward models must be developed to compare observed precipitation trends with climate model simulations to assess the consistency of model predictions which may be used for adaptation and resilience are leveraged (Alexandre et al., 2012; Fellmann, 2012) .

## **2.2 Namibia and climate change**

According to climate risk profile of Namibia (2021) climate change is expected to increase the risk to extreme events such as floods and droughts which have affected approximately 70 000 people annually. Between the year 2000 and 2007 the country experienced at least 5 crippling droughts and affected an estimated 300 000 people (X. Liu & Zhou, 2021). The years 2012/13 were recorded as the driest as it affected all the thirteen regions of country leading to a state of emergency declaration. In contrast, during floods, water related diseases such as cholera, dysentery and malaria become common. In 2008, 1415 suspected cholera cases were recorded, and 19 deaths confirmed (The World Bank Group, 2021). Other notable impacts include forest fires in the Caprivi and Kavango region, which destroy biodiversity, forestry and pastureland which is already fragile.

Information related to weather and other environmental parameters are well documented in Namibia. According to Angula & Kaundjua (2016), Namibia actively participates in international and regional climate system observations, with approximately one hundred weather stations scattered across the country with full year records. At a localised scale, there are various ongoing programmes that are meant to tackle climate change. These programmes, through legislation are supported by the Namibian Policy on Climate

Change (National Policy on Climate Change for Namibia, 2010). The main purpose of the policy is to create an inclusive and supportive structure on managing climate risk that is in line with the development agenda of Namibia. Other support programmes include different initiatives by non-governmental organisations (NGOs), for example, the United Nations Development Programme (UNDP); Global Environmental Facility/ Small Grants Programme (GEF/SGP), Southern African Science Service Centre for Adaptive Land Management (SASSCAL), and the United Nations, Educational, Scientific and Cultural Organisation (UNESCO).

Many communities in Namibia are affected by seasonal climatic change, one such area being Oshakati Town, located in Northern Namibia in the Cuvelai- Etosha Basin and is the study area for this research.

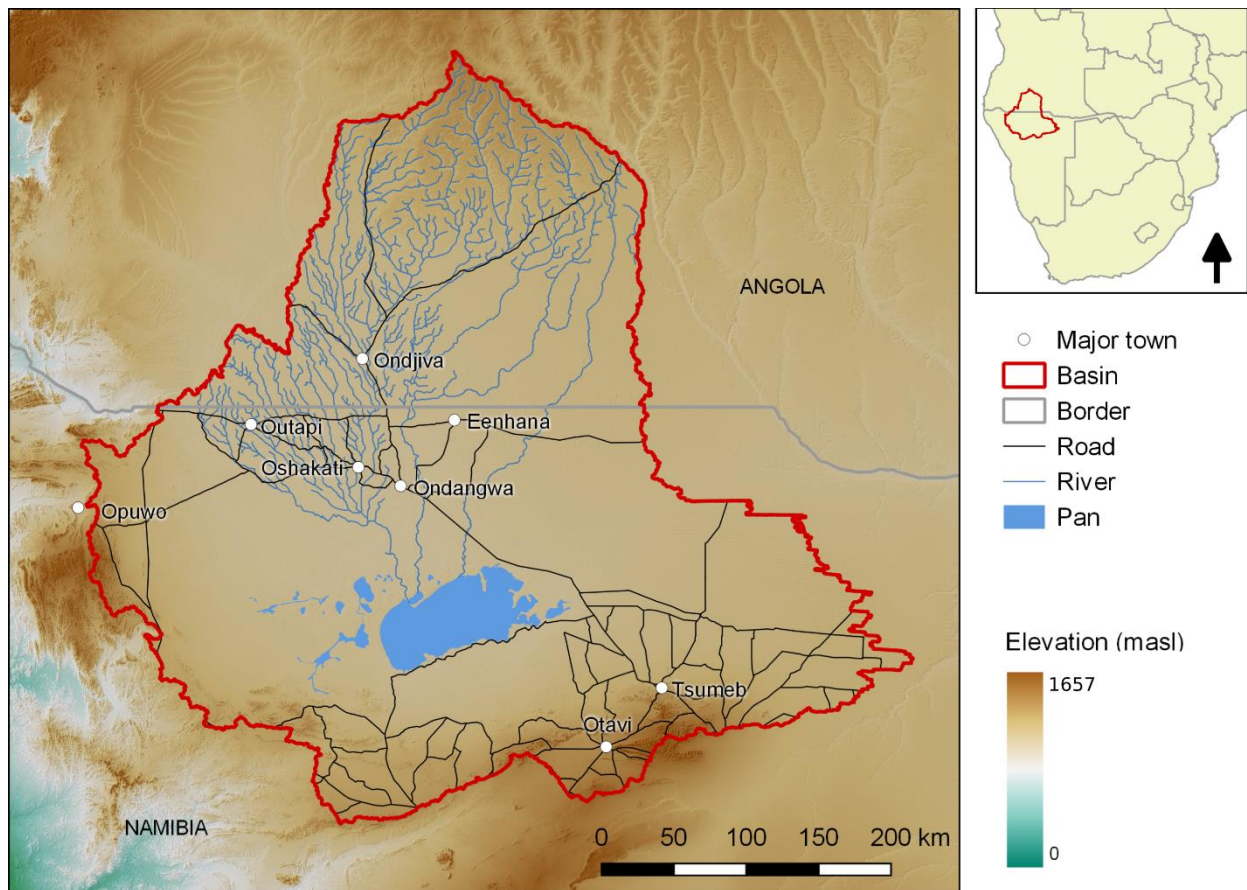
### **2.3 The Setting: Cuvelai-Etosha Basin**

According to Mendelsohn& Beat (2011), the Cuvelai- Etosha Basin is a natural trans-boundary wetland that is shared by Angola and Namibia and is homeland to many communities and has the highest population density and is the fastest growth rate in Namibia. The landscape is characterised by the presence of shallow groundwater and relatively fertile soils. is an important system as numerous ephemeral rivers convene in the basin and the natural pans are an important surface water resource.

Oshakati Town, located at latitude 17°46'59.99"S and longitude 15°40' 59".9"E is the regional and commercial capital of northern Namibia and was founded in July 1966. The region is named after the geographic landscape, which is characterised by shallow depressions that are seasonally inundated with rainwater, which support agro ecology in the area (Van Zyl et al., 2012). Over the years, the town has seen some infrastructural development, that has influenced rural to urban migration. As of 2023, the population stood at 36 541 (Namibia Statistics Agency, 2011). The increase in population gave rise to a demand for human habitable land, which led to settlements on the low-lying areas and sometimes even within the water depressions commonly known as *oshanas* (Van Zyl

et al., 2012). Among the main livelihood activities practised by local people, are rain dependant crop production and extensive livestock rearing, mainly cattle (Zeidler et al., 2010). During the rainy season, if heavy rain persists, rivers end up bursting their banks leading to many residents experiencing substantial flooding in their houses and homesteads. In Ehenye, the Okatana river serves as the boundary between Oshakati East and Oshakati West and most communities around this river depend on small scale farming for their survival. The livelihoods are vulnerable to climate change to some extent and the frequent flooding that these communities face, has been and still is a challenge.

The Cuvelai Basin has experienced and continues to experience extensive flooding, with negative repercussions including the loss of human lives and property (Hango, 2017). The flood history of the Cuvelai specifically highlights 2008, 2009, 2010, 2011 and 2018 being the years that brought floods into the area. In 2009 for example, the floods displaced approximately 13 000 people from different communities and left 92 people dead (Kotir, 2011). In other years, the floods destroyed crops and interfered with livelihoods thus putting the region at risk of food shortages amongst other consequences (Allen, 2009). Climate temporal dynamic projections and sensitivity analyses of the area predict extremes of temperature, evaporation, and variable rainfall and these are likely to worsen the challenges that Namibia is already facing as an arid country (Wilhelm, 2012). To be able to ensure adaption and resilience to flooding, it is necessary to have timeous information as this will strengthen the adaptive capacity and in turn, scale up adoption of coping mechanisms and measures thus ensuring that communities become resilient. Figure 2.2 shows a map of the Cuvelai Etosha Basin expanse between Angola and Namibia



**Figure 2. 2 Hydrological map of the Cuvelai Etosha Basin.**

Source: Ruetkener et al., 2018.

## 2.4 Climate change and its effects on communities

Ongoing research indicates that climate change in Namibia causes more significant impacts on rural communities than urban communities (Thorn, 2023). The coping and adaptive capacities to respond to impacts of climate-related risks are different because vulnerability and capacity of an individual to adapt in a changing climate is related to the access to, and control of, natural, social, physical, political, and financial resources (Shaamhula & van Rooy, 2019). Therefore, the rural communities, who have the lowest resources and are sustained by rain-fed crops and animal production are the most

affected and this ultimately affects their food security and livelihood stability (Hegga, Salma & Siyambango, 2015).

According to Welborn (2018), limited sources of income and employment options increase the vulnerability of households and limit the exploration of other non-farming livelihoods. Furthermore, limited access to capital, productive land, knowledge, and services further exacerbates the conditions and these factors decrease resilience and adaptive capacities of especially the communities (Niang et al., 2015; Smith et al., 2001). Identifying the challenges communities face with respect to climate change, requires a holistic approach that is sensitive to community differentiation, because communities are not homogenous (Hooli, 2016). Such efforts, will ensure that appropriate adaptation and resilience measures are instituted (Guillaumont & Simonet, 2011).

As earlier alluded, Namibia is regarded as a middle-income country but there are considerable disparities in income (Namibia Statistics Agency, 2011). The disparities are multidimensional spanning from wealth and income, level of education, access to health care, ownership of assets such as land and others. When individuals do not have the same opportunities, they are hindered from achieving individual goals and it is worsened when natural and other disasters strike. Communities are further incapacitated and have a limited ability to recover from the impacts of the disaster (Markkanen & Anger-Kraavi, 2019). Despite the challenges highlighted above, the Namibian Government has introduced policies to reduce inequalities and disparities (Füssel, 2010; National Planning Commission, 2017).

## **2.5 Climate variables**

Temperature and precipitation are two important variables in climate science and climate risk management. Precipitation is a critical component in understanding rainfall and how it relates and influences weather phenomenon such as floods and droughts (Chattopadhyay & Edwards, 2016). Temperature plays an important role in the water cycle as well as water demand by ecosystems and humans, and therefore, affects how much

water is required and any measures to ensure sustainable availability (Zhang et al., 2020). In Africa, temperatures have increased at least by 0.5 °C and more in the last 50-100 years (Hulme et al., 2001). The rising temperatures are more evident in minimum rather than maximum temperatures (Hoffmann et al., 2013; Zhang et al., 2020). According to the Fourth Communication to the United Nations Framework Convention on Climate Change in March 2020, temperature in Namibia has been increasing at a 0.0123 °C from the year 1901-2016 with the north eastern parts of the country experiencing the highest increase (Government of Namibia, 2021).

### **2.5.1 Rainfall**

The general, of rainfall at a given time can have wide ranging effects on the environment in general as well as on human lives and how they function. It affects the amount of surface water, influences how ground water is replenished and may even influence river flooding (Trenberth, 2011). Any small changes in rainfall can cause disruption to a wide range of natural processes especially when changes occur quickly therefore, it is important to pay attention to rainfall trends so that any anomalies and or differences beyond the known average can be closely monitored as they may have impacts on living things (Arnbjerg-Nielsen et al., 2013). According to Shea (2017), a trend is the pattern or behaviour of any variable observed over a period. In climate research, the detection, estimation, and prediction of the trend is important as the information is used for decision making in planning around a changing climate (Alemu & Dioha, 2020). Investigations into the changing trends of temperature and rainfall are important as they help identify vulnerable areas and populations at risk so as to implement targeted interventions so as to reduce vulnerability whilst enhancing resilience. (El-ashry & Zeidler, 2009; Niang et al., 2015).

Rainfall data is used for different purposes in planning, research, and practice. Real time daily measurements can be used for decision making in town planning, agriculture productivity, climate change analysis and water resource management and in some cases may be used to estimate flooding in some geographical areas (Harsha, 2017). Real

time rainfall data refers to rainfall data that is available from database daily and sent through electronic means for utilisation (Morbideilli et al., 2021). It can be analysed historically or in real time to check for rainfall amounts, frequency, and intensity. Historical records are useful in analysing trends and pattern and can be used to anticipate drought and flood conditions. According to Rogers (2020), a combination of techniques is used to measure rainfall, and each has its own advantages and disadvantages. Traditionally, rainfall is measured at a weather station using rain gauges such as tipping buckets which measure rainfall using a tipping mechanism, where each tip is recorded by a data logger. Current new technologies are now complementing the traditional rain gauge with radar technology, satellite imagery and interpolation techniques to estimate rainfall over a spatial surface (Auguste, 2018; Carvalho, 2014). Rainfall measurement in Namibia is important as it supports agriculture which is a key sector and the largest employer in northern part of the country. Agricultural output is extremely sensitive to climatic conditions and is directly impacted by changes in rainfall. (Alahacoon et al., 2022; Olanrewaju, 2019).

### **2.5.2 Challenges with rainfall measurement**

Rainfall measurement and the need for quality climatic data is more vital in Africa due to the vulnerabilities presented by a changing climate. In Africa, the primary sources of climate observations are the national meteorological services, whose data is derived from classic conventional stations such as synoptic, climatological, and agrometeorological stations and rainfall stations (Auguste, 2018). Although reliable, rainfall monitoring by conventional means (rain gauges) is unfortunately deficient in most of sub-Saharan Africa, as many rain gauge networks provide inadequate data, thus restricting the usefulness and application weather information, especially if it is required quickly. According to le Coz & van de Giesen (2020), some weather stations in some parts of Africa are few, sparsely located and declining, leading to critical gaps in both historical and current observations. In Zimbabwe for example., the number of functioning weather stations have declined over the years, and this is attributed to aging infrastructure and

that have led to constant breakdowns and thus leading to missing data (Zambuko ,2011),. The main reason for this challenge is the decline in investment especially in harder to reach/ remote weather stations as well as an ailing economy. Where stations exist, they are often of poor quality, with many missing observations due to poor data capturing and monitoring (Mamombe et al., 2017).

Political conflict is another reason why there may be rainfall data challenges, and in most cases, it may lead to disruptions in observation in weather stations. Many parts of Africa have experienced conflicts in one form or another and these have led to loss of data and disruption in observations. In Rwanda for example, the 1994 genocide led to a disruption of records, and it took 15 years for the country to return to its pre conflict level of observation (Dinku, 2019). Other challenges noted in Africa include random errors during observation that created variations in recording data thus distorting the true rainfall amounts (Africa Climate Policy Centre, 2013). In South Africa for example, a project on the maintenance and upgrading of rain gauge and radar infrastructure revealed that the rainfall records in the archives had systematic errors and many record inconsistencies and this was due to deficiencies in equipment calibration (Dinku, 2019; Oluwagbemi et al., 2022). Also, that rainfall records were fragmented amongst different institutions, leading to inconsistencies, and ultimately affecting the quality of data. To overcome the challenges highlighted above, it would require addressing them individually most of which requires active participation from government and in some cases, private stakeholders. Challenges such as ailing infrastructure and sparse data due to limited and inadequate number of weather stations requires intentional financial investment to address them (Oluwagbemi et al., 2022). Other challenges such as systematic and data logging errors require strengthening of capacities and training of personnel at the meteorological centres (Elasha, 2006). Other than investment in physical structures, there are other approaches that can be used to reduce missing data by using data observations from other weather stations such as spatial interpolation and data gridding. Interpolation is described as a process of using known data values to estimate unknown data values and it is important

as it is used to produce continuous rainfall surfaces thus bridging the spatial gaps in a time series data (Wahab, 2017).

Challenges with missing rainfall data can also be solved using satellite imagery which provide spatial data for large areas. The images and estimates can be used to complement and or used to verify rainfall data obtained from rain gauges (Africa Climate Policy Centre, 2013; Oluwagbemi et al., 2022). The advantage of using satellite imagery is that the global coverage give near real time data in a short space of time and the rainfall estimates and spatial products are available mostly for free from different global centres and therefore developing economies can access this to complement their own ground observations (Thies & Bendix, 2011). Unfortunately, though, geostationary weather also has limitations such as the inability to monitor the entire planet due to its fixed design above a particular region of the earth meaning therefore that, a satellite is unable to monitor the earth at the same time. To counter act the disadvantages, mixed methods can be used in collecting data so that results of one can be used in the verification and confirmation of the other. In Southern Africa, the Southern Africa Science Service Centre for Adaptive Land Management (SASSCAL) in partnership with the German Federal Ministry funded the implementation of automated weather stations in 5 southern African countries thus extending monitoring networks to provide freely and accessible data sets for the southern region (SASSCAL, 2020). A total of a 154 automated weather stations and its necessary infrastructure were implemented between the years 2010-2017 and a total of 58 weather stations are in Namibia which give daily readings of temperature, wind, rain and relative humidity (Muche et al., 2018). Not all-weather stations are able to give continuous data due to vandalism and communication interruptions.

Research on precipitation seems to depict more uncertainties in the future for the world at large. The predictions are that there will be tangible changes in rainfall patterns but what is uncertain is the nature of these changes whether there will be decreases or increases in rainfall and at what intensity (Huddleston, 2016). Africa for instance, has been prone to prolonged droughts and spatio temporal variations in rainfall regimes

(Grassl & Menzel, 2007). Recent precipitation data sets depict negative trends in precipitation especially in sub-Saharan Africa (Harrison et al., 2019), which unfortunately will have a negative bearing on the livelihoods of communities that rely on agriculture for subsistence. According to Kotir (2011), sub-Saharan Africa has been highlighted as a vulnerable region due to its dependence on rainfed agriculture, erratic rainfall, and its low capacity to adapt and frequency of extreme weather events.

Extreme weather is defined as an unexpected, unusual, severe, and unseasonal weather phenomenon that causes damage, destruction and sometimes even loss of life (Huber & Gullege, 2011). Examples include heatwaves, cold waves, droughts, floods, and landslides. At a global level, scientists predict that extreme weather events, will increase in frequency and the environment will become more sensitive to extreme weather due to population growth in areas more vulnerable to weather and climate extremes (Mika, 2011).

## **2.6 Understanding floods**

Floods have become one of the consequences of climate change that countries are faced with. They normally occur when there are excessive amounts of precipitation received. Floods are defined as a relatively high-water flow that overtakes the natural channels provided for runoff (Balasubramanian, 2016). There are many reasons why floods occur, and, in some cases, they may not be directly related to an ongoing weather event and therefore, the flood description needs to be holistic and include information and processes that may not be directly linked to the meteorological events (Doswell, 2003a).

### **2.6.1 Types of floods**

Different types of floods occur time and again in the world and for this study only riverine and pluvial floods are discussed because of the identified unique characteristics of the study area which has a river cutting across the urban area. Riverine flooding is defined as flooding that occurs when streams and rivers exceed the capacity of their natural or

constructed channels to accommodate waterflow and spills out into adjacent low-lying dryland (Smith et al., 2021). Riverine flooding can occur slowly as the water increases over a period of a few days or even a month. The slowness in occurrence is because stem rivers are typically fed by many other tributaries that discharge into it, which then causes the river to gradually increase (Doswell, 2003b). According to Eccles et al (2019), river floods are known to pose a lower risk for fatalities when compared to other forms of flooding because they take longer to occur, and this allows for monitoring whilst at the same time, giving room for decision making and action thus preventing possible catastrophes. According to Spaliviero et al., (2014) in the Limpopo River basin, human settlements tend to be closer to the river due to the semi-arid climatic conditions found in the area and often these areas are prone to flooding.

Pluvial floods refer to flooding that is caused by extreme precipitation such that the ground cannot absorb rainwater effectively leading to accumulation of large volumes of water on the ground surface (Douglas et al., 2010). During pluvial flooding, urban stormwater drainage systems are overwhelmed and the carrying capacity exceeded because the rainwater quickly accumulates in a localised area. The likelihood and occurrence of pluvial flooding is higher in urban areas due to the high proportion of tarmac and paved surfaces, which limit infiltration thus increasing the amount of surface runoff as well as the pressure from the growing population densities and degree of urbanisation puts pressure on existing drainage systems (Houston et al., 2011). Unfortunately, pluvial flooding gives citizens and emergency responders limited time to act as they happen fast, leading to consequences that include death and damage to property. In Dortmund, Germany for example, local rain of 200 mm fell over a three-hour period which led to a loss of 20 million US dollars, whilst in the UK flooding in 2015/16 was estimated to have cost the economy 1.6 billion pounds (Prokić et al., 2019; Rözer et al., 2016). Other challenges with pluvial flooding include the fact that they occur at a much smaller scale, often localised to one area and this makes them overlooked in most flood management plans and warning systems. Most cases of pluvial floods occur in areas that are not prone to flooding and where no flood defences are in place. Pluvial floods can be minimised by installation of

flood proofing infrastructures such as flood shoulders and walls, increase of drainage capacities by separating storm and foul drainage systems (Becker et al., 2022).

### **2.6.2 Impacts of floods**

Floods produce damage through the immense power of moving water. During flooding, accelerated runoff occurs and the moving water carries along debris and dirt, and these can cause problems when deposition occurs when the water finally recedes (National Oceanic and Atmospheric Administration, 2005). If the water moves fast enough, it leaves terrible scenes of disaster (Müller et al., 2011a). Floods impact both individuals and communities in different ways and they have various consequences, on humans and the environment. Southern Africa in the last decade has experienced a number of flooding episodes that have affected communities negatively. Notably, most floods that have devastated communities in Southern Africa are because of tropical cyclones for example *Cyclone Idai* in 2019, *Dineo* in 2017 and *Chedza* in 2015 (Chapungu & Nhamo, 2021). These cyclones and tropical storms displaced communities and left people without drinking water and basic sanitation and as a result conducive conditions for the proliferation of diseases such as cholera and malaria resurfaced (Eine & Tshilunga, 2014). In Mozambique, in particular, Cyclone Idai, swept across the city of Beira causing 90 percent damage to the city (IRI, 2007).

The impacts can be short or long term and can bring out both positive and negative consequences which vary according to location, economy, extent of flooding and vulnerability before flooding. The immediate impacts to humans include loss of life, damage to property and service infrastructure such as power lines, transport, and communication, shutting down of schools and businesses and contamination of drinking water which may lead to outbreak of diseases (Twigger-Ross, 2005). Flooding also affects the natural environment in many ways including destruction of wildlife habitats, siltation and bursting of riverbanks, pollution of rivers due to contamination by flood waters and destruction of agricultural crops due to water inundation amongst others (Aldardasawi & Eren, 2021; Hickey & Salas, 1995). On the positive side, floods and flood waters also bring

about benefits. According to Parker et al (2005), beneficial flooding normally inundates over 20.5 % of the land area and this allows floods and the flood runoff to bring nutrients, which are beneficial to the different land uses, such as agricultural land as well as natural ecosystems. The increase of nutrients comes from algae and other stems of plants in flood water which decompose, thus releasing nutrients to plants. Floods also replenish ground water aquifers especially in parts of the world, where there are reoccurring droughts (du Plessis & Viljoen, 1999). In such a case, ground water aquifers fully recover by natural recharge and the water can be used at a later stage. Flooding can also benefit fisheries and communities through increase in habitat for fish, stimulating fish productivity in communities and increase in specie abundance and richness (De Graaf et al., 2001). In northern Namibia for instance, flood waters are called 'efundja' which refers to nutritious flood waters that bring different kinds of fish species. Furthermore, Phillipe(2022), explains that fish are also a source of animal protein and can supplement a diet especially for rural communities, who have less access to other forms of animal protein. For communities to reap the benefits, prudent flood management approaches must be instituted to reduce damage to acceptable levels

### **2.6.3 Long term impacts**

The long-term impacts of floods are caused by the consequences arising out of short-term impacts of flooding. The country of Mozambique faces challenging tropical storms and cyclones repeatedly due to its geographical location along the coastline. This has led to significant economic and infrastructural losses every year. According to ORCA, 2023, the country was battling with infrastructural damage caused by cyclones in previous years. The damage of flooding because of cyclones is felt across all development including schools, hospitals, roads, and power lines. In February 2023 after cyclone Freddy an estimated 18 000 people in Mozambique were left without electricity due to damaged energy poles. The impacts of such disasters slow down economic growth and development due to high cost of relief and recovery. According to the Bloomberg Business, 2019, estimated cost of damage caused by cyclone Idai in Mozambique is \$773

million (Koivisto, 2020). Reoccurring flooding in an area may also discourage long term investment thus slowing economic growth. Damage to infrastructure causes prolonged disruption of vital service equipment, such as communication and drinking water delivery (Gray, 2008).. Floods can traumatise families for long periods of time due to loss of loved ones, injury, and displacement from homes. Furthermore, loss of income may negatively affect livelihoods due to inadequacy in home provisions leading to stress (Foudi et al., 2017). In 2019, Cyclone Idai and Cyclone Kenneth swept across Mozambique, Malawi, and Zimbabwe just before the annual harvest leaving devastating impacts on agriculture, leading to dire impacts on food security and livelihoods beyond that season (IRI, 2007).

Floods are difficult to manage and mitigate effectively without data about the cause, impacts and the associated damages (Jonkman & Dawson, 2012). This is caused by the fact that during a flood, the priority is to save lives and minimise impacts, thus flood impact data is often collected reactively. According to IPCC Fifth Assessment Report, Southern Africa is also experiencing “upward trends” in temperature, as well as increased variability in precipitation (Easterling et al., 2012). It is not clear to what extent a natural hazard develops into a disaster; it is dependent on a community’s capacity to withstand the effects of the hazard. Basin communities are attractive locations because of the aesthetic value, viable farming land and accessibility to water, which make them a favourable settlement area (Aktaş & Yıldız Donmez, 2019).

## **2.7 Flood Management**

Human beings are limited in efforts to stop the occurrence of extreme precipitation, however, there are many interventions that can be instituted to minimise the impacts and consequences of flooding through structural, non-structural, and natural means (Forbes et al., 2015). The structural means include flood defence mechanisms such as flood and storm water drainages that channel water away from settlements and flooding buffers that stop water from accumulating in an area (Osti, 2018). Other means include construction of man-made defences such as levees, reservoirs, and weirs to prevent the river from bursting its banks leading to flooding to adjacent settlements and when these fail,

emergency measures such as the use of sandbags and inflatable tubes are pursued (Tariq et al., 2020). Natural means ensure that rivers that flow upstream are slowed down through their natural defences in the catchment allowing for water storage and slow release of water through the channel (Forbes et al., 2015). The flood type will prescribe the flood structures that will be required.

### **2.7.1 Non-structural flood management practices**

Structural measures can never eliminate the risk of flooding and can also create a false sense of security in some cases. Non-structural measures play an important role in reducing consequences of residual risk and must be used as complementary measures. Common non-structural flood management measures include land use regulations, flood forecasting and warning, flood proofing and emergency preparedness and response recovery (Kang et al., 2009).

Land use regulation are rules and ordinances relating to the use of land for any development, and the regulations play an important role in flood management as the legal frameworks protect and guide development of land and ensure non encroachment in water pathways and flood plains (Poussin, 2016). In Mozambique for example., policies are in place for domestic flood management such as the National Policy on Disaster Management 1999 and the Land Tenure Act which allows for planned resettlement of its citizens, on account of disasters and vulnerability to climate change (IRI, 2007).

Other than regulating land use, administrative actions are required to ensure that structural provisions meant to reduce flooding work are constructed and maintained accordingly otherwise they can contribute to flooding if they are not cleaned and cleared before the onset of the rainy season (Der Sarkissian et al., 2022). Other non-structural means in flood control measures include the use of flood forecasting and warning. Flood forecasts are defined as the process of predicting and estimation of the possible flood based on known characteristics, and it may indicate the possible flood levels and likely impacts (Jain et al., 2018). The forecast provides decision makers with information so

that appropriate preparation is undertaken to protect people and ensure minimal damages occur (Soleimani-Alyar et al., 2016; Tilford et al., 2007). Furthermore, forecasts are used in sensitising the community at risk to flooding to ensure they are aware what to do, should an emergency occur (Granberg, 2013), .

## **2.8 Flood mapping**

Floods can occur anywhere and whilst they are unpredictable, certain tools can be used to reduce the risk and help minimise loss and damage to property. Flood maps are one of the tools used in communicating the risk associated with floods and they are useful for decision making in several activities for example, land-use planning, building standards, transport networks and emergency management. The maps outline the probable risk so that preparation can be done accordingly (Mohanty & Simonovic, 2022). There are two main types, namely flood hazard map and a flood risk map. A flood hazard map provides information on how probable and how extensive the floods will likely be if they were to occur and reveals the type of flood expected in the area (Spachinger et al., 2008). A flood risk map on the other hand, uses information from the flood hazard map to identify vulnerability through identifying potential consequences that a community may face during a flood scenario. Consequences may be on businesses and infrastructure and anything else that is at risk of flooding.

In Namibia, following the floods of 2008 and 2009 in the Northern region, the National Planning Commission undertook a Post Disaster Needs Assessment (PDNA) in coordination with the European Commission and United Nations. The purpose was to assist Namibia in developing a holistic approach to recovery and reconstruction whilst incorporating sustainable disaster risk (Government of Namibia, 2009). This PDNA led to the initiating flood mapping exercise to identify areas of high risk of recurrent flooding. Unfortunately, this was not completed, instead various piecemeal studies are being conducted at research level, after flooding events.

### **2.8.1 Flood data techniques**

To be better prepared for the flood event, a combination of various technical data is required to ensure comprehensive understanding of the flood hazard as well as to produce the maps. To produce flood maps environmental data such as water quantity, water level, topography, climate, and meteorological data are required. (Mohanty & Simonovic, 2022). Furthermore, a combination of various techniques is used to determine flood hazard and risk to develop the flood map. The most common tools for risk mapping are the use of drones for capturing real time images, GIS, and remote sensing techniques and other cartographic software.

### **2.9 Vulnerability, adaptive capacity, and resilience**

Vulnerability, adaptive capacity, and resilience are three concepts that are often used to explain how human and natural systems respond to environmental changes. Fellman (2012), describes vulnerability as the level to which a community is susceptible to the adverse effects of climate change with or without coping mechanisms. The net result or impact may be positive for resilience or negative to become vulnerable. Lavell et al., (2012), explain that diverging views on the definition of vulnerability allows flexibility in application across the differing contexts in the world, because resilience cannot be reduced or simplified to one single perspective. Moreover, no two locations are the same, meaning therefore, that progress in human development, such as standards of living, access to basic services, education, housing, and sanitation will vary across locations and these have a direct bearing on vulnerability. Thus, the definition of vulnerability is largely defined by the context in which it is applied because the indicative indices and methodologies employed to measure it vary across regions and countries (Baky et al., 2020).

As with the definition, there is no definitive way to calculate vulnerability as it is a complex subject that considers several inherent factors in a community before the exposure to the hazard. According to the Reisinger et al (2020), the level of risk of the hazard needs to

be known before vulnerability is determined and they suggest the following formula to calculate risk as proposed by Ristic (2013):

$$Risk = Probability \times Severity$$

Where;

**Probability** is the likelihood of occurrence of a particular hazard.

**Severity** is the magnitude of the consequences that may arise from the occurrence of the event.

Risk in this instance is given a numerical value and the quantitative assessment allows for hierarchical ranking or grading risks so that control measures are prioritized. This risk assessment is used alongside a risk key that assigns values for both probability, severity and the results envisioned shown below:

**Table 2 1:Risk key**

Risk =P x S	
<b>Probability:</b>	<b>Severity:</b>
1- Harm unlikely to occur.	1- Negligible consequences.
2- Harm less likely to occur.	2- Minor disturbances and losses.
3- Average chances of harm occurring.	3- Medium disturbances or losses.
4- Harm occurs often.	4- Serious disturbances/impacts or losses.
5- Harm is highly probable.	5- Catastrophic consequences, e.g., death, damage to building structures,

The outcome gives an estimation of risk and is then used in the prioritization of risk control.

OUTCOME
---------

<b>20-25:</b> Catastrophic risks
<b>10-16:</b> Serious risk
<b>4-9:</b> Medium risks
<b>3-4:</b> Minor risks
<b>1-2:</b> Negligible risks

The preceding process of risk assessment informs the level of risk present and whether it is tolerable or not. A tolerable risk is a risk that can be lived with if control measures are instituted (Pereira et al., 2022). The instituted measures include engineering controls, and in the case of floods, the building of flood control buffers is an example of engineering controls that can be considered. In administrative control the drawing up of a flood policy could be taken into consideration. This whole process will then guide decision makers in mapping the potential risk. Risk mapping is often used inextricably with risk analysis because the two stages overlap and are interdependent (Moss et al., 2001). The risk assessment process involves analysis of the characteristics of climate threats such as intensity, probability of occurrence and location (Institute of Risk Management, 2018). The focus on these characteristics will reveal the likely impact of the threat on different sectors of the society while also evaluating the effectiveness of current and optional coping strategies in specific scenarios (Sherbinin, 2014). According to Kim & Lee (2016), a climate risk assessment is incomplete without computerized geo-referenced data as it is used to disseminate spatial information that is used in analysis of the risk.

Once the risk is known, vulnerability is then calculated as:

$$Vulnerability = Risk - Adaptation$$

In this instance, vulnerability is the sum of residual impacts after adaptation measures have been implemented. Indices are used to measure adaptation; their application, however, varies from location to location. Whilst vulnerability can be calculated, it cannot be declared with confidence as vulnerability is complex and adaptive methods may not

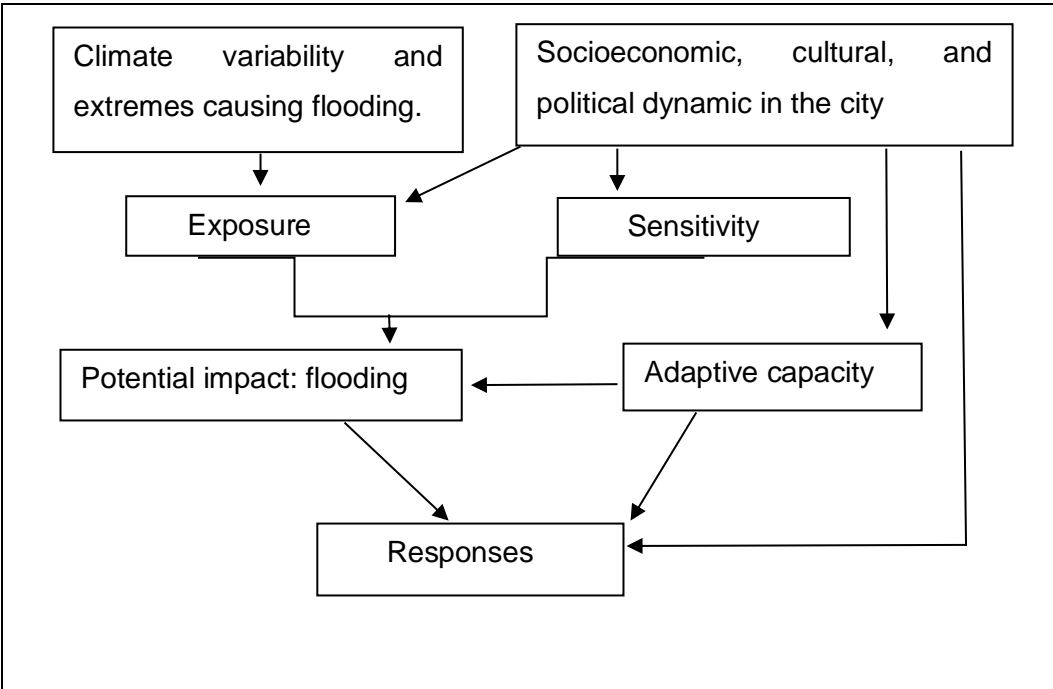
work as intended as the intensity of the hazard may be greater than expected despite measures put in place (Gravitiani et al., 2018).

Vulnerability has many dimensions to it that must be assessed to obtain a holistic picture and these dimensions include spatial, temporal, social and biophysical (Schneiderbauer et al., 2020). Spatial reference refers to how wide the vulnerability is as well as identification of inequalities that exist in the community, for example in an urban area those living in slum dwellings are more vulnerable than in wealthier dwellings (Duncan, 1988). Temporal reference refers to vulnerability understood in terms of time scale for example what happened in the past and what is happening currently, and social reference refers to socio-economic constraints for example poverty and limited access to resources which then limit response capacity to external pressure. This can be at an individual level or group level (Füssel, 2007).

Although vulnerability may be different across geographical scales, the assessment follows a similar pattern as the common idea is to reveal areas at risk. The assessment mostly includes identification of vulnerable groups and their livelihoods that are threatened due to climate risk and describes potential vulnerabilities if no mitigatory or risk reduction measures are put in place (Thornton et al., 2014). When this is done, points and options where interventions can be instituted to ensure adaptation are identified within the community. Community vulnerability is determined by how well a community responds to exposure to an environmental stress and its response depends on its inherent sensitivity and capacity to adapt (Wang & Sebastian, 2021). It is influenced by various factors that include but are not limited to, the economy, governance, institutions available and physical and infrastructural resilience. How well a community responds to environmental stress is linked to how vulnerable the community was before the stress occurred. Understanding and addressing community vulnerability is essential for risk reduction and resilience building. There are several countries that have been classified as vulnerable due a variety of factors such as geographic location, socio economic

conditions and existing infrastructure. For example, low lying coastal countries such as the Philippines and Indonesia are particularly vulnerable due to coastal location and rising sea levels. In Africa, countries like Somalia and Sudan are classified as vulnerable because of the extreme climate they face.

Lankao and Qui (2011) posit that vulnerability is shaped by both internal and external factors, which disturb the status quo of a system, and they propose a conceptual model on vulnerability to flooding depicted in Figure 2,3:



**Figure 2. 3 Conceptual model on vulnerability.**

Source: Lankao and Qui (2011)

The diagram above explains that a community is made up of the socio-economic, cultural, and political dynamics and these will determine the extent of vulnerability and its adaptive response. If the system already has pressure on the baseline or foundation, flooding induced by climate change will simply amplify challenges and worsen the already existing situation. So therefore, communities that have a higher adaptive capacity and a strong

foundation will be able to bounce back much faster back to its known normal than a community that has less capacity.

Research on risk and vulnerability of humans to climate hazards have increased in the last couple of years. The purpose of these studies are mainly on identifying the groups that often experience adverse effects (OCCIAR, 2019). Knowledge of vulnerability is important in identifying hotspots and this can be done through several developed methodologies, either singularly or combined (UN Environment, 2017). The methods used to measure exposure to risk, and vulnerability for various groups of people are in high demand as the development of such, will determine the strength of the response strategies as well as enhance the understanding of underlying processes (Adger et al., 2004).

### **2.10 Adaptive capacity and resilience**

An understanding of climate change impacts through vulnerability mapping, means proactive strategies can be coined and implemented. This can either be through adaptation and or resilience. Adaptation is explained as taking appropriate action to prevent and or minimise the adverse effects of climate change (Greve & Boswell, 2014). According to the UNFCCC report on National Adaptation Plans, adaptation solutions may take different forms and are dependent on the specific context (UNFCCC, 2012). For the adaptation strategies to be successful, there is a need to have active and sustained engagement with all stakeholder's such as government, civic society, and the public. This will ensure that the different dimensions of adaptation are addressed and should be driven by the local communities to enable transparency and gender sensitivity.

The term resilience, on the other hand builds up from adaptation. The essence of the approach goes beyond acclimatising to a situation. According to Vasseur & Jones (2015), resilience is the means that a social or ecological systems has, to be able to absorb interruptions and still be able to function even when there is a change. It is imperative to

recognise that, despite the challenges brought out by climate change, there are still opportunities for transformation within the challenges, that will allow socio-ecological systems to be renewed and developed (IEMA, 2015). These challenges provide latitude for innovation and create pathways to improve the system structure (Ebi, 2016).

Creating climate resilient communities requires co-operation from communities' businesses and government in addressing the threat of adverse weather events because communities that are resilient to climate change can effectively prepare for and recover from its effects, thus continuing to thrive (Charles et al., 2022). Resilience is not a onetime event; it requires deliberate and enabling action and environment for it to be successful. The important enabler in any community is supportive governance and policies that can be implemented at local and national level (Mu et al., 2020). The examples include governance structures, adaptive management frameworks and legal frameworks that can enhance coordination and accountability. Furthermore, equipping communities with the necessary skills, knowledge, and resources to adapt to a changing climate is important as it will empower individuals and communities to implement resilience measures effectively (Rigolini & Bank, 2021). Technical training programmes for example can build capacity at the community level.

Other than an enabling environment, community resilience leverages on various resource assets that enable them to withstand, adapt and recover from shocks and stresses. An asset is described as resources, advantages, and capacities that a community or individual possess that can leverage to achieve specific goals or challenges (UCLA, 2020). These assets can be grouped into natural, human, financial and physical assets. Financial assets include money, savings, and investments, whilst physical and natural assets include physical properties such as land, ecosystems, biodiversity, and environmental quality (Lazarus et al., 2017). Various assets can interact and complement each other to create a strong asset base that is essential for resilience and sustainable development.

According to Shammin et al (2022), in flood resilience, the focus is lowering vulnerability so as, promote fast recovery despite changes and disturbances encountered. (Mcbean et al., 2021). Minimising flood damages can be addressed through flood resistant strategies such as land use controls, flood preparedness, financial support, and risk awareness. In land use control, spatial planning considers flood aspects and in turn define land use through building regulations such as building codes, zone ordinances and prohibitions. Building codes and standards set the minimum acceptable requirements necessary for protecting people and property, whilst zone ordinances regulate land use in the location or community (Pottier et al., 2005). Any strategy that works towards minimising floods requires some financial resource support. Flood prevention structures, policies and insurance all require funding, and these should be availed before and after the flood to allow for planning and ensuring preparedness for the floods whilst also supporting the recovery of the communities after the flood event (Aerts, 2018) . The financial support accelerates recovery plans allowing the community to recover faster and bounce back to normal.

Thus, flood preparedness requires adoption of a comprehensive approach that integrates prevention, preparedness, response, and recovery efforts so as to minimise impact on human lives, property and the environment. For this to be possible, communication needs to be clear and consistent and must be framed in a deliberate and tactful way to ensure that people understand the potential threats and take appropriate action to protect themselves. (Heldsinger et al., 2018). Also, hazard communication must be continuously updated to move communities from learning from experience to learning from education so that adverse threats of floods are prevented (Africa Climate Policy Centre, 2013).

### **2.11 Steps to building resilience**

According to Mbah & Ayegba (2013), building resilience to climate requires a holistic approach to prevent, anticipate, and ensure slow onset of events, adapt, and transform in the longer term. To enable this, all stakeholders must be involved.

The United Nations Climate Change Action Pathway (Global Climate Action, 2021) proposes the following steps as necessary for building resilience across communities.

a) Raising awareness

Information dissemination regarding climate is important for decision making at individual and community level as changes in climate have significant impacts on present lives. The disseminated message should be clear so that risk perception facilitates informed decision making.

b) Risk assessments

To ensure action is taken to prevent and adjust to climate change, the actual risk must be known to encourage action from society to ensure that specific climate risk management is appropriate for the context is implemented.

c) Mobilising financial resources

Capacity building and some climate action requires financial resources to support the activities to combat climate change.

d) Monitoring and tracking progress

Climate change action requires constant evaluation and tracking of adaption progress across a range of scales as a means of ensuring that the stated objectives are achieved.

e) Knowledge sharing

Knowledge sharing in the climate change discourse is important as it ensures that vulnerable communities have access to the requisite information to enable them to adapt.

While it is essential to note that building resilience is an ongoing but complex process rather than a fixed status, many countries are recognised worldwide for their effort in building resilience to climate change. Examples include Denmark, Sweden, Norway, and the Netherlands. Norway has implemented policies to reduce use of fossil fuel and has invested in hydropower and wind power whilst also actively protecting its carbon sink through sustainable forestry practices (Antonsen et al., 2022). Sweden on the other hand

is known for its commitment to sustainability and has actively implemented measures to reduce carbon emissions and invest in green technologies (Kristianssen & Granberg, 2021). In Africa, the country Ethiopia is celebrated for its active efforts in building resilience through investing in hydropower, solar and wind energy and climate resistant agriculture that focuses on drought resistant crops (UNFCCC, 2019).

## **2.12 Conceptual model in research**

In recent years, the use of conceptual models to explain ideas in many fields of research has increased. A conceptual model is defined as an abstract visual representation of generalised ideas (J. Liu et al., 2011) . The main purpose of a conceptual model is to analyse different variables and their assumed cause and effect relationships. The advantage of using a conceptual model is that the stakeholder is forced to think carefully about variables and give precise descriptions that will help in attaining the result (Robinson et al., 2016).

According to Grant & Osanloo (2014), the problem statement and the research questions are the starting point of developing a conceptual model where relationships are loosely defined. From the problem and research questions, the researcher must draw up dependent and independent variables and these will form the frame of the research. Once the variables are known, the causal link need to be established and relationships between them and how they influence each other will be unveiled in a cause-and-effect relationship (Pilkington & Prestorius, 2015).

## **2.13 Conceptual approaches of resilience**

Literature provides a variety of conceptual models that are used to understand how communities move from being vulnerable to develop coping mechanisms that will render them adaptive. The following section reviews different models put forward as possible roadmaps to adaptation and/ or resilience. In flood risk management, the concept of

resilience can be analysed through three main approaches namely engineering, ecological and socio ecological.

### **2.13.1 Engineering resilience**

In engineering, the definition of resilience is measured based on outcomes, focusing on flood hazard mitigation through flood resilient design and technologies to ensure that the risk is reduced significantly (Woods et al., 2016). It is mostly applied in planning, architecture and in building technology with the aim of reducing failure to a minimal so that recovery time is reduced in the event of a flood (Leveson et al., 2006). According to Keenan (2014), there are different engineering dimensions considered in the life cycle of flood management. Firstly, when planning and designing a system, the infrastructure must have the ability to absorb and withstand disturbance through including an allowance for excess capacity so that it can remain unchanged in the event of a disturbance (Hickford et al., 2018). Furthermore, the system should also be flexible to allow for adaptation when the circumstances have changed during the disturbance and lastly, the system should be able to respond quickly. An example of a framework used to measure engineering resilience is the graph theory framework where mathematical algorithms are applied on spatio-topographical networks in a hydrological system of a city to measure resilience of infrastructural assets to flooding (Nam et al., 2022). On the overall, engineering resilience assumes that a system, if designed properly, remains the same over time.

### **2.13.2 Ecological resilience**

Ecological Resilience refers to the ability of an ecosystem to absorb disturbances for example storm surges but remain functioning under a wide flood wave or rainfall intensities (Jianguo & Tong, 2013). The definition implies that the natural system can return to its original state after disturbance and or absorb the change and disturbances but remain the same meaning that the system continues to function by withstanding the floods or through quick recovery after the flood (Holling, 1973). Unlike engineering resilience

that remains the same, in ecological resilience the post disruption state is different from the pre-disruptive state.

### **2.13.3 Socio-ecological resilience**

Socio ecological resilience is defined as the ability of a system to absorb recurrent disturbances such as floods and be able to retain essential structures and processes whilst building capacity for adaptation (Garmestani et al., 2019). This implies that the system does not remain static like that of engineering resilience but changes slowly due to exposure to drivers such as climate change, population growth and resource depletion (Cinner & Barnes, 2019).

### **2.14 Comparison of the three approaches**

Engineering resilience describes functional stability of infrastructure and technological systems, it assumes that system remains constant over time, which may be true if flood events are moderate but however, may not necessarily hold true for extreme events as they may be disruptive may induce transformation. Ecological resilience on the other hand, is associated with complex dynamics of ecosystems that aim at reaching a state of equilibrium in whatever circumstance whilst socio ecological resilience overcomes both approaches by not remaining constant but slowly adjusting to changing conditions, thereby transforming over time. In essence, the concept of resilience as articulated in the three approaches is the same and the main aim is to learn to live with floods and not to seek to avoid them completely. Learning to live with them implies that a combination of measures needs to employ to reduce risk through protection, prevention, and preparedness.

### **2.15 Review of frameworks**

This section will evaluate four frameworks that have been developed and used to address community resilience. The purpose is to learn, reflect and improve on gaps identified.

### **2.15.1 Climate resilient cities framework**

The Climate resilient cities framework was developed by ARUP International Development in 2014 and it proposes a pathway to think differently about climate adaptation in urban areas. It proposes three main key elements and explanation of each that provides a way to think differently about climate adaptation in cities. Normally, researchers on climate resilience, focus on future climate projections to define uncertainties of climate risks, but in this framework local planners attempt to address resilience by identifying the enabling infrastructure, ecosystems, and capacities that affect resilience in the city (ARUP, 2015). The framework highlights that resilience will often be successful if it is led by local actors who will partake in operationalising the planning process of resilience. Involving both the locals and agent capacities ensures that the system designs and links proposed by technical agents are interlinked with socio economic data and ensures that information is available to the people, who are affected, who can then actively participate in decision making.

### **2.15.2 PEOPLES resilience framework**

The PEOPLE's resilience framework is an approach proposed by the United Nations Office of Disaster Risk Reduction as a revision of the Hyogo Framework for Action 2 and it is used to holistically measure resilience using seven different dimensions and lead indicators and these dimensions are identified using the acronym PEOPLES, which stand for People and demographics; Ecosystem; Organised governmental services; Physical infrastructure; Lifestyle and community competence; Economic development and Socio-cultural capital (Renschler, 2013). The PEOPLES framework allows for development of specific quantitative and qualitative methodologies that continuously measure the functionality and resilience of communities against extreme events or disasters in any combination of the above-mentioned dimensions. The dimensions can be observed independently or interdependently or at fixed time intervals and it is also performance based, applicable to both large and small scales.

### **2.15.3 Disaster resilience framework**

This framework proposed by the U.S. Government Accountability Office (GAO) in 2019 and is a guide to strengthen community resilience when it comes to natural disasters. The framework's objectives are designed to create a blueprint to assist governments explore opportunities to promote resilience to disasters by reducing the costs related to the climate disasters and is organised around three main principles, which are information, integration, and incentives (GAO, 2019). In the framework, it is important to note that authentic and understandable information is critical as it will assist decision makers in identifying current and future risks. Once this information is obtained, integrating the information in decision making is vital as this will lead them to take coherent and coordinated actions. Lastly GAO, proposes that provision of incentives will ensure that long term risk reduction investments are attractive and viable to competing priorities. The guiding aim of this theory is that the costs in preparing, responding, and recovery in natural disasters is going up in both the public and private sectors. Rather than reacting to disasters, GAO is meant to provide a proactive guide for future policy and funding decisions that impact us all.

### **2.15.4 Building resilience against climate effects (BRACE)**

The Building Resilience Against Climate Effects (BRACE) is a framework developed by the US Centres for Disease Control to assist public health officials adapt to the health impacts of climate change by providing a structured approach for identifying climate related risks, assessing vulnerabilities, and implementing adaption strategies at community level. (Kintziger & Jagger, 2013). Atmospheric data and climate projections are used and incorporated into public health planning and response activities so that health officials are better placed in effectively responding to a range of climate sensitive health impacts.

According to Marinucci et al., (2014), the five sequential steps of the BRACE framework involve firstly anticipating climate impacts and possible vulnerabilities. This is done so

that one can then project the disease burden (estimated quantities), which will then direct precise health interventions while also allowing for development of a climate and health adaptation plan. The health adaptation plan then ensures strategic implementation to help curb any vulnerabilities while also allowing for evaluation of the whole process.

## **2.16 Gaps in existing frameworks**

A summary of each framework has been discussed above. Some of the four selected frameworks were not all specifically developed for the purpose of community resilience assessment, but each was chosen since because it was found to address one or more important aspects of community resilience. The primary objective for the review was to identify if any of the above could be used as a theoretical framework that could guide this research. However, the review revealed that the tools and methodologies of each, independently were inadequate as a guide that could be followed as each had its own strength and weaknesses.

For instance, the disaster resilience framework as proposed by GAO, dwells more on the provision of timeous information being a propeller for any climate resilience efforts (GAO, 2019). Therefore, not much effort is done on ground methodologies on ensuring community resilience. The climate resilient cities framework on the other hand advocates for community participation in creating resilient cities and their argument is that the local people and organisations are knowledgeable about their systems and therefore are better placed to provide information for planning (ARUP, 2015). Amongst the four frameworks discussed above, the PEOPLES's framework is the only one that incorporates the three resilience dimensions discussed above. It recognises the engineering, ecological and adaptive processes required for resilience in a community, but however seems to put emphasis more on disaster recovery rather than pre disaster preparation (Renschler, 2013).

In summary, this chapter sought to evaluate literature on key concepts that are important to the subject of resilience, vulnerability, and adaption. Effects of flooding were

considered, and examples of countries affected by floods were highlighted. Further examples of countries who have taken strides in resilience were also highlighted and resilience pathways identified in the respective countries were reviewed. Lastly 4 frameworks were evaluated were shown to be important and valid as they provide valuable insight on strengths and weaknesses of implemented programs implemented across sectors to address climate hazards. The frameworks provided guidance for opportunities for improvement in addressing the complex and urgent climate change challenge.



## **CHAPTER 3: MATERIALS AND METHODS**

### **3.1 Introduction**

This chapter describes the materials and methods used to collect and analyse data in this research. The obtained results were then used in developing a conceptual model of resilience.

### **3.2 Material and methods**

#### **3.2.1 Sampling**

The rainfall data from used in this research was obtained from the Namibia Meteorological Services Department for the year 1968-2018. The historical data sets given were from two complimentary weather stations in Oshakati Town, Namibia. Both had daily and monthly records of rainfall data

Data collection for the research occurred in phases, with historical precipitation data obtained in 2020. However, due to various COVID-19 lockdowns faced by the country during that period, the field research was delayed and eventually conducted between 2021 and 2022.

### **3.3 Data collection and analytical techniques**

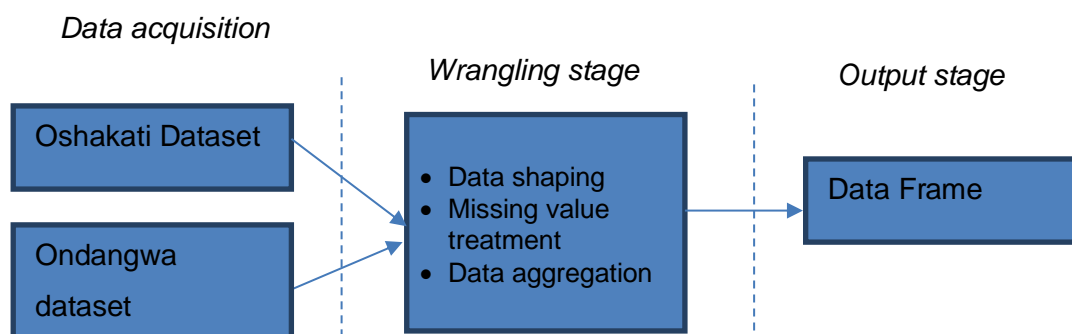
Data collection refers to a stage in the research process, where information is gathered using different means and instruments. In this research, data was gathered after the researcher was granted ethical clearance from the North-West University Research and Ethics Committee; the National Commission of Science and Technology (NCRST) in Namibia and the Oshakati Town Council governing the study area (Appendix 1).

#### **3.3.1 Climate variability- objective 1:**

To assess historical trends of climate variability in the Cuvelai-Etosha Basin (Namibia).

To assess historical trends, monthly rainfall data for 50 years (1967- 2018) was analyzed to understand the changes in precipitation patterns over time. According to WMO (2011), a trend analysis is an ordering of observations by their time of occurrence. It is an important tool for identifying time-related variations (Gofa et al., 2019).

The following steps were taken in dealing with the rainfall data, and this includes data acquisition and data wrangling, whose stages are abstractly highlighted in Figure 3.1 below.



**Figure 3. 1 Data handling process to evaluate the climate variability.**

As indicated in Figure 3.1, the data handling process has the data acquisition, wrangling and output stages, each with a specific focus. The first stage was to acquire the data and prepare it for data wrangling. The wrangling stage adds value to the received data units by applying operations that deal with missing values, eliminating non-significant attributes, decomposing composite attributes, and reshaping the data to produce a data-frame. A data-frame is the output of the wrangling process and contains data shaped in a manner that is supportive of ad-hoc querying as well as further simplifying data analysis. The three stages highlighted in Figure 3.1 for data preparation are discussed in the subsequent sections, and are specified using a mix of *Relational algebra*, *List*, and *Tuple* theories.

### 3.3.2 Data acquisition:

The precipitation data used in this study was obtained from the archives of the Namibian Meteorological Service (NMS), from two basic weather stations, Oshakati and Ondangwa. The primary data set for this research was for Oshakati, while the Ondangwa data set was used in the wrangling process during the treatment of missing data. The Ondangwa weather station is within the 10 km radius of Oshakati weather station, and this research by comparison, identified no significant differences in rainfall readings between the two, and therefore used Ondangwa's values, where the Oshakati's data has some missing values and vice versa. Such a decision is also supported by Jaffrés & Gray, (2023) who put forth that there exist no significant differences in precipitation data for areas within the 10 km radius of each other. The structure of the collected precipitation data is highlighted in Figure 3.2:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	
1	DsetID	StnID	Code	YYYY-MM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2	005	1200375A	5	Mar-67	0.2	16	8	0	0	2.5	7.8	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.3	0	0
3	005	1200375A	5	Apr-67	0	0	0.3	1.5	6.5	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.5	4	0	0	0	0	0	0	-99999
4	005	1200375A	5	Nov-67	0	0	0	19.5	1	0	10.5	16.1	0	11	0	20.1	3	5.2	10	37	2	45	3.1	12	0	0	0	0	0	30.8	0	32.5	0	0	-99999	
5	005	1200375A	5	Dec-67	0	0	0	0	0	0	9.5	10.5	17.5	46.7	13.5	0	0	10.7	12	0	0	12	0	21.4	0	0	0	0	0	0	0	0	0	0	0	0
6	005	1200375A	5	Jan-68	0	0	0	0	4.4	0	5.5	29	0	0	0	0	0	15	3.5	15.5	0	0	0	0	0	0	0	0	0	0	0	7.5	0	0	2.7	
7	005	1200375A	5	Feb-68	0	0	3	0	0	16.3	8	6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3.5	0	0	0	0	0	0	-99999	-99999	
8	005	1200375A	5	Mar-68	2	28.3	12.8	0	0	2.5	19.5	21	0	9	2.9	17.5	4.2	14.4	10.2	0	1	27.3	2.5	0	0	0	0	3	0	17.5	0	0	0	0	0	
9	005	1200375A	5	Apr-68	0	0	0	0	16.6	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-99999	
10	005	1200375A	5	Nov-68	0	1.5	0	0	4	0	7.7	5	0	0	0.2	28.7	0	0	0	0	0	0	0	0	1	0	0	0	0	8	18.4	0	5.5	0	-99999	
11	005	1200375A	5	Dec-68	0	0	0	0	20.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	10.4	0	0	0	0	0	0	0	0	

**Figure 3. 2 Precipitation data format.**

Figure 3.2 is a snapshot for the format of precipitation data computed by this research and was uniform for both Oshakati and Ondangwa. It consists of 35 columns; however, the first three columns were of no significance to this research. A further visual inspection indicates Column 4 (YYYY-MM) as being composite, as it combines both the year and the month. Columns E through to AI, represents the days of the month. Values -99999 are prominent in columns AH and AI, indicating that the respective months did not get to either to the 30<sup>th</sup> or the 31<sup>st</sup> days. The collected data could not be used by this research in its manual Microsoft excel format, as such, data wrangling was conducted as discussed in the section that follows below.

### 3.3.3 Data wrangling

Data wrangling is a multi-step activity that involves combining different data sets, removing errors, dealing with missing and improperly formatted fields to have a data frame that is more accessible and easier to analyze (Ritvik, 2020). The data set for this research had to be wrangled because of the following:

- i. It contained more attributes than the research required, ie, the first three columns in Figure 3.2 were not required.
- ii. The fourth attribute (YYYY-MM) in Figure 3.2 is composite and needed to be decomposed into month and year so pivoting that of data would be possible.
- iii. There was some missing data within the Oshakati data set for some specific days indicated with an asterisk. The data was then completed using the dataset values from Ondangwa.
- iv. Finally, there existed some improper data formats of -9999 for the 30<sup>th</sup> and 31<sup>st</sup> day of months, which did not get to the 30<sup>th</sup> or 31<sup>st</sup>.

To address the issues identified, the researcher visually inspected the data to identify areas of concern. The wrangling process involved the pruning of some columns, decomposition of composite attributes, treatment of missing values and the reformatting of the malformed data as discussed in the following sub-sections.

#### 3.3.3.1 Pruning the attribute set

The precipitation data contained the columns DsetID, StnID and Code, which were of no value to this research. Assuming the Oshakati data set as OSH, the afore-mentioned columns were pruned from the Oshakati data set, this thus;

```
OSH.drop(['DsetID','StnID','Code'],inplace = True, axis = 1)    (1)
```

*DsetID, StnID and Code columns were dropped from the OSH data set, and making the change permanent as indicated by a inplace flag that set to True. The axis flag value of 1 indicated it is a column, otherwise it would have been a row. The resulting data set after pruning some columns is shown on the snapshot in Figure 3.3*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF		
1	YYYY-MM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
2	Mar-67	0.2	16	8	0	0	2.5	7.8	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.3	0	0	
3	Apr-67	0	0	0.3	1.5	6.5	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.5	4	0	0	0	0	0	0	
4	Nov-67	0	0	0	19.5	1	0	10.5	16.1	0	11	0	20.1	3	5.2	10	37	2	45	3.1	12	0	0	0	0	0	0	0	30.8	0	32.5	0	0	-99999
5	Dec-67	0	0	0	0	0	0	9.5	10.5	17.5	46.7	13.5	0	0	0	10.7	12	0	0	12	0	21.4	0	0	0	0	0	0	0	0	0	0	0	0
6	Jan-68	0	0	0	0	0	4.4	0	5.5	29	0	0	0	0	0	1.5	3.5	15.5	0	0	0	0	0	0	0	0	0	0	0	0	7.5	0	0	2.7
7	Feb-68	0	0	3	0	0	16.3	8	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3.5	0	0	0	0	0	0	-99999	-99999	
8	Mar-68	2	28.3	12.8	0	0	2.5	19.5	21	0	9	2.9	17.5	4.2	14.4	10.2	0	1	27.3	2.5	0	0	0	0	0	3	0	17.5	0	0	0	0	0	
9	Apr-68	0	0	0	0	16.6	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-99999	

**Figure 3. 3 Snapshot of OSH data set after eliminating some columns.**

As can be seen in Figure 3.3, the columns DsetID, StnID and Code were eliminated. The next step was to decompose the YYYY-MM column.

### 3.3.3.2 Decomposing the composite attributes

Composite attributes are columns that represent more than a single domain of values and are made up of two or more variables or measures that are either conceptually or statistically related (Song et al., 2013). Composite attributes are commonly used in cases where sample size is insufficient for controlling TYPE 1 Error rate or for addressing multicollinearity regression analysis, or for organizing highly correlated variables. Composite attributes, however, reduce the flexibility of what one can do with the composite values, for example., pivoting becomes tedious or impossible. This research had the YYYY-MM column of Figure 3.3 decomposed so that it was possible to query the data from a variety on angles. The decomposition process separated the YYYY from the MM representing the year and month respectively, thus:

```
split = OSH['YYYY-MM'].str.split('-',expand = True). (2)
```

```
split_index = [0,1]
```

*Splits the YYYY-MM column at the delimitation character '-', and expanded into separate respective columns thus keeping the results in variable split. The variable split had column indexes 0 and 1 to represent MM and YYYY respectively.*

```
OSH['YYYY-MM'] = split[0] (3)
```

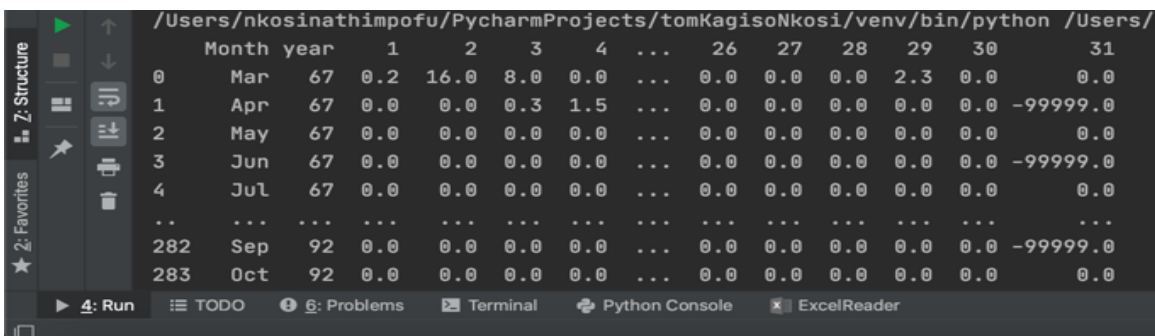
```
OSH.rename (columns = {'YYYY-MM' : 'Month'}, inplace = 'True') (4)
```

*(3) Assigns the values at index 0 of the split variable to the 'YYYY-MM' column of OSH dataset. (4) renames YYYY-MM to 'Month' within the OSH data, represented by the in place flag that's set to True.*

```
OSH.insert (1,'Year', split[1]) (5)
```

*Inserts a new column 'Year' into OSH at index 1, and assigns it values of split variable that exist in column indexed as 1.*

After decomposing the composite column, the OSH data set now had the separate month and year columns as shown in Figure 3.4:



**Figure 3. 4 Snapshot of OSH dataset.**

Figure 3.4 is a snapshot of OSH data set after eliminating the unwanted column and decomposing the YYYY-MM column. The data set now had the year column separated from the month column. The first column with values 0 through to 283 is an index column to uniquely identify each row/case within the OSH data set.

### **3.3.3.3 Data cleaning**

Data cleaning is a crucial data preparation stage as it guarantees data quality by removing incorrect, corrupt, incorrectly formatted, incomplete and duplicate data within the dataset (Rahm & Hong, 2012). This research adopted a multistep strategy towards data cleaning, which encompassed the handling of missing data, removal of duplicate and irrelevant cases and the filtering of the unwanted outliers, discussed under the respective headings below:

#### **i. Handling missing data**

A missing value analysis on the precipitation data had revealed 2.4% of the cases as having some missing values. While 2.4% of the missing values is within the 5% of statistical significance (Kern, 2013), this research felt that ignoring the missing values might introduce some bias, reduce the statistical power of the results, and break the trend analysis graph. This research was aware of the different approaches towards treating missing values, which included data imputation, using a series mean or median or mode, regression analysis or complete elimination of the affected case amongst others. With the many options of treating missing values at hand, this research developed and implemented the following condition-based strategy towards ensuring the completeness of data.

Any missing value within the Oshakati data set was to be replaced by the Ondangwa data set value. i.e., if precipitation value for the data 3 Jan 1967 was missing, but the Ondangwa data set had a value for the same date, then the Ondangwa value for that date

was used. Ondangwa is the central weather station in Oshakati, and it had better records of climate -data. This thus:

For x in OSH.index: (6)

If OSH.loc[x,'day<sub>n</sub>'] is NULL and OND.loc[x,'day<sub>n</sub>'] not NULL then (7)

OSH.loc[x, 'day<sub>n</sub>'] = OND.loc[x,'day<sub>n</sub>'] (8)

Or else if both the OSH and OND data sets are missing a value of the same day, then

OSH.loc[x,'day<sub>n</sub>'] = OSH.seriesMean(day<sub>n</sub>). (9)

*(6) loops through the Oshakati data set OSH with x representing each row*

*(7) checks if a day's value day<sub>n</sub> is NULL for each row x*

*(8) if (7) is true, the Oshakati value is replaced with the Ondangwa (OND) value,*

*(9) assigns a series mean value if both the Oshakati and Ondangwa data sets have missing value of day<sub>n</sub>*

*Where day<sub>n</sub> represents any day from 1 through to 31<sup>st</sup>.*

ii. Removing duplicate and/- or irrelevant cases

It is argued that including duplicate data affects the reliability of data, and consequently results in decisions which are uninformed (van Elst, 2013). When this research suppressed all other attributes except the days (1 through to 31<sup>st</sup>) and ran a duplicate test, the months that had received no precipitation throughout were flagged as duplicated. Such a flagging came as no surprise to this research given that Namibia is in Africa, south of the Sahara and receives seasonal rainfall for a period from November through to April. This research, therefore, took a decision to reduce the size of the dataset by removing the months that were off the rainfall season, thus:

OSH.drop\_duplicates (duplicated = True, inplace = True) (10)

*Drops all cases flagged as duplicated 'True', within the OSH dataset as represented by the inplace flag of True.*

The duplicated cases had precipitation values of zero (0) rainfall and were deemed as irrelevant cases towards achieving the objectives of this research.

iii. Filtering unwanted outliers

Data outliers are observations that lie an abnormal distance from other observations (Adeyemi, 2009). A scatter plot for the OSH dataset revealed a few outliers, which a visual inspection had also noted. The outliers had the value of -9999.99, which were deliberately introduced by data recording system as an indicator that the months of the cases did not get to either 29, 30 or the 31<sup>st</sup> day. This research, however, decided to preserve the values, but to suppress them when conducting data analysis and further data tests.

### **3.4 Analysis of data**

Descriptive statistical analysis was used on rainfall data using the SPSS software version 29 for the selected period to describe the variation and distribution patterns using various statistical measures, including the mean, median, kurtosis, and skewness.

### **3.5 Data sources**

The precipitation data used in this study was obtained from the rainfall data bank of the Namibian Meteorological Service (NMS), from two basic weather stations, Oshakati and Ondangwa. The period considered was from 1967-1993 and 2003-2018 for Oshakati and Ondangwa respectively and seasonal precipitation was analyzed from November- March i.e., the rainfall season per year. There was no continuous precipitation data for either weather stations, thus data from both were considered.

### **3.6 Vulnerability risk factors of communities- Objective 2**

A hazard risk assessment was conducted within the study area of Ehenye community, in Oshakati. Assessing the risk was an important step to identifying main risks and impacts on communities, as well as their vulnerability.

The researcher used the indicator-based approach, which allowed for a holistic assessment of risk factors e.g., social, economic, and environmental vulnerability and capacity (Müller et al., 2011b).

The risk dimensions/characteristics that were considered are outlined in the staged sequence below:

1. Hazard Identification- floods
2. Analysis of the hazard (data from objective 1)
3. Environmental Analysis/geographical location (ground truthing exercise)
4. Societal and legal environment (obtained from demographic survey desk secondary search)
5. Critical Facility analysis/services (ground truthing)

For each data collection for stages 3 and 4 highlighted above, the researcher used a checklist to:

1. Identify variables under the headings (societal, physical, and critical facility)
2. And check for any visible anomalies.

#### **3.6.1 Hazard identification**

The study focused on the most prominent hazard in the area which are floods. The data outlining/ demarcating these seasons were already available from the Ministry of Environment and Namibia Meteorological Services.

### 3.6.2 Hazard analysis

Information pertaining to the nature and frequency of the hazard was obtained from the data analysed from Objective 1. The data was stratified into 2 datasets due to missing data. In each dataset the hazard was analysed for frequency and concentration.

### 3.6.3 Societal and legal analysis

Social characteristics of the community were captured through secondary data which was already available through the demographic census analysis survey, legislation, policies, and other reading material.

### 3.6.4 Environmental and physical analysis

- a) An environmental analysis was conducted through observations with specific attention paid to physical characteristics, such as topography of land, soil characteristic and presence of wetlands.
- b) A physical assessment was also done by measuring parameters such as position of buildings in relation to street level, availability of flood infrastructure and distance of houses from nearest water body/river.

The parameters for the environmental and physical analysis are summarised in Table 3.1:

**Table 3. 1 Environmental and physical parameters**

<b>Physical analysis</b>		
Variable	Relevance	Reference
Position of buildings in relation to street level	Determines the likelihood of constructions to suffer damage in case of flood event. People that live below or at street level show	(Schneiderbauer, 2007)

	a much bigger exposure to the floods.	
Roads	Availability of alternatives De routing possibilities	
Availability of flood protection infrastructure? 1. Municipality constructed. 2. Community constructed. Green spaces Number and proportion	Flood protection infrastructure reduce chances of flooding.  The higher number of green spaces the lower the flood hazards.	(Schneiderbauer, 2007)  (Niehoff et al., 2002)
<b>Environmental analysis</b>		
Are there any depressions? If so, how big? How many? <ul style="list-style-type: none"> <li>Distance between the depressions/inundations</li> <li>Distance from the depression to the nearest settlements/houses.</li> <li>Distance of the depression from the local Okatana river.</li> </ul> Other?	The higher number of depressions the higher the possibility of flooding  Size determines water retention. Distance between the depressions and river determine flooding possibilities.	(Niehoff et al., 2002)
Distance of house from nearest water body	Determines risk of flooding in case of heavy rain.	(Niehoff et al., 2002)

**3.6.5 Critical facility analysis**

This analysis consisted of an evaluation of the availability and state of infrastructure and services. Critical facilities such as roads, availability of alternatives, de-routing possibilities, capacities police, fire & rescue, communication, and transportation were analysed descriptively.

**Table 3. 2 : Critical facility analysis**

		Y	N	Comments
Communication and emergency operations	Are there any forms of government emergency? Telecommunication between and among agencies? Does the community have emergency operations? Mobile network coverage? Satellite Commands systems Mass notification systems (SMS alert? And others) Is there a formalised emergency plan?			
Roads	Availability of alternatives De-routing possibilities			
Hospitals	Capacity Integrated communication Emergency plan arrangements			
Police station	Capacity Integrated communication Emergency plan arrangements			
Fire station	Capacity Integrated communication Emergency plan arrangements			
Town council	Planning and disaster unit Past flood issues/frequency Mitigation taken or planned.			

### 3.7 Risk mapping – objective 3

Once the environmental analysis was conducted, and areas of high risk were identified, the researcher then mapped out risk areas using geodata, such as land cover maps

derived from satellite data and created maps using Geographical Information System (GIS) software.

a) Risk criteria

To determine whether the location was a high, medium/ tolerable, or low risk, the researcher adapted and used a risk assessment formula and matrix as proposed by Ristic (2013) where:

**Table 3. 3: Risk key**

<i>Flood risk = Probability x Severity</i>	
<b>Probability:</b>	<b>Severity:</b>
1- Harm unlikely to occur.	1- Negligible consequences.
2- Harm less likely to occur.	2- Minor disturbances and losses.
3- Average chances of harm occurring.	3- Medium disturbances or losses.
4- Harm occurs often.	4- Serious disturbances/impacts or losses.
5- Harm is highly probable.	5- Catastrophic consequences, e.g., death, damage to building structures,

Probability and severity were plotted against one another or multiplied. The outcome gave an estimation of risk which was used in the prioritization of risk control.

b) Risk estimation and categorization

<b>OUTCOME</b>
<b>20-25: Catastrophic risks</b>
<b>10-16: Serious risk</b>
<b>4-9: Medium risks</b>
<b>3-4: Minor risks</b>

## 1-2: Negligible risks

Using the results from a) above, the researcher then adapted and used the Ontario technical guide for flood hazard limit: rivers and stream systems (Lorant & Dillion, 2002). Using this adapted guide, the researcher created and defined buffer zones of 100 m and 200 m on the study area and they are defined below:

- 100 m: Flood way- where it is determined that the risk of flooding, its chance of occurrence and likely severity of consequences are the highest therefore, then development should be prohibited.
- 200m: Flood fringe- where it is determined that the risk of flooding, its chance of occurrence, and likely consequences are low and can be tolerated therefore, then conditional development can be accommodated if risk reduction measures are instituted.

### c) Risk mapping

Areas of high risk were identified by the researcher during the environmental/physical analysis and the results served as a guide to risk mapping. The maps were created using GIS ESRI ArcGIS Desktop 10.8; Google satellite image 4cm by 4cm and varied shapefiles data obtained from the Namibian Statistics Agency, and they are listed below:

**Table 3. 4 List of shapefiles used to create risk maps.**

<b>Data</b>	<b>Description</b>	<b>Creator</b>	<b>Date</b>
Ehenye	Oshakati zoning plan base map	Urban Dynamics Town and Regional Planners	2012
Rivers	HYDRO_Rivers, National	Ministry of Agriculture, Water & Forestry	01/04/2002
Railways	TRANS_Railways	Ministry of Land Reform	01/04/2014
Regions	Regional Boundaries	Ministry of Land Reform	12/08/2013

Water bodies	Locations of water features in Namibia (Water Features, Oshanas, Swamps, Lake Liambezi, Omadhiya Lakes)	Ministry of Agriculture, Water & Forestry	02/02/2002
Cad_Town_Surburbs	Town Surburbs	Ministry of Land Reform	2010
Landuse	Oshakati zoning plan base map	Urban Dynamics Town and Regional Planners	2012
Embankment	Oshakati Embankment	on-screen digitized from Google satellite image	2021

### 3.8 Secondary data analysis

For objective 3, the researcher sought to assess vulnerability risk factors and this was conducted through a secondary research using data from the Namibia demographic survey 2013, government publications and websites and town council records were analyzed thematically and collated to increase the overall effectiveness of the research. The purpose of the secondary analysis was to understand, amongst others, the coping strategies that have been put in place and investigate any further plans to avert any possible impacts through plans put in place for example.

To be able to adequately capture information, a list of broad themes was used to capture the information and they are listed below:

- Environmental analysis (the hazards faced)
- Social analysis (community demographics, socio economic status)
- Critical support factors: (critical infrastructures)

Once the review of secondary data was completed, interpretation of data was done by narration, explaining the significance of identified themes which were then detailed according to a hierarchy to make sure that the most important issues affecting

communities with respect to climate change were highlighted at the top according to ascending importance.

### **3.9 Development of the model**

A conceptual model is an approach used to explain a phenomenon by connecting variables in a course of study thus creating a roadmap for guiding an investigation (Ahearne, 2010). The model is important as it asserts the significance of the topic, guides the development of research questions, and selects theories and methods within the methodology framework. In other words, it has interactive components that serve as a connective tissue on various influences on aspects in the research, which should be viewed collectively rather than piecemeal. Information from the literature survey, specifically the reviewed frameworks was used as the starting point of developing the framework. Key concepts and dimensions of resilience that were proposed in similar contexts were identified and considered for the study. The results of the rainfall trend analysis, and vulnerability risk factors were analysed and conceptualised, considering both the direct (settling in flood fringe and flood way) and indirect pathways (inadequate policies) through which disturbances can propagate within a system and influence its adaptive capacity and stability. The indirect pathways were analysed through secondary document analysis such as legislation and town plans and policies. Following this, indicators were then developed to assess the various dimensions of resilience. The indicators used in the model had to be defined, relevant, reliable, and valid to the system and finally was refined and sent to experts for feedback.

### **3.10 Model evaluation**

Once the model was developed, it was internally evaluated/cross checked by the researcher and academic supervisors using the guidelines listed below:

1. Clarity of the conceptual model and its identified guiding enablers?
  - a) How relevant are the different aspects of the developed model?

- b) Is it easy to understand?
- 2. Is the model implementable/achievable?
- 3. Can the model be applied to other environments/ situations?
- 4. How significant is the suggested model to the climate change resilience?

Once the model was evaluated using the questions above, it was then further pilot tested in the study area. A pilot test is defined as an evaluation of a designed tool or model with the purpose of checking if the tools work as intended (Fraser et al., 2018). The testing is done under real time operating conditions and the results help fine tune or improve the tool. In this case, pilot testing provided the researcher the opportunity to cross check the applicability of the task and the usability of the tool, and this improved the model by making it clear and better to implement.

### **3.11 Model validation**

The model was cross validated through participatory application at a smaller simulated scale at the Namibia University of Science and Technology and feedback was sought from participating lecturers on the strengths, limitations, and practical implications. Feedback was sought and the model improved and then sent lastly to four experts for empirical verification. The experts were from diverse settings including government, academia and non-governmental organisations working closely in climate change.

- The model was verified using the questions recommended by Richey, Klein, & Nelson (2004). The strategies were as follows:
  - ✓ Does the framework highlight/include the key components?
  - ✓ To what extent does the framework address the relevant environmental factors.
  - ✓ To what extent is the framework usable to a wide range of settings?

✓ Is the framework cost effective?

## **CHAPTER 4: RESULTS AND DISCUSSION**

Flood risk assessment and mapping play a crucial role in identifying the potential impacts of flooding on human communities and ecosystems. In this chapter, the results of the research objectives set out at the beginning of the study are discussed. The results are presented and discussed based on the individual research objectives. For ease of reference, the following section divisions are used:

- Section 4.1: Objective 1 - This section is dedicated to the discussion of the results related to Objective 1.
- Section 4.2: Objective 2 - The findings pertaining to Objective 2 are presented and analysed in this section.
- Section 4.3: Objective 3 - This section is solely focused on the results and implications of Objective 3.
- Section 4.4: Objective 4 - The results and conclusions related to Objective 4 are covered comprehensively in this section.

By organizing the chapter in this manner, the research outcomes and their relevance to each specific objective are clearly outlined, facilitating a better understanding of the study's overall findings.

### **4.1 Objective 1- Analysis of historical rainfall trends**

The research study aimed to analyse the precipitation trends in the Cuvelai-Etosha Basin in Namibia over a 50-year historical period from 1967 to 2018. The monthly and daily rainfall data for these years were obtained from the rainfall data bank of the Namibian Meteorological Service (NMS) and the Ministry of Agriculture, sourced from the Oshakati weather station. The research question associated with this objective was: "What precipitation patterns have been experienced over the last 50 years?"

To achieve the stated objective and answer the research question, the research is divided into sub-sections that cover the entire value chain of the study. These subsections include:

- I. **Data Set:** This section discusses the dataset used in the study, which comprises the monthly and daily rainfall data spanning the 50-year period from 1967 to 2018.
- II. **Data Access:** Here, the process of obtaining the rainfall data from the rainfall data bank of the Namibian Meteorological Service and the Ministry of Agriculture is explained.
- III. **Data Quality:** This subsection focuses on the assessment of the quality of the rainfall data to ensure its reliability and suitability for the analysis.
- IV. **Precipitation Data Analysis:** The final part of the research deals with the actual analysis of the precipitation data, where historical trends and patterns are evaluated to address the research question.

By breaking down the research into these sub-sections, the study aims to comprehensively evaluate the historical precipitation trends in the Cuvelai-Etoshia Basin and provide insights into the patterns experienced over the past 50 years.

#### **4.1.1 The data set**

The dataset used in this research consists of precipitation data collected from two weather stations, namely Oshakati and Ondangwa. The primary data source is from the Oshakati weather station since it aligns with the area of study. However, data from the Ondangwa weather station was utilized as backup data to fill in any missing values within the primary dataset through extrapolation. Both datasets share similar structure, coding, and formatting, which ensured consistency and comparability. However, some of the daily precipitation values were missing, and these missing values were represented in two different formats: either as -99999 or as \*\*\*\*\*.

To facilitate further analysis, the raw data had to undergo additional pre-processing steps. These steps aimed to transform the data into a more suitable format for analysis and interpretation. The specific details of the pre-processing steps undertaken to clean and prepare the data for further analysis are discussed in section 4.1.3. Access to data was not as smooth as the researcher envisioned, and several requirements had to be fulfilled, as discussed in the section that follows.

### **4.1.2 Data Access**

Despite the data being available in one form or the other, it was rather difficult to access the data. Permission had to be sought through various bureaucratic processes even though the researcher was armed with a research ethics clearance from Northwest University and an approved research permit from the National Commission of Research, Science and Technology. It seemed that the sharing of data with anyone or other institutions was quite limited. There are several reasons that could be attributed to this. From observation, there were many legal restrictions and unclear dissemination capacity protocols as at the time of data request, the researcher was taken from office to office. According to Dinku (2019), there are many reasons why climate data is difficult to access. In some cases, it could be due to historical data being available on paper or microfiche and it may not have been digitized thus reducing accessibility. There may also be mistrust on how the data may be used or misused, without their consent. Despite the hurdles, this research managed to get hold of the raw precipitation data for both the Oshakati and the Ondangwa weather stations albeit late after several attempts. This research primary data set is the Oshakati data whereas the Ondangwa was to be used for extrapolation purposes where data completeness is in question.

When the data from both weather stations were finally obtained, it became apparent that the datasets were not entirely uniform. There were discrepancies in the coding, and the representation of missing values. This inconsistency hindered direct integration and analysis of the datasets, necessitating additional efforts to standardize the data for meaningful comparison. The additional step towards standardizing data is discussed in the section that follows.

### **4.1.3 Data quality**

Data quality is a measure of how well the data reflects the real-world phenomenon it is intended to represent and how suitable it is for its intended purpose. It can be assessed based on variables such as completeness, accuracy, consistency, reliability, timeliness, validity, and fitness for use amongst others. This research anticipated that data quality

issues might arise and, therefore, planned some data wrangling steps to address them. The wrangling steps involved treating missing data, conducting reliability testing, and shaping the data to ensure it is suitable for its intended use.

#### **4.1.3.1 Treatment of missing data**

The data was analyzed for continuity to check for any missing data, and it was noted that there was no rainfall data available for a 10-year period between 1994 and 2003. The data obtained from both weather stations was consistent, and there were no other records in the archives specifically for the study area. Consequently, the researcher decided to divide the data into two subsets: subset 1 covering the years 1967 to 1993 and subset 2 covering the years 2004 to 2018. Thus, a total of 40 years were investigated.

Furthermore, a missing value analysis on the daily recordings indicated that 0.6% of the data was missing, and these missing values were coded as either -99999 or \*\*\*\*\* on the raw datasheet. For data completeness, this research performed interpolation of Oshakati data with the Ondangwa data, reducing the proportion of missing values to 0.41%.

However, during the initial analysis, the fact that some months were completely missing data was not identified. This issue was later discovered when the data was integrated into respective months for each of the forty years, as shown in Table 4.1 below.

**Table 4. 1 Aggregate number of precipitation days per month and per year.**

Year	Month												rainy days per year	months missing
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1967			7	6							16	9	38	8
1968	8	6	17	2	1	0	0	0	0	2	10	3	49	0
1969	10	9	6	5	0	0	0	0	0	1	7	5	43	0
1970	11	11	4	2	0	0	0	0	0	1	6	4	39	0
1971	12	12	4	0	0	0	0	0	0	0	1	4	33	0
1972	7	6	11	0	0	0	0	1	0	4	1	2	32	0
1973	6	2	14	3	0	0	1	0	0	3			29	2
1974	13	9	7	2	0	1	0	0	0		6	3	41	1
1975	10	4	9	6	1	0	0	0	0	6	8	1	45	0
1976	11	12	10	2	0	0	0	0	1	2	5	1	44	0
1977	11	7	4	1	0	0	0	0	0		3		26	2
1978				2	0	0	0	0	0	1	5	2	10	3
1979	9	13	3	0	2	1	0	0	0	2	6	7	43	0
1980	9	10	4	0	0	0	0	0	1	1	4	5	34	0
1981	6	8	4	2	0	0	0	0	0	1	3	6	30	0
1982	12	16	14	2	0	0	0	0	3	0	10	4	61	0
1983	14	5	6	5	1	2	0	0	0	2	0	7	42	0
1984	8	4	11	2	1				1	0	6	3	36	3
1985	7	11	4	0	1	0		0	0	1	4	2	30	1
1986	11	5	9	1	0	0	0	0	0	2	4	4	36	0
1987	3	11	3	0	0	0	0	0	0	1	3	2	23	0
1988	5	1	2	0	1	0					4	9	22	4
1989	2	6	1	3	0	0	0	0	0	0	0	0	12	0
1990	9	4	5									0	18	8
1991	5	9	2	0	0	0	0	0	0	1	0	2	19	0
1992	5	1	0	0	0	0	0	0	0	0	1	0	7	0
1993	3												3	11
2003			4	3		0	0	0	0	2	5	12	26	3
2004	17	11	11	3	0	0	0	0	0	4	8	3	57	0
2005	11	11			0	0	0		0	2	1	6	31	3
2006	14	9	0	6	0	0	0	0		11	3	3	46	2
2007	10	11	7	4	2	0	0	0	0	6	5	4	49	0
2008	15	20	16	2	1	0	0	0	0	0	7	10	71	0
2009	10	24	7	3	0	0	0	0	2	4	6	10	66	0
2010	13	10	12	1	0	0	0	0	0	0	9	11	56	0
2011	13	16	18	12	1	0	0	0	0	1	4	10	75	0
2012	11	14	11	2	0	0	0	0	0	0	7	10	55	0
2013	6	5	12	0	0	0	0	0	0	1	7	9	40	0
2014	6	9	19	3	0	0	0	0	3	1	9	6	56	0
2015	13	6	12	1	0	0	0	0	0	1	3	10	46	0
2016	8	5	5	0	0	0	0	0	0	0	14	22	54	0
2017	6	14	10	2	0	0			0	3	2	6	43	2
2018	7	5	10	8	4								34	7
<b>Total</b>	<b>367</b>	<b>352</b>	<b>315</b>	<b>96</b>	<b>16</b>	<b>4</b>	<b>1</b>	<b>1</b>	<b>11</b>	<b>67</b>	<b>203</b>	<b>217</b>	<b>1650</b>	<b>60</b>
<b>contribution per month (%)</b>	<b>22.2</b>	<b>21.3</b>	<b>19.1</b>	<b>5.8</b>	<b>1.0</b>	<b>0.2</b>	<b>0.1</b>	<b>0.1</b>	<b>0.7</b>	<b>4.1</b>	<b>12.3</b>	<b>13.2</b>	<b>100.0</b>	<b>11.60%</b>

Table 4.1 shows an aggregation of the number of precipitation days per month for each respective year. Of interest is the last column showing the number of months missing and the last row showing the contribution each month has to the total number of days with precipitation over the period of interest. The aggregation reveals that there are 11.6% of months without precipitation. A closer look attributes this higher figure to the years 1967, 1990, 1993, and 2018, with 8, 8, 11, and 7 months, respectively, accounting for 56.7%  $[(8+8+11+7)/60] * 100$  of the missing months. The contribution of each month towards the total precipitation days is shown on the last row labeled "contribution per month (%)." The

data indicates that the months of May, June, July, August, and September contribute 1%, 0.2%, 0.1%, 0.1%, and 0.7%, respectively, towards the total number of precipitation days.

#### 4.1.3.2 Reliability of data

A normal distribution test on the number of precipitation days over the period of study shows that data is normally distributed with a mean of 38.37 days and a median of 39 precipitation days per year, as shown in table 4.2.

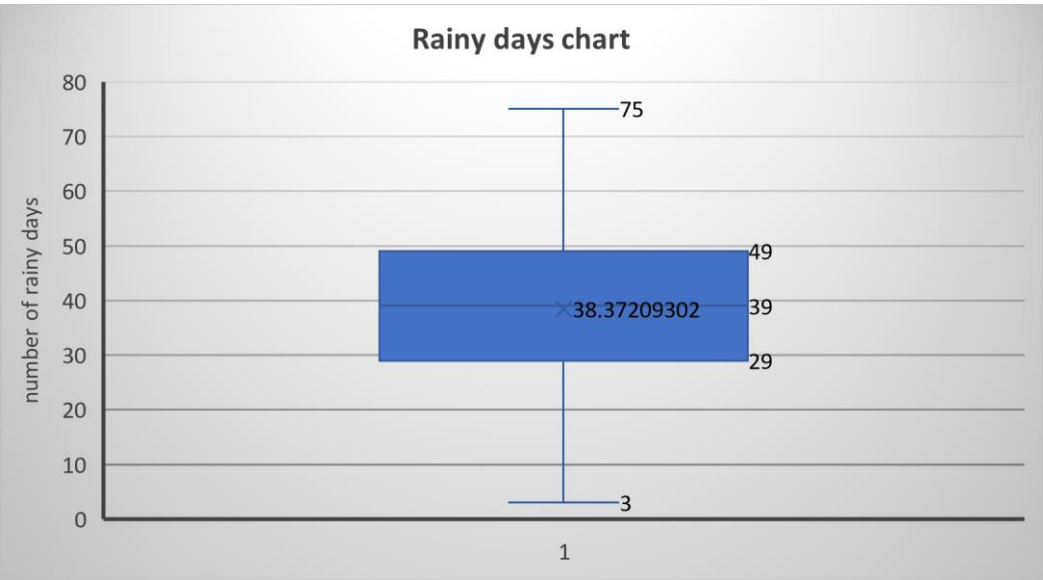
**Table 4. 2 Normal test statistic for precipitation days**

<i>statistic</i>	<i>value</i>
Mean	38.37209302
Standard Error	2.51397495
Median	39
Mode	43
Standard Deviation	16.48523619
Sample Variance	271.7630122
Kurtosis	-0.087212626
Skewness	-0.001914462
Range	72
Minimum	3
Maximum	75
Sum	1650
Count	43

The results presented in Table 4.2 showcase the normal distribution test statistic performed on the number of precipitation days, aimed at assessing the fit of the data to the normal distribution model. The analysis involves various statistical measures, including the mean, median, kurtosis, and skewness. The mean and median values are found to be in proximity, with values of 38.37 and 39 days, respectively. This close alignment between the mean and median indicates that the data follows a symmetric distribution, typical of a normal distribution. The similarity between these central tendency measures further suggests that the data points are evenly distributed around the central value.

Additionally, the kurtosis and skewness values are computed to be  $-0.0872$  and  $-0.0019$ , respectively. Both values are very close to zero, which is another indication that the data is normally distributed. A kurtosis value close to zero implies that the distribution has a similar shape to the standard normal distribution (mesokurtic), and a skewness value near zero signifies that the data is nearly symmetric around the mean.

The normality of the data is further supported by the box and whisker plot presented in Figure 4.1. The plot reveals a nearly symmetrical box, centered around the median, with no significant outliers beyond the whiskers. This visual representation aligns with the findings from the normal distribution tests, providing more evidence that the data conforms to a normal distribution.



**Figure 4. 1 Box and Whisker plot for the number of precipitation days**

The box and whisker chart displayed in Figure 4.1 indicates a mean value of  $39.37$ , which nearly bisects the box symmetrically. This symmetry suggests that the data distribution does not exhibit skewness, a finding consistent with the normal distribution test. The interquartile range (IQR) spans from the value of  $29$  to  $49$ , signifying that  $50\%$  of the data falls

within this range. The absence of any data points beyond the whiskers implies the absence of outliers, eliminating the need for further investigations in this regard.

The relatively narrow height of the box in the plot suggests that the data is not excessively spread or scattered. It indicates a more compact distribution of the data, with the middle 50% being concentrated within a limited range of values. This compactness indicates a certain level of consistency or stability in the number of precipitation days recorded during the investigated period.

While the normal test on the number of precipitation days yielded positive results, it was observed from the findings that there are months with an insignificant contribution to the phenomenon being investigated, and some years even have missing monthly data, amounting to approximately 11.6% of the total data. Since this figure is slightly double the acceptable threshold of 5%, the research made two decisions to address this issue:

a) Pruning Months with Less Than 5% Contribution:

The research decided to remove the months that have a contribution of less than 5%. The rationale behind this decision follows the assumption made by a Little & Rubin, (2019) that data representing less than 5% has an insignificant impact on the results of the investigation. Therefore, it is reasonable to discard data from such months. There were no cumulative effects as the rainy season in Namibia is clearly defined.

b) Adherence to official rainy season

The research also decided to adhere to the official definition of the rainy season for the area of study. This means that only data from the months considered part of the official rainy season will be retained for further analysis. Therefore, the months of May through to October are not considered part of the official rainy season, thus, it makes sense to remove data from these months as they are less relevant to the investigation of the phenomenon.

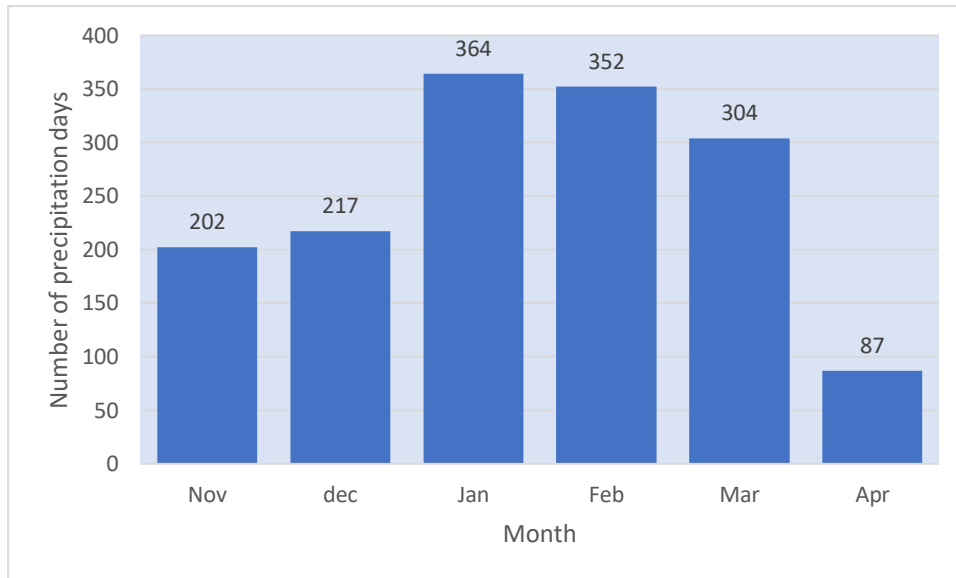
After implementing the decisions to prune the months with less than 5% contribution and sticking to the official rainy season, the proportion of missing data has significantly

reduced from 11.6% to 4.1%. This reduction in missing data can improve the overall quality and reliability of the analysis. Additionally, to organize the data and facilitate the analysis, the research has grouped the data into seasons. For instance, a season like "1968" includes data from November and December of the preceding year (e.g., 1967) and data from January to April of 1968. This season grouping method helps in considering a broader timeframe and captures relevant patterns across multiple months. As a result of this data organization, the total number of seasons under investigation is 40, as shown in Table 4.3.

**Table 4. 3 Data after treatment of missing values, organized in seasons.**

Season	Month						missing months	total rainy days
	Nov	Dec	Jan	Feb	Mar	Apr		
1968	16	9	8	6	17	2	0	58
1969	10	3	10	9	6	5	0	43
1970	7	5	11	11	4	2	0	40
1971	6	4	12	12	4	0	0	38
1972	1	4	7	6	11	0	0	29
1973	1	2	6	2	14	3	0	28
1974			13	9	7	2	2	31
1975	6	3	10	4	9	6	0	38
1976	8	1	11	12	10	2	0	44
1977	5	1	11	7	4	1	0	29
1978	3					2	4	5
1979	5	2	9	13	3	0	0	32
1980	6	7	9	10	4	0	0	36
1981	4	5	6	8	4	2	0	29
1982	3	6	12	16	14	2	0	53
1983	10	4	14	5	6	5	0	44
1984	0	7	8	4	11	2	0	32
1985	6	3	7	11	4	0	0	31
1986	4	2	11	5	9	1	0	32
1987	4	4	3	11	3	0	0	25
1988	3	2	5	1	2	0	0	13
1989	4	9	2	6	1	3	0	25
1990	0	0	9	4	5		1	18
1991		0	5	9	2	0	1	16
1992	0	2	5	1	0	0	0	8
2004	5	12	17	11	11	3	0	59
2005	8	3	11	11			2	33
2006	1	6	14	9	0	6	0	36
2007	3	3	10	11	7	4	0	38
2008	5	4	15	20	16	2	0	62
2009	7	10	10	24	7	3	0	61
2010	6	10	13	10	12	1	0	52
2011	9	11	13	16	18	12	0	79
2012	4	10	11	14	11	2	0	52
2013	7	10	6	5	12	0	0	40
2014	7	9	6	9	19	3	0	53
2015	9	6	13	6	12	1	0	47
2016	3	10	8	5	5	0	0	31
2017	14	22	6	14	10	2	0	68
2018	2	6	7	5	10	8	0	38
<b>Total</b>	<b>202</b>	<b>217</b>	<b>364</b>	<b>352</b>	<b>304</b>	<b>87</b>	<b>10</b>	<b>1526</b>
<b>contribution per month (%)</b>	<b>13.25</b>	<b>14.23</b>	<b>23.87</b>	<b>23.08</b>	<b>19.93</b>	<b>5.70</b>	<b>4.10</b>	<b>100</b>

Table 4.3 presents the distribution of precipitation days grouped into seasons, specifically focusing on months within the rainy season. The data reveals that in total, January has the highest number of wet days (364), while April experiences the fewest with only 87 days of precipitation. This distribution is visually represented in the following histogram.



**Figure 4. 2 Histogram for number of precipitation days organized in months**

The histogram in Figure 4.2 illustrates the distribution of rainy days for the months from November to April. According to the data, January and February have the highest number of rainy days, with 364 and 352 days respectively, resulting in an average of 9.1 days and 8.8 days of precipitation per season for each respective month.

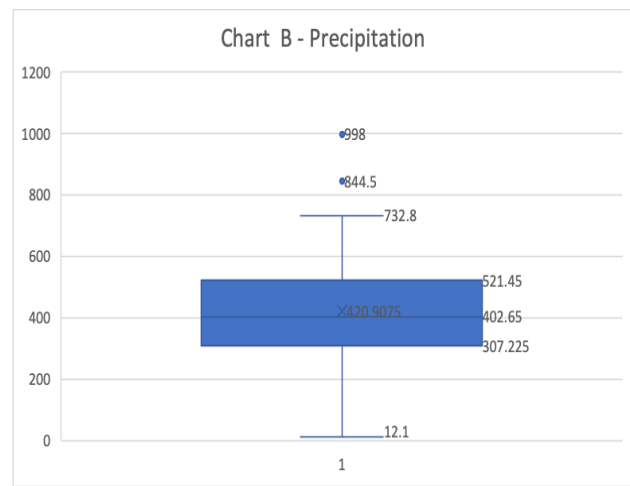
Furthermore, the average number of precipitation days for November, December, March, and April are calculated as 5 days, 5.4 days, 7.6 days, and 2.1 days respectively.

Overall, the bar chart and the provided data revealed the varying frequency of rainy days across the specified months, with January and February having the most significant number of rainy days, while November and April experience the fewest. The information obtained above was utilized in the subsequent section of the research to assess and determine the average precipitation expected per each precipitation day.

#### 4.1.4 Analysis of precipitation data

The descriptive statistics for the precipitation data over the period under review indicate that the data closely follows a normal distribution. The mean and median values are not significantly different, suggesting a symmetrical distribution around the central tendency. This is highlighted in figure 4.3 below:

Statistic	Value
Mean	420.9075
Standard Error	30.9382991
Median	402.65
Mode	#N/A
Standard Deviation	195.6709842
Sample Variance	38287.13404
Kurtosis	1.324644999
Skewness	0.558418045
Range	985.9
Minimum	12.1
Maximum	998
Sum	16836.3
Count	40



**Figure 4. 3 Data normality test results for precipitation data**

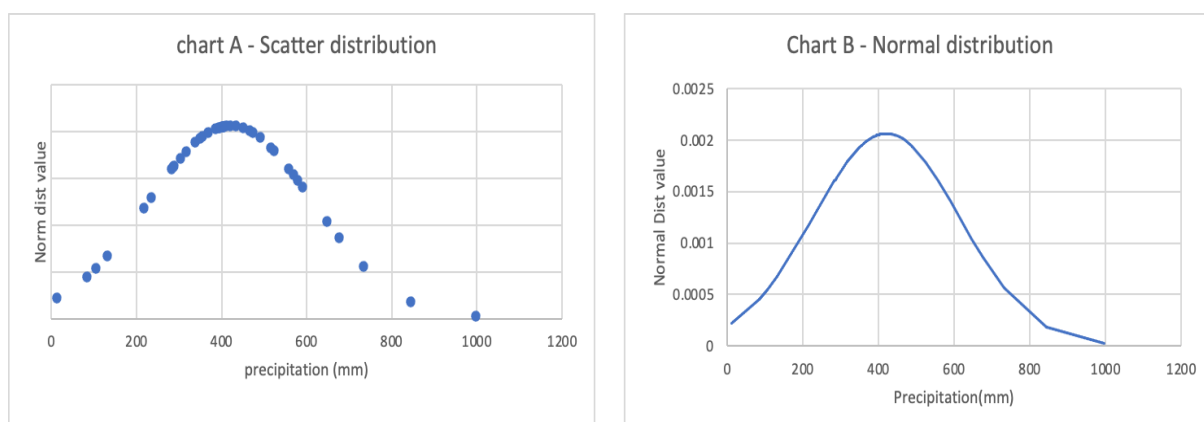
Figure 4.3 presents the descriptive statistics and a Box and Whisker chart for the precipitation data in Table A and Chart B, respectively. The mean and median values are 420.9 mm and 402.65 mm per season, and they are not significantly different. The data shows a slight positive skewness of approximately 0.558, which is within the acceptable normal standard range of +/- 1.5. The kurtosis is also within the acceptable range at approximately 1.324, as highlighted in Table A.

The Box and Whisker chart illustrates that the average precipitation across the years appears relatively even, with little variation represented by the thinness of the box. The differences between the median and the upper and lower quartiles are approximately 118

mm (521.45 mm - 402.65 mm) and 95.43 mm (402.65 mm - 307.225 mm), respectively, indicating a normal distribution of the data.

Two outliers are observed beyond the whiskers on the Box and Whisker chart, with values of 998 mm and 844.4 mm, representing above-normal rainfall seasons for the years 2011 and 2009, respectively. A closer inspection confirms the accuracy of these values, requiring no further action.

Moreover, when the precipitation data was transformed into normal distribution probability values and graphed, the resulting curve exhibits the characteristics of a normally distributed dataset, as shown in Figure 4.4.



**Figure 4. 4 Normal probability plot and curve for precipitation data**

Figure 4.4 presents two representations of the precipitation data, Chart A in scatter form and Chart B in curve form, both displaying the normal distribution plots. The horizontal axis represents precipitation measured in mm, while the vertical axis represents the associated normal probability values.

In Chart A, the density of the plot points is highly concentrated around the peak of the curve, confirming that most of the years have their total precipitation centered around the mean value of approximately 400 mm. Connecting these plot points results in a somewhat smooth curve, as seen in Chart B. However, a slight tail is visible on the curve due to the

presence of two outliers of 998 mm and 844.5 mm of precipitation, which were previously identified from the Box and Whisker plot shown in Chart A of Figure 4.3.

The overall shape of the curve in Chart B indicates that the data closely follows a normal distribution pattern, with most of the data points clustered around the mean, representing the typical precipitation levels experienced across the years.

The descriptive statistics, Box and Whisker chart, and the normal distribution probability graph collectively provide strong evidence supporting the conclusion that the precipitation data adheres to a normal distribution pattern. This confirmation of normality is essential for ensuring the validity of statistical analyses, modeling, and making accurate predictions based on the data.

The analysis of precipitation data spanning 40 years reveals significant variations in the amount of precipitation received across different months. January, February, and March stand out as the months receiving the highest amounts of precipitation, contributing 25.97%, 25.42%, and 21.71% respectively to the total precipitation over the entire period. In contrast, April's contribution is notably lower, representing only 5.1% of the total precipitation. This is summarized in table 4.4.

**Table 4. 4 Summary of precipitation data organized in seasons.**

Season	Month						season total (mm)	Season Contribution	stdev	mean
	nov(mm)	dec (mm)	Jan (mm)	Feb(mm)	Mar (mm)	Apr (mm)				
1968	258.8	153.8	69.6	37.8	195.6	17.2	732.8	4.4	95.88	122.13
1969	80	51.2	140.8	158.8	29	30.4	490.2	2.9	56.18	81.70
1970	60	17.5	89.4	69.1	42	5	283	1.7	31.98	47.17
1971	15.5	22.8	178.6	253	109.5	0	579.4	3.4	102.67	96.57
1972	1.7	84	150.5	15.5	168.1	0	419.8	2.5	75.94	69.97
1973	1	18.3	58.7	13.4	171.5	92.5	355.4	2.1	64.62	59.23
1974	0	0	219.2	202.3	187	38.5	647	3.8	105.51	107.83
1975	25.5	62.5	127.2	53.8	135.5	46.8	451.3	2.7	45.25	75.22
1976	38.8	5.5	177.9	246.5	186	21	675.7	4.0	102.85	112.62
1977	57.9	9	124.3	164.5	20.7	26	402.4	2.4	63.34	67.07
1978	8.5	0	0	0	0	3.6	12.1	0.1	3.49	2.02
1979	43.5	46	109.8	244.7	29	0	473	2.8	88.88	78.83
1980	55.3	43.7	49.9	131.9	113	0	393.8	2.3	48.53	65.63
1981	41.4	96.8	104.2	65.9	18.5	22.7	349.5	2.1	36.83	58.25
1982	6.6	9.9	91.1	98.4	134.3	27.2	367.5	2.2	53.65	61.25
1983	32.5	12	81.2	43.3	34.2	30.8	234	1.4	23.07	39.00
1984	0	54.5	66	121.4	136	22.9	400.8	2.4	53.50	66.80
1985	80.4	16.5	76.2	109	122	0	404.1	2.4	49.18	67.35
1986	28.5	59.5	171.7	70.7	157.2	28	515.6	3.1	63.28	85.93
1987	47.5	39.8	18.9	141.4	40.5	0	288.1	1.7	48.99	48.02
1988	28.2	7.5	29.5	6.5	12.5	0	84.2	0.5	12.15	14.03
1989	63.3	174.3	65	45.5	5	42	395.1	2.3	57.37	65.85
1990	0	0	156	109	73.5	0	338.5	2.0	67.12	56.42
1991	0	0	9.2	100.5	21.8	0	131.5	0.8	39.44	21.92
1992	0	16.4	77.2	11.7	0	0	105.3	0.6	30.06	17.55
2004	16.9	103.9	153.5	103.3	179	33	589.6	3.5	64.04	98.27
2005	136.6	1.7	154.7	93	0	0	386	2.3	72.68	64.33
2006	1	39.2	240	132	0	53.9	466.1	2.8	93.01	77.68
2007	23.3	10.9	100.2	48.7	78.6	24.3	286	1.7	35.24	47.67
2008	24.7	5	195.5	177.5	164.2	2.6	569.5	3.4	93.03	94.92
2009	73.4	77.5	213.2	378.4	94.4	7.6	844.5	5.0	134.27	140.75
2010	58	39	165.4	97.5	73.7	0.4	434	2.6	56.19	72.33
2011	119.7	85.4	221.1	243.6	246.4	81.8	998	5.9	79.06	166.33
2012	18.3	101.8	170.8	135	96.5	1	523.4	3.1	65.96	87.23
2013	55.6	100.6	36.6	18.2	92.8	0	303.8	1.8	40.28	50.63
2014	53.6	67.3	57.8	58.7	130.1	35.4	402.9	2.4	32.60	67.15
2015	30.4	63.3	95	40.8	64.4	23.6	317.5	1.9	26.55	52.92
2016	7.2	70.2	29.4	13.3	96.7	0	216.8	1.3	38.83	36.13
2017	142.6	115.2	41.1	190.3	40.2	28.6	558	3.3	66.41	93.00
2018	9.5	43.5	56.5	32.6	156.5	111.5	410.1	2.4	55.01	68.35
<b>Total</b>	<b>1745.7</b>	<b>1926</b>	<b>4372.9</b>	<b>4277.5</b>	<b>3655.9</b>	<b>858.3</b>	<b>16836.3</b>	<b>100</b>		
<b>Month's contribution (%) average precipitation/ month (mm)</b>	<b>10.37</b>	<b>11.44</b>	<b>25.97</b>	<b>25.41</b>	<b>21.71</b>	<b>5.10</b>	<b>100</b>			
	<b>49.88</b>	<b>53.50</b>	<b>112.13</b>	<b>109.68</b>	<b>101.55</b>	<b>31.79</b>	<b>420.91</b>	<b>2.5</b>	<b>49.18</b>	<b>67.35</b>

Table 4.4 provides a comprehensive summary of the total precipitation received for each month during the 40-year period, organized into seasons. The "Season Total" column presents the cumulative amount of precipitation, representing the sum of precipitation for the months in columns 2 through 7. The "Season's Contribution" column expresses this value as a percentage, indicating the proportion contributed by each season to the total precipitation over the 40-year period. The last two columns display the standard deviation and Month mean precipitation values on a seasonal basis. The standard deviation serves as an

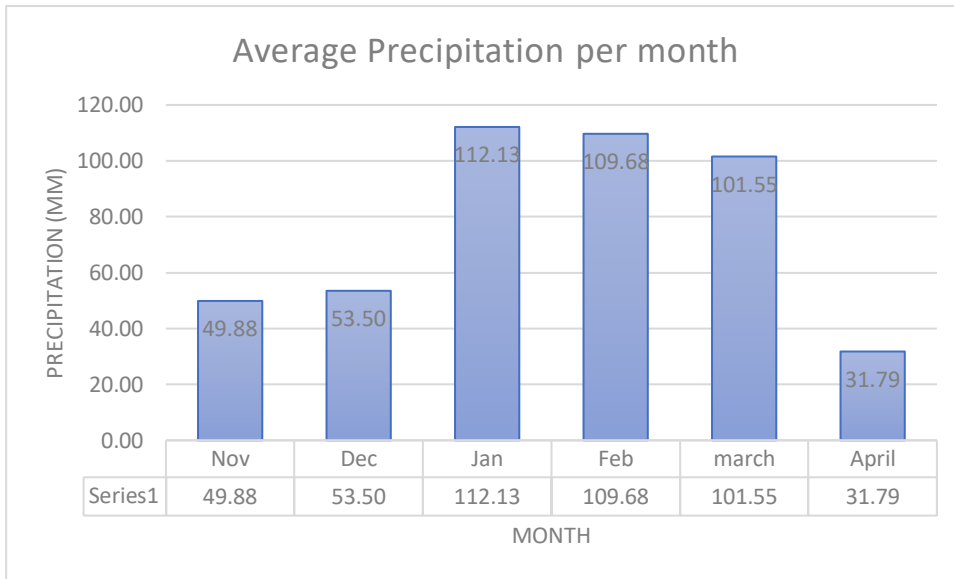
indicator of how the data is clustered around the mean. Seasons with higher standard deviations, such as 1971, 1974, 1976, and 2009, exhibit greater data spread, which explains the presence of some outliers in the dataset. As a result, this research assumes that the probability of floods is higher during these seasons due to the likelihood of extremely elevated precipitation levels.

Upon scrutiny is evident that the rainy seasons of 2009 and 2011 received the highest precipitation, recording 998 mm and 844.5 mm, respectively. Conversely, the season of 1998 experienced the least amount of precipitation, totaling only 84 mm. Interestingly, this amount is even lower than the mean monthly precipitation of other seasons like 2009, 2011, and 1976, among others.

For the season of 1978, a closer examination revealed that records were unavailable for four out of six months, possibly impacting the representation of data for that season.

Among the months within the rainfall season, January, February, and March stand out as the wettest, with average monthly precipitation of approximately 112.13 mm, 109.68 mm, and 101.55 mm, respectively. Additionally, the seasons from 2009 to 2018 are recorded to have experienced floods in the community of Ehenye. However, this does not infer other seasons flood-free. The main reason why there are no flood records for other seasons is due to the fact that the study area was un-inhabited pre-2007, as such, none was affected by the floods.

For further visualization, please refer to Figure 4.5 below, where the graphical representation of these monthly averages is presented.



**Figure 4. 5 Monthly average precipitation**

Figure 4.5 depicts the monthly average precipitation over the period, with the horizontal axis representing the months and the vertical axis indicating precipitation in mm. A notable observation from the graph is the intensified precipitation experienced during a three-month period from January through to March. Based on this finding, the research suggests that these three months should be the primary focus for any resiliency efforts, considering their higher precipitation levels.

By utilizing the monthly average precipitation data from Figure 4.5 and combining it with the average number of precipitation days per month, this research successfully computed the approximate level of precipitation per day. The results of this computation are summarized in table 4.5, provided. This information allows for a more granular understanding of the daily precipitation patterns, which is valuable for various applications, such as planning and preparedness for weather-related events.

**Table 4. 5 Average precipitation per day of the month**

	Nov	Dec	Jan	Feb	Mar	Apr	seasons average
avg precipitation/ month (mm)	49.88	53.50	112.13	109.68	101.55	31.79	420.91
avg no of precipitation days	5	5.4	9.1	8.8	7.6	2.1	38
avg precipitation per day (mm)	9.98	9.91	12.32	12.46	13.36	15.14	11.08

Table 4.5 provides a summary of the approximate level of precipitation for each precipitation day across different months. Interestingly, while January and February have the highest average precipitation values, it is the month of April, followed by March, that experiences higher daily precipitation levels, averaging approximately 15.14 mm and 13.36 mm, respectively.

This observation is significant because it implies that even though April has fewer precipitation days (only 2.1 days on average), the rainfall levels on those days are relatively higher. Consequently, this could lead to a higher risk of flash floods during those short rainy periods.

Moreover, the fact that April experiences fewer rainy days may also lead to the likelihood of a prolonged dry spell, which can have implications for farmers and agriculture in the region.

#### **4.1.4.1 Rainfall intensity/concentration**

The recorded flood history of Oshakati town reveals that notable/significant flooding started in the year 2008 and has been recurring every rainy season since then. According to Hango (2021), the notable floods in Ehenye are during the years 2011; 2014; 2017 and 2018. Despite the recorded flood history, the analyzed precipitation data of the seasons 1968 through to 2018 did not reveal any obvious relationship between amount of rainfall and flooding. What was observable is the rainfall intensity thus, further scrutiny of the precipitation data was undertaken to isolate the problem.

To investigate rainfall intensity and concentration, the researcher determined the criteria that would help identify intense rainfall and they are:

1. Onset of rainy season
2. Normal average rainfall
3. Rainfall intensity

The onset of a rainy season in a semi-arid climate as defined by Seregina et al., ( 2019), is rainfall that exceeds 5 mm for 3 consecutive days or more. The rainy season in Namibia is clear and easy to identify as seasons are clearly defined and according to the rainfall data, the rainy season is from November to April although there are a few outliers in other months such as October and May. Average annual rainfall can range from between 200 ml to 700 ml. Heavy rainfall is defined as 100 mm of rainfall in 24 hours or less for 3 days or more (Zambuko, 2011). Using the above criteria, daily and weekly records were scrutinized to isolate incidents of intense rainfall and the days and weeks that had the highest rainfall were scrutinized as depicted in the table below. This manual scrutiny was preferred because of the sporadic/ intermittent rainfall episodes experienced by Namibia even during the rainfall season, any generalization using clasped monthly rainfall data would have been inadequate in isolating any indication of extreme rainfall that leads to flooding.

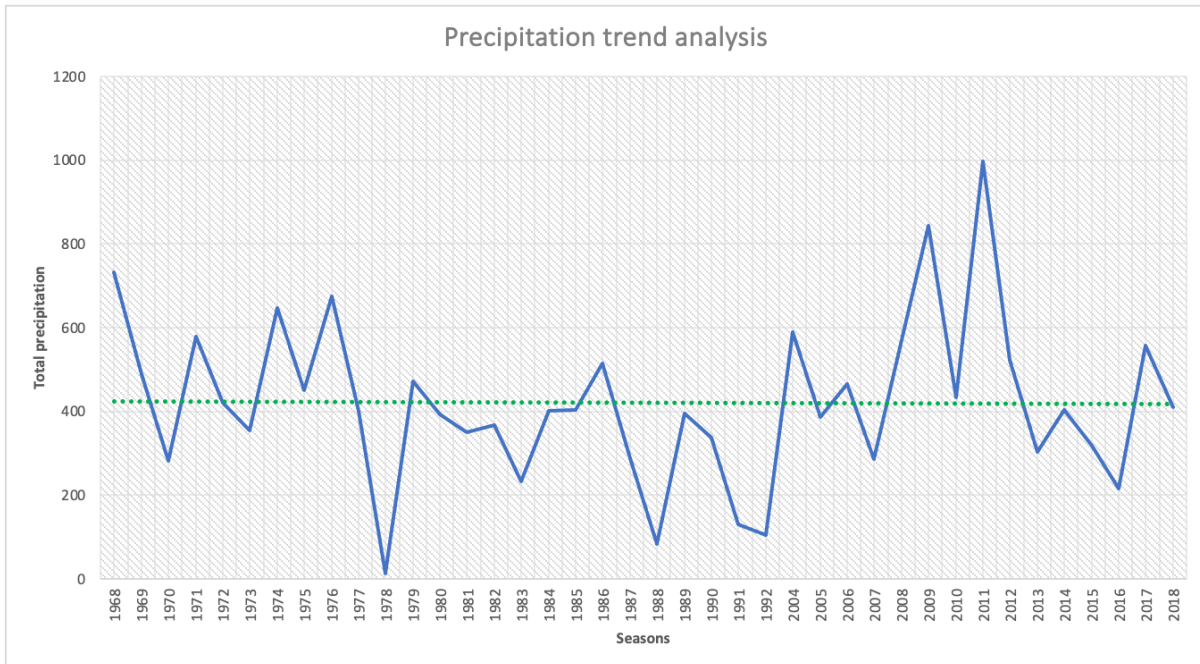
**Table 4. 6 Highest rainfall record given in mm/month (total years).**

Month	Highest rainfall record -mm
November	0
December	2
January	17
February	12
March	8
April	1

In the 40 years of analyzed rainfall data, the month of January is where the highest rainfall amount was recorded followed by the month of February with a record of 12/40 and March with an 8/40 record of months with highest rainfall. Rainfall intensity seemed to be higher between the months of January to March during the rainy season and was highly episodic and intense and this correlates with the reported flooding incidences. Less rain was recorded in the months of November and April.

#### 4.1.4.2 Precipitation trend analysis

The precipitation trend observed over the 40-year period does not provide a definitive indication of whether the rainfall pattern is following a specific trajectory. However, the trend graph does reveal that the precipitation levels from 1977 to 1992 were consistently below the average of 410mm, save for seasons 1979 and 1986 as depicted in Figure 4.6



**Figure 4. 6 Precipitation pattern for Oshakati 1968-2018)**

The depiction of the precipitation trend in Figure 4.6 shows the variations in total precipitation across seasons over the observed period. The horizontal axis represents the seasons, and the vertical axis represents the total precipitation per season. The green dotted line represents the average precipitation, while the blue line represents the overall trend.

The trend line's position below the average line for many seasons indicates that many of the seasons experienced precipitation levels below the average annual rainfall. This suggests a pattern of lower-than-average rainfall over the observed period. However, it is important to note that while the trend line provides valuable historical information about

the seasonal precipitation patterns, it might not be sufficient to predict future seasonal precipitation accurately. Predicting future weather patterns and rainfall with certainty is challenging due to the complexity and variability of climate systems. To make more accurate predictions about future seasonal precipitation, additional factors, and sophisticated models, such as climate models, should be considered. These models consider various climatic influences, atmospheric conditions, and other variables to provide more reliable forecasts. Nonetheless, the trend line in Figure 4.6 serves as a valuable representation of the observed historical patterns of seasonal precipitation.

#### **4.1.5 Conclusion for Objective 1**

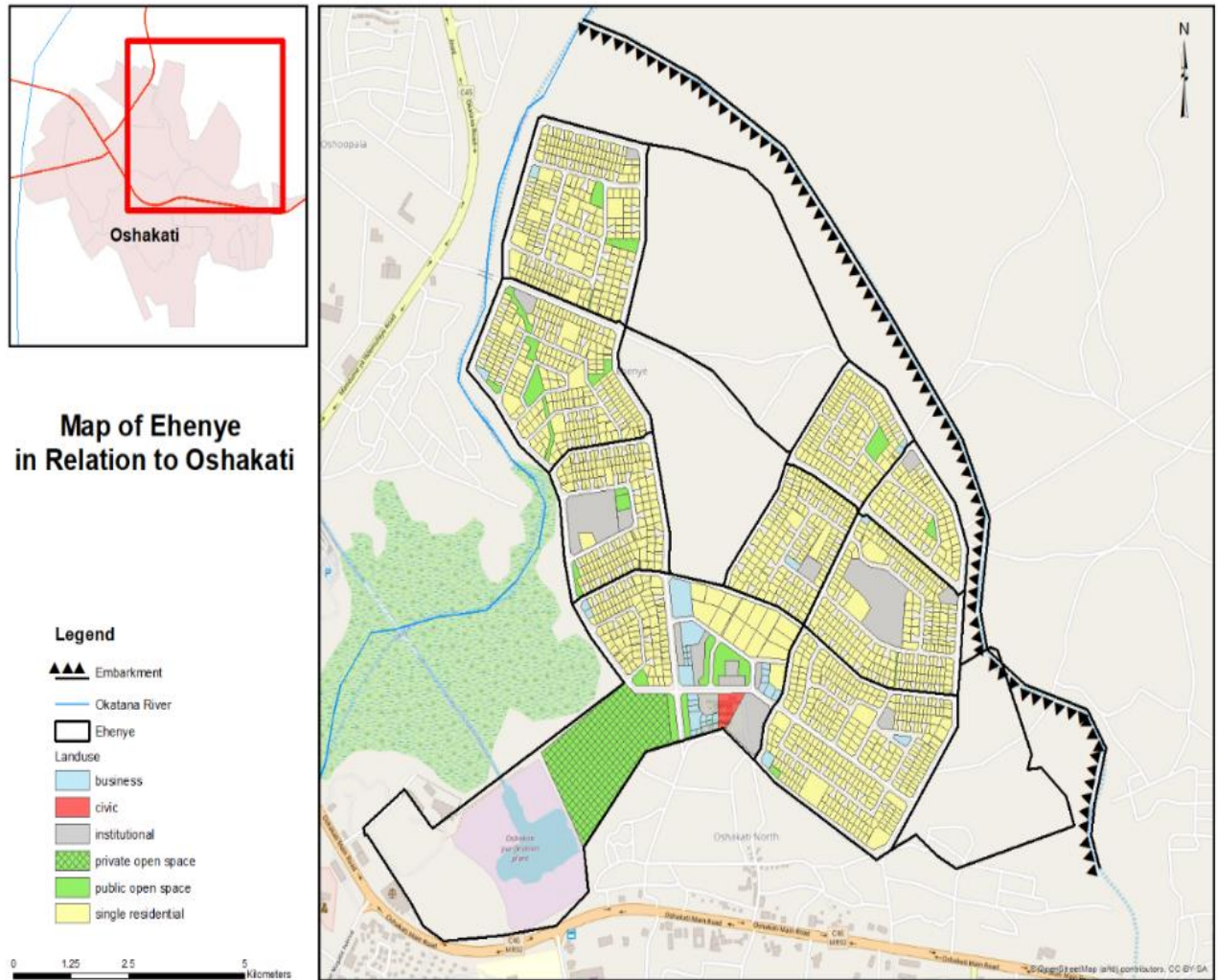
Based on the statistical tests conducted, it was observed that the rainfall amounts received by Ehenye were generally low, although there were a few years with intense rain over short periods. According to the analysis, the amount of rainfall received was not substantial enough to warrant flooding. Despite this, the reason behind the recurrent flooding in the Ehenye community remained unresolved. In summary, the results indicated that the rainfall, except for the year 2011, was not significant enough to explain the frequent flooding in the area. To delve deeper into the flooding issue and identify any problematic areas, a ground truthing exercise was carried out under objective 2 of the study.

## **4. 2 Objective 2 risk vulnerability factors**

Objective 2 of the study was to map the study area into risk zones. The purpose of this objective was to identify the affected and the potentially affected areas to identify level of risk. The research questions associated with this objective was: "Which parts of the study area are at risk and why? What is the level of risk?"

### **4.2.1 The general landscape**

The Ehenye community is situated on a flat land northeast of Oshakati town and is one of the newer housing developments in town first commissioned in 2006. A digitized map of the Ehenye community depicting the key landmark features precisely the embankment and the Okatana river is presented below.

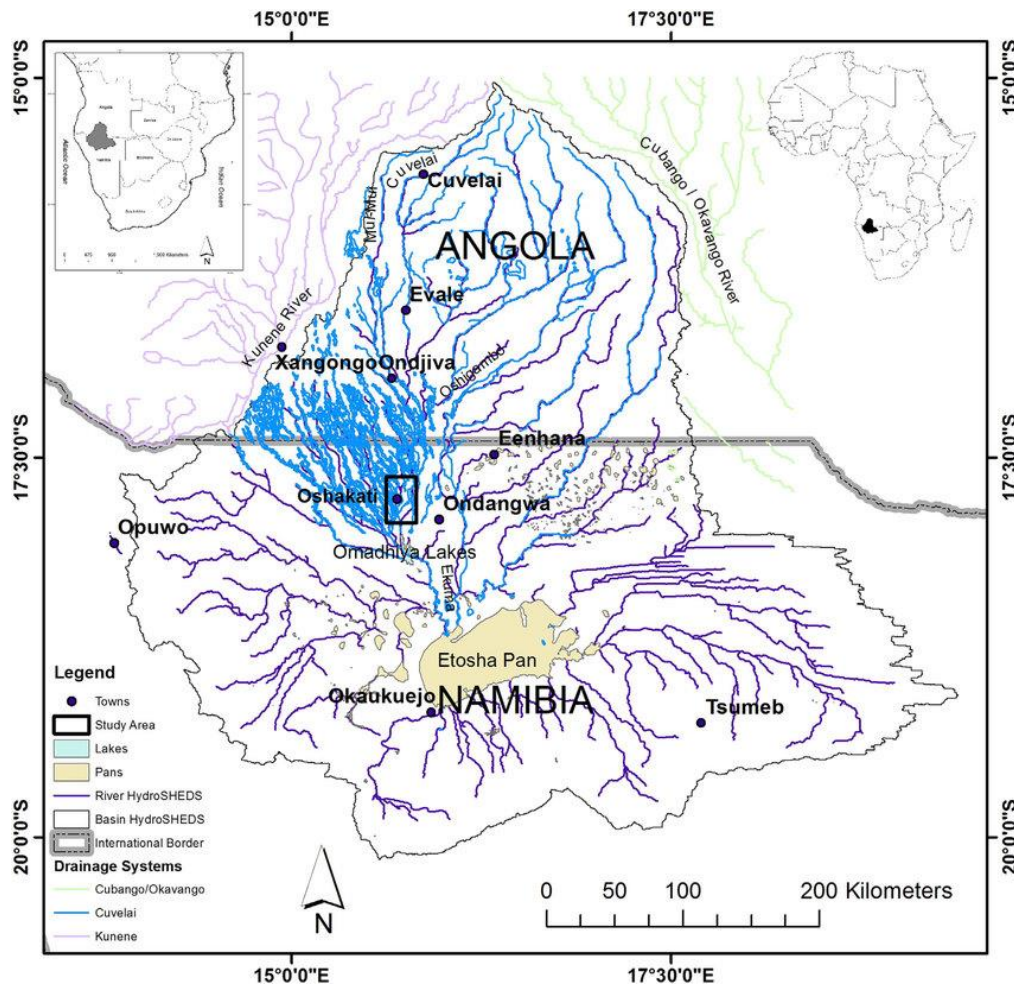


**Figure 4. 7 Map of Ehenye in relation to Oshakati Town**

Source: Developed by author

As seen in Figure 4.7 above, the community of Ehenye is built up to approximately 70 %. The black flagellated line is the position of the ongoing construction of the embankment and to the opposite direction, is the Okatana river depicted as a blue line. The area has limited vegetation in the form of trees and shrubs but there were visible and salt pans/depressions that fill up during the rainy season. According to Mendelsohn & Beat, (2011) the shallow depressions are seasonally inundated by *efundja*. The *efundja* is a local Oshivambo term used to describe flood waters from neighbouring central southern

Angola that flow, and drain using many small waterways and silently spread across into the flat terrain of Northern Namibia (Persendt & Gomez, 2016). The flood water is an important part of the Cuvelai drainage system that starts in Angola, drains into northern Namibia, and ends in the Cuvelai-Etосha Pan as depicted in the map below.



**Figure 4. 8 The Cuvelai drainage system depicting concentration of waterways around Oshakati Town.**

Source: Persendt & Gomez, (2016)

In Figure 4.8 above, the water ways that are part of the Cuvelai drainage are depicted in a deep blue colour and concentrated in the southern part of Angola and drain into Oshakati area in Namibia where this research is focused.

According to Nakale (2022) the depressions/oshana's are dry during most of the year and only fill up during the annual rainy season. They bring together various fish species, fertile soils, and nutrients but there are some years when there are extreme efundja events that cause flooding in the communities found in the drainage area. Figure 4.9 is an example of the inundated depression/oshana from Oshakati floods experienced in January 2023.



**Figure 4. 9 Image of oshana/depression during the 2023 rainfall season**

Source: namibian.org

Photo credit: Lambert Heil

In Ehenye specifically, the ground truthing revealed that the land is uneven, with limited vegetation. Investigating the physical environment was important as some attributes of the land may have contributed to the flooding challenge. In a study in South Asia in the

Ganges - Brahmaputra basin, flooding was found to be caused by monsoon rainfall many of which were transboundary in nature (Debnath et al., 2023). The rivers flow from the Himalayan mountains and cross borders into the Bay of Bengal passing through land that is craggy in nature thus inducing flash floods unlike the land in the Cuvelai that is flat and has depressions.

#### **4.2.2 Physical analysis**

##### **a) Position of houses in relation to street level**

The main road leading to the community is tarred and positioned higher than the houses alongside it. In the event of any rain, the likelihood of flooding is high as there was insufficient gradient to allow the free flow and passage of water. All other roads within the settlement were dirt roads and uneven and, thus creating a conducive environment for water retention making mobility difficult. According to Schneiderbauer (2013), people who live below or at street level are more likely to experience flooding in their homes and have a higher likelihood to suffer from significant loss in the case of a flood event than those at the street level or higher. The community culverts that were constructed as a temporary stop gap measure and were meant to channel water into the depressions/oshana did not work since during the rainy season, as they too were already full of water (Hooli, 2016).

##### **b) Availability of flood protection infrastructure**

###### **I. Embankment**

At the time of this research, the town of Oshakati had demarcated and had started constructing an embankment behind the Ehenye Township (Northwest of the town). This was meant to block the floodwater coming into the town mainly from the Angolan catchment territory. This, although present, and partly completed reduced the floods but did not eliminate the seasonal flooding challenge. The complete construction of the embankment was impeded by lack of funds which affected implementation as key parts

of the embankment were not constructed owing to slow release of funds According to Nuusita, (2018) the construction of the embankment was not completed owing to slow release of funds and this affected the rolling out of the project. The partly constructed embankment proved to be a temporary relief and not a solution because it did not have any tributary storm drains to harness the water from the residential plots. Thus, the depressions found in the community withheld the rainwater thereby exacerbating the flood conditions. Figure 4.10 images below depict part of the actual ongoing construction and part of the completed embankment.



**Figure 4. 10 (a) and (b): Ongoing construction of the embankment.**

Source: namibian.org

Figure 4.10 shows the construction of the embankment in 2022. The image to the left depicts the actual construction taking place, with visible inundated depressions to the right. Figure 4. 10a shows the side view of the construction of the embankment in relation to the Ehenye residential houses. As assessed after the completion of the construction of the embankment, the houses will be at a significantly lower level.

## II. Storm water drainages

There were no storm water drainages in the community, therefore, when it rained, the rainwater remained within the depressions and uneven land. Again, within the community, there were no tarred roads, only dirt roads were observed, which were uneven and thus creating favorable conditions for flood water retention. The image below shows part of the houses affected by the seasonal flooding.



**Figure 4. 11 Images depicting flooded Ehenye**

Image obtained from [namibiansun.com/news/ehenye-floods](http://namibiansun.com/news/ehenye-floods) 02-21-2018

Figure 4.11 a and b are from Extension 8 and 4 of the Ehenye community and they depict the general topography of the land. As seen above, there are no storm water drainages and the land is uneven, making it susceptible to water retention and possible flooding. The lack of municipal engineered drainages and other storm water facilities contributed to the environment retaining rainwater that could have been channeled away from the residential area. Visible man-made drainages and culverts were observed in front of the houses along the main road leading into Ehenye, they were however, very rudimentary, shallow, not continuous to allow flow of water, and could easily be flooded. Visible erosion from previous rain was present as the man-made drainages were not lined with concrete and served only as a stop gap measure. According to Ndeunyema (2023) flooding in

Ehenye occurred in January 2023 again due to the good rains received and the amount of 'efundja' flowing in.

### III. Green areas

On observation in the built-up areas of the community, there was poor insertion of green zones. The houses took up most of the space and were densely packed. The only areas that were not built up had been left by the contractor and no construction continued further.

#### 4.2.3 Risk Mapping

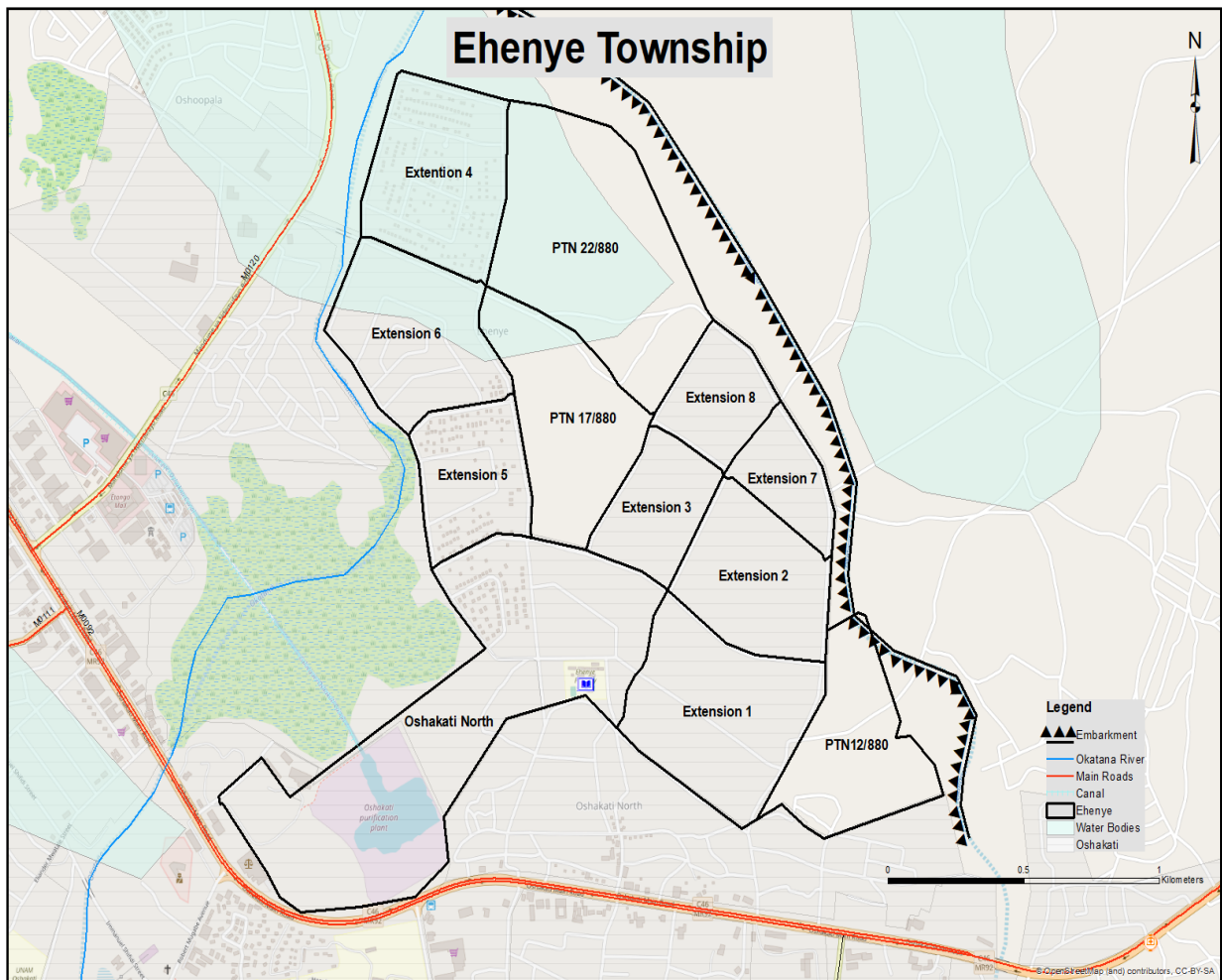
To understand the case area further, the researcher obtained various shapefiles from the Namibian Statistics Agency to create a detailed map of Ehenye. The list of shapefiles used to create the maps is tabulated below.

**Table 4. 7 List of shapefiles used in map creation of Ehenye**

<b>Data</b>	<b>Description</b>	<b>Creator</b>	<b>Date</b>
Ehenye	Oshakati zoning plan base map	Urban Dynamics Town and Regional Planners	2012
Rivers	HYDRO_Rivers, National	Ministry of Agriculture, Water & Forestry	01/04/2002
Railways	TRANS_Railways	Ministry of Land Reform	01/04/2014
Regions	Regional Boundaries	Ministry of Land Reform	12/08/2013
Water bodies	Locations of water features in Namibia (Water features, Oshanas, swamps, Lake Liambezi, Omadhiya Lakes)	Ministry of Agriculture, Water & Forestry	02/02/2002
Cad_Town_Surburbs	Town suburbs	Ministry of Land Reform	2010
Land use	Oshakati zoning plan base map	Urban Dynamics Town and Regional Planners	2012

Embankment	Oshakati embankment	on-screen digitized from Google satellite image	2022
------------	---------------------	---	------

The information above was used to further understand the study area. Of immediate interest were the different water features found in the area as depicted in the map below.

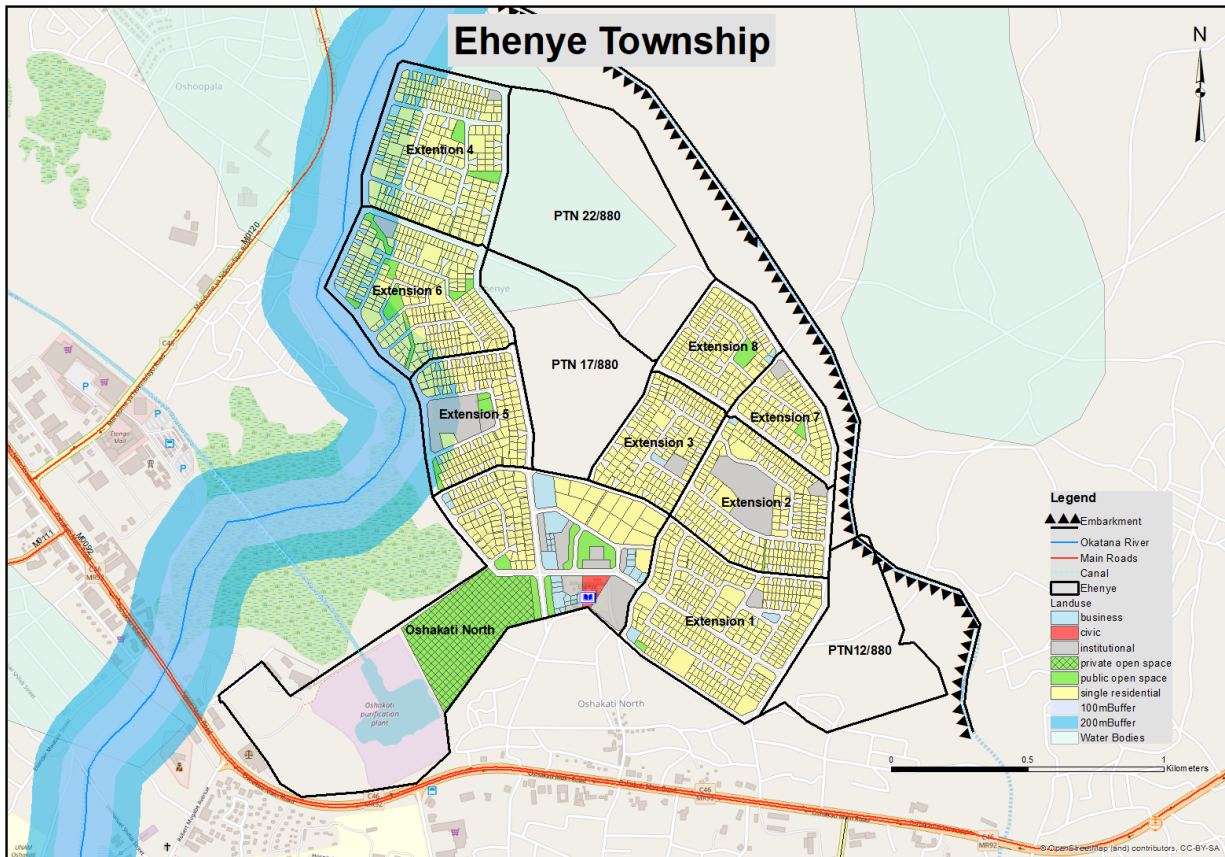


**Figure 4. 12 Map of Ehenye showing natural and manmade water features.**

Source: Developed by author

The map above depicts the water various natural and manmade water bodies found in the case study area namely the Okatana river (to the left of the map), the Oshana's, and the Calueque water canal. The Okatana river is a naturally occurring ephemeral river that forms part of the Cuvelai- Etosha drainage and often seasonally floods during the rainy season. To the north of the map are 2 delineated ground water features and according to the explanation accompanying the shapefiles, these are the location of the depressions/oshana's in Ehenye as identified by the Ministry of Agriculture, Water and Forestry in the year 2002. Thus, the northern part of the Ehenye settlement is positioned over a depression/oshana and this is where there are Extensions 4 and 6 of the community. On the map, to the right, is another oshana before the embankment. All the shapefiles pertaining to location of water features were available before the commencement of the mass housing in Ehenye in 2006, so likely some facts were overlooked, or ignored when planning the mass housing scheme. Possibly because the depressions are seasonally inundated and for the rest of the year are dry. Therefore, the presence of the water bodies, and the sandwiching of the Ehenye community between the embankment of the Okatana River increases the risk of flooding in the area.

To get a fuller understanding of the real extent of risk, Map 1, (Figure 4.12) was used as a base and a land use map was superimposed to obtain a clear picture of the flooding risk. The map is depicted below.



**Figure 4. 13 Superimposed map showing water features and landuse in Ehenye.**

Source: Developed by author

In Figure 4.13, land use features were superimposed on figure 4.12 showing water features to gain an understanding of the possible risk. The researcher, using the Ontario flood guidelines, created buffer zones of 100 m and 200 m from the river. For the 100 m, any land use within this distance was deemed to be in the flood way, meaning the risk of flooding was at its highest and development is not advisable. Any development within the 200 m (flood fringe) can be permitted provided risk reduction measures are instituted.

In this case, any development within Extensions 4 and 5 was determined to be in the high-risk category. The proximity to the river, the presence of the Oshana and the

absence of storm drainage all made settlement in this area at high risk of flooding. Therefore, any settlement in Extensions 4, 6 and 5 were at high risk whether within the buffer regions or not as flood infrastructure was deemed inadequate and there were no engineered storm drainages within the community and alongside the main roads. The residential houses were also without flooding buffers and storm drainages.

Despite the presence of the embankment, which seemed to be a temporary solution, as it diverted water flowing from the Angolan catchment away from the settlement, the biggest drawback was the absence of the tributary storm drainages to harness the rainwater from the settlement. If this was present, the flood effects would have been less as the water could be channeled away from the settlement.

The flooding that happens in Ehenye community as assessed under this objective is attributed to a combination of factors. Namely the presence of *oshanas*, the lack of engineered storm drainages and the piecemeal implementation and non-completion of projects meant to alleviate the flooding challenge and allow settlement in flood prone areas. It seems from the results from objective 1, what is now Ehenye community was an area that had been deliberately left unused, likely because the area serves as a drainage from the water flowing from the Angolan highlands, as well as the fact that the area is situated in an area with a natural depression, meaning therefore, that flooding as a possibility had been considered before. The research could not ignore the fact that shapefile information on various water bodies and rivers around the country and those found within Oshakati town had been created in 2002 by the Ministry of Agriculture, Water & Forestry and stored as such at the Namibian Statistics Agency, meaning that it was available earlier than the commencement of demarcation of town suburbs and construction of the mass housing of Oshakati and Ehenye. Thus, Ehenye community's calculated risk is 16 (Harm occurs often x Serious disturbances), which means that risk of flooding is high. The calculation gave consideration of all the other factors found on the ground.

Based on the observation above, there were critical facts that were overlooked when considering land use in Ehenye. The information pertaining to water features around Oshakati is well documented and easy to access, some of it freely to the public via the NSA website. Two possible reasons can be attributed to this, firstly the depressions are seasonal and therefore only fill up during the rainy season and therefore assumptions could be made that the area is habitable and the depressions may cause little to no harm., secondly prior to 2006, there was no human settlement in the area and therefore the flood waters could drain and affect no one. The rainfall patterns also as reported in objective 1 varied only a little in the area. It is only after the year 2006 that heavy rainfall is recorded. Unfortunately, with a changing climate, information pertaining to historical features and meteorological events is important because it may give an indication of what could likely happen in the future and therefore this cannot be ignored. Approval of land use thus needs to be an all-encompassing process that includes all information including historical environmental data.

Flood risk management is a critical component for adaptation and resilience in communities that are frequently confronted by flood hazards. Scientists now widely acknowledge that there is increased frequency of extreme events due to climatic transformations (Hoegh-Guldberg et al., 2018). While each area that is affected is unique on its own, in the case of flooding in basin communities especially in Africa, land use developments into potentially hazardous areas are the main cause of the catastrophes that befall the community members (Barredo et al., 2007). While flood risk maps are important as they serve to inform or identify where the problem is. In most cases, especially in this study area, they become reactive rather than proactive as development would have taken place and reversal of some developmental decisions may be impossible.

#### **4.2.4 Conclusion**

The purpose of objective 2 was to identify if there are other factors that could be contributing to the challenge of flooding in Ehenye as well as to map out specific areas

that are at risk of flooding. The results obtained above show that Ehenye in its totality is at a high risk of flooding whether during extreme rainfall or not. A combination of factors increases the risk of flooding during the rainy season. This includes natural factors such as the presence of Oshana's/depressions in Ehenye, the presence of the river which was reported to overflow in years of extreme rainfall, the Cuvelai drainage system that bring along slow-moving flood waters from southern Angola during the rainy season. Other factors include the lack of engineering storm water drainages in the community and incomplete construction of the embankment which had missing tributary drainages to direct rainwater away from the community.

### **4.3 Objective 3- Assessing Vulnerability risk factors**

Objective 3 of the study to was to assess the vulnerability risk factors. The purpose of this objective was to identify what makes the community vulnerable to floods and what adaptive capacity was available to ensure that the system had the ability to reduce risk and cope with consequences resulting from exposure (communities, institutions, and public). Qualitative secondary data was collected from the census demographic survey of Oshakati, the Oshakati Town Master Plan 2008 and the Oshakati Strategic Plan 2015-2020 and various Acts of Parliament. The legal environment and critical support factors were investigated.

#### **4.3.1 History of Ehenye**

Ehenye township was commissioned in November 2006 by the Oshakati Town Council and the National Housing Enterprise (NHE) to construct and provide affordable low-cost housing to its residents for the purpose of alleviating the housing challenge that was affecting Oshakati due to rural-urban migration and the general growth of the town (Moses, 2020). This mass housing development was the biggest housing development to be undertaken in Oshakati since independence in 1990 and the target of houses to be built was 2235 houses by project completion (Nampa, 2006). The housing project was built in phases, with phase 1 completing 500 houses and the housing project benefitted

Oshakati town in various ways such as house ownership and employment creation during the construction phase (Nembwaya, 2014). There are currently 8 Extensions that are fully built up while the rest of the other land has been left fallow due to challenges with flooding and servicing of land.

#### **4.3.2 Oshakati Migration Patterns**

There are many factors that influence migration whether rural-urban and sometimes between cities and towns. The major drivers responsible for the pull factors are employment and educational opportunities (Awumbila, 2017; Selod & Shilpi, 2021). Oshakati town is the administrative capital of the north with a population of 36 541 and the fifth largest town in Namibia (Mwazi, 2010). The town has grown significantly from the time it was proclaimed to be a town 1992, drawing inhabitants from around the northern rural areas of Namibia. According to the Population and Housing census 2011, Oshakati in 2001, had a population of 28 255 and thus between 2001 and 2011, the town grew by 29.3% (Steytler & Kafidi, 2011). The migration into Oshakati town put pressure on the available services and demand for land, prompting the town council to engage in formalising informal settlements, approving a mass housing scheme and provision of serviced land at large scale to reduce the demand for settlement land (Mendelson & Beat, 2022). Unfortunately, servicing of land has not gone according to the plans of the Oshakati Town Council largely due to budgetary constraints and limited allotted funding from the government of Namibia (Elago, 2017).

#### **4.3.4 The legal environment**

To effectively investigate flooding, the legal environment was considered to understand what statutory instruments are available in supporting and protecting the people of Namibia from flooding disasters. A combination of legal instruments was reviewed namely the Disaster Risk Management Policy 2009, Climate Change Policy and the Urban and Regional Planning Act 5 of 2018, National Housing Development Act 28 of 2000, and Local Authority Act 23 of 1992 as amended.

All the Acts of Parliament cited above have clear roadmaps on land use planning and zoning, construction, and the responsibilities of servicing of land. However, they cease to be of any good if key components to curb flooding are not implemented. For example, in the Local Authority Act of 1992 as amended, part VII subsection 38 states that one of the duties of the local authority is to

‘construct, maintain and carry on a system of sewerage and drainage including sewerage works, public sewers and storm water drains whether within or outside its area’.

The Act however is not prescriptive on when this construction should be done, whether before, during or after. In the case of Ehenye, for the provision of portable water and sewerage system network was done before the commencement of the construction of the houses. The storm water drainages and roads were left out before and during the construction. Currently, post construction and occupancy of land, there still are no storm drainages, and this has affected at least 500 homes and made them vulnerable to floods.

Furthermore, according to part IX subsection 48 (1a), the local authority also has the responsibility to construct roads and accompanying drainages. According to Part IX, the local authority has the mandate to construct roads within its jurisdiction and construct and maintain streets with the written approval from the minister. In this case, in Ehenye, there is only one asphalt road that is constructed, that leads into the community, the rest are dirt roads in between the allotted plots. The plots are divided and demarcated by the council and the council has responsibility over the maintenance of the dirt roads. Thus, the absence of road construction means that there is no accompanying road drainage system. The primary purpose of a road drainage system is to remove the water from the road and its surroundings (Yunianta et al., 2018). An efficient design of a road drainage system should consist of two main parts that is, dewatering and drainage. De watering refers to the removal of rainwater from the surface of the road, whilst drainage refers to the different infrastructural elements that keep the road structure dry (Aranda et al., 2021). Roadside drainages are important as they collect and transport water from the surface and structure of the road so that there will be no ponds on the road or in ditches. In this

case in Ehenye as seen in the results of objective 2, the roads are not maintained and as a result have become uneven and rainwater is collected into the depressions presented and those created.

The absence of storm water drainages in a built-up housing community is probably the biggest contributor to the flooding in Ehenye community as water cannot be drained away from the community as it rains. Analysis of the current Oshakati Town Planning Master Plan revealed that the previous town master plan had limited drainage in some parts of Oshakati, and especially the areas that were not developed by year 2000 (Iita, 2015). The current town masterplan was presented in 2008 to cabinet and was meant to overhaul the design of the town whilst also improving sanitation and drainage system. It was also necessitated by the need to reduce flooding during the rainy season (Elago, 2017). Part of the plan also included deepening of the Okatana river to mitigate against floods unfortunately, due to budget constraints, all components of the town council master plan could not be implemented at

#### **4.3.5 Disaster Risk Management**

The major goal of the Disaster Risk Management Policy 2009 is to contribute to strengthen national capacities to significantly reduce disaster risk and build resilience to disaster. The policy aims to achieve its major goal through a national risk management plan or framework, which provides a holistic approach to disaster risk management by outlining objectives and activities to be done in disaster prevention, preparedness, response, and recovery. The policy and framework plan acknowledge the different hazards and disasters that normally befall Namibia, but they are not specific with each hazard, the policy deals with disasters broadly.

The likely reason why the policy deals with disasters broadly is the fact that most hazards in Namibia have a specific policy addressing it. For example, droughts in Namibia have a National Drought Policy that clearly outlines a sustainable approach to prevention and management of droughts. The policy compels communities to engage in practices such

as proper rangeland management and sustainable farming practices that mitigate the occurrence of drought or lesson the impacts. In terms of floods, there is no legislation that deals with floods and its associated consequences. Perhaps if this was available, it would have helped in raising awareness and prevent practices that may leave a community flood prone. Furthermore, it is not clear if there are any specific regulatory instruments and or guidelines in regulating the settlement in flood prone areas such as in the Cuvelai-Etосha Basin. Thus, regulations need to be developed to guide the nations actions in prevention as well as in the reaction when floods do occur. A flood policy and its associated regulations could firstly address the impacts of floods and offer solutions to address the consequences whilst also at the same time outlining guidelines on settling in flood prone areas, flood plains and near rivers and dams and stating the recommended flood structural requirements for settling in these areas.

#### **4.3.6 Town strategic plans**

The Oshakati Town Council formulates 5-year strategic plans to help to guide activities of the town council during that period. These plans take into cognisance the environment that the council operates in so that they are aware of their strengths, weaknesses, opportunities, and threats. The 2017-2022 strategic plan acknowledges floods as a threat to the function and activity of the town. Solutions to flooding are also known and tabled and they include the deepening and lining of the Okatana river to reduce silting along its channel as this has restricted the free flow of water causing flooding of suburbs on its banks. Another solution that is highlighted in the plan is the construction of a dyke that will control the flow of water into the town. The planned dyke was supposed be about 25 km in length along the periphery of the town and the estimated cost of the construction was N\$1.5 billion in 2011, however, the construction was halted in 2016 due to budget constraints (Nuusita, 2018).

The Oshakati strategic plan also highlights other threats and weaknesses that could likely contribute to the failure to curb annual floods. These include budget constraints, slow process of transfer of funds from central government, less budget allocation to implement

projects, slow implementation of infrastructure development and maintenance and rural to urban migration(Elago, 2017). With respect to resourcing of projects, the Government of Namibia is the major funder of the flood prevention projects and if the money is not released for whatever reason, the infrastructural projects cannot continue (lita, 2015). The unavailability of funds is due to economic challenges that Namibia has been facing thus affecting project implementation whether new or continuing leading to slow infrastructural development and maintenance (AFDB, 2012) . Whilst all this is happening, the demand for land and housing is high due to rural-urban migration and the pressure mounts on the council to provide these services.

Thus, the legislative environment governing the settlement of communities, the servicing of land and building of houses is available and detailed in terms of responsibilities. Further to this, the Disaster Risk Management Policy 2009 elaborates and acknowledges the hazards experienced in Namibia. What is lacking is the full application of the various pieces of legislation and the reason is attributed to inadequate funding to support programmes.

#### **4.3.7 Critical Support Factors**

Disasters will time and again happen in any part of the world and the types of disasters and their consequences differ depending on the case areas' unique characteristics. The consequences may be minimised if critical services and support factors are available on the ground and are dispensed in time to assist. Services such as a good road network, hospitals, emergency services and communication are necessary to ensure swift service during a disaster.

##### **a) Support Services**

In Ehenye community as noted in the findings of objective 2, the road networks within the community are uneven dirt roads that hold water during rainy days, and this is due to the absence of road drainage and there is also one asphalt road leading into the community

from town. Access to the community by road is limited to that one main entry road, the rest are smaller dirt roads that also are easily flooded during the rainy season. Ehenye community is also in a lower lying area sandwiched between an embankment on the eastern side and the Okatana river on the western side as such, during the 2009 floods, the community was cut off from many services (Thulkanam, 2010). Support services, therefore, must find other means to access the community such as by boat and air. Most services are situated in Oskakati town, that includes 2 hospitals, the fire brigade, and a few police stations. The Ehenye community has no local clinic.

#### b) National early warning communication

Climate data and evidence are important in any society as they are part of baseline information used in planning and decision making. If decisions are to be made on any sector in society, there needs to be quality evidence, normally from a trusted source such as an official meteorological office. The meteorological office in the Oshana region is in Ondangwa and it collects data from other observation centres across the region to create a database of climate data. Hazard communication is done by the town council and although it is done in time, there is no relocation offered before the hazard happens. Community members relocate at their own cost to their preferred location. Through an analysis of the Disaster Risk Reduction Policy of 2009, there seems to be no clarity of command during emergencies. Ideally, the chain of command must be clear and undisputable to efficiently mobilise rescue efforts. The post-disaster needs assessment report on the 2009 floods revealed that the Cuvelai system had limited rain gauges, and this needed to be improved to strengthen the early warning system in the region (Government of Namibia, 2010).

#### **4.3.8 Summary causes of flooding**

The flooding in Ehenye is caused by several intertwined factors. Firstly, the flooding is seasonal, as it only occurs during the rainy season between the months of January to March of the year. The trend analysis conducted under objective 1, revealed that

precipitation had increased in intensity over a very short rainy season from the year 2008 through to 2018. However, there are several other factors on the ground that directly contributed to the worsening of the floods, and these include natural features such as the presence of oshana's in the study area, the efundja flood waters flowing from southern Angola as well as the presence of the Okatana river in proximate distance in Ehenye. The river as explained under objective 3 is silting and therefore easily bursts banks during the rainy season and overflowing to the adjacent area. Other identified reasons for flooding include the absence of flood dewatering drainages as there was no road construction in the area as well as the absence of tributary storm drainages from the embankment thus water is retained within the community instead of flowing out.

Other peripheral reasons as highlighted from the results of objective 3 include non or piecemeal implementation of flood infrastructure such as the embankment and drainages owing to limited funding and allowing settlement in flood prone area without due consideration of future possibilities.

#### **4.3.9 Solutions**

Based on the results given above, recurring floods are a challenge in Ehenye, therefore solutions need to be found to address inadequacies that have been identified. A community that is flood resilient is one that can anticipate, prepare for, respond to, and recover from significant floods with minimum damage to social wellbeing, the economy, and the environment (Magnuszewski et al., 2019). Careful steps thus, need to be taken to ensure that communities are prepared for the frequent floods whilst leveraging on any opportunities presented. The following solutions are suggested to mitigate and minimise floods in Oshakati.

##### **4.3.9.1 Immediate Solutions**

- a) Construction of storm water drainages and road drainages.

- Water control structures must be adequately designed, constructed, and maintained.
- Regular maintenance of existing culverts such as cleaning debris to ensure that they are operating optimally.

b) Relocate to less vulnerable areas

Where development already exists in vulnerable areas, priority must be protection of people, buildings, and facilities. If protection is impossible, then with the consultation the of affected individuals and homeowners', relocation can be considered and affected people assisted by the local government through creating incentivised packages that cover financial and logistical support. Those described as vulnerable in the area are those with houses located in the depression, extension 4 and 5.

c) Explore transboundary watershed management

Part of the flooding challenge in Ehenye is attributed to water drainage from the Angolan highlands. The countries and local governments concerned can engage in integrated transboundary watershed approach to storm and flood water management. The watershed plan must include enhanced stormwater management techniques to slow, spread and infiltrate flood water before it reaches downstream thus reducing flood risk. The current CUVECOM management acknowledges the floods, but concrete management plans are still underway (Mensah & Ahadzie, 2020).

d) Community preparedness

The local government working closely with residents, business and government must develop and update early warning systems and emergency plans, procedures, and protocols.

#### 4.3.9.2 Long term Solutions

- a) Discourage new development in flood hazard areas and river corridors.

Local governments must identify flood areas and river corridors and ensure that no new development is carried out in those locations. This can be done through the passing of flood hazard regulations that prohibit any new development whilst encouraging mitigation of existing development within the areas. Existing structures within the flood plain should be protected if they cannot be moved. Protection can be done through various flood proofing methods.

- b) New development

New development should have adequate stormwater drainages and control mechanisms and under no terms should development be allowed when servicing of land is not completed. The new development should also take into consideration existing development and adjust carrying capacity.

- c) Protection of areas that help attenuate flooding.

Protection of wetlands, river corridors, flood plains and land adjacent to rivers and streams is important in reducing flood risk damage. This can be done through introducing riparian buffers and management zones as well as passing of ordinances that prohibit encroachments into these areas.

- d) National level legislation

Legislation that aims to reduce the impact of flooding is required. This will support the actions by various stakeholders in risk reduction e.g., a Flood Policy.

- e) Encourage compatible land used activities.

Land use activities such as different forms of recreation and agriculture should be encouraged on floodplains.

f) Monitoring and forecasting of rainfall

Consistent recording of rainfall must be done to ensure that flood sensitive areas have complete records of precipitation. The complete records allow for trend monitoring, analysis, and flood forecasting. Furthermore, real time monitoring and forecasting of rainfall and river conditions especially during the rainy season.

g) Early warning systems

Using the knowledge from the rainfall records, end to end early warning systems that detect, forecast disseminate and respond to potential hazards in a timely manner can be developed and these must include risk knowledge and response capabilities. The forecasts must be expert translated into targeted warning messages and into local language varieties.

All the above recommendations can be incorporated into an integrated flood management system with different proactive approaches to adaptations that can be monitored formally and corrected where needed as the challenges presented by climate keep changing.

#### **4.4 Opportunities for resilience**

Despite the challenges highlighted in this research, there is room for leveraging benefits from the annual flood waves. Flood wave waters coming from Southern Angola reoccur consistently although they differ in intensity. Thus, with deliberate and intentional planning, the flood waves and the flood waters from the rainfall can be harnessed to the advantage of the local communities around Oshakati town. This can be done through:

a) Fish and agriculture industry

The flood wave brings with it plenty of fish and water to the normally dry parts of the country thus improving forage, ground water reserves as well as the Oshana's. The influx of fish can be commercialised beyond the flood season by creating fish farms. The water available can be harvested and used for irrigation when the rainy

season is over. This will boost the local economy, by creating jobs and sustainable livelihoods.

b) Growing a sustainable town

The flood waters can be leveraged to by redesigning and refocusing flood waters through, for example., flood retention facilities and or cisterns that can store flood water for later use or rain harvesting. In the flood plains, rain gardens can be created that can contain native shrubs, perennials, and flowers. The rain gardens will create an aesthetically pleasing environment while preserving vegetation and controlling storm water and localised floods. The water from the cisterns can be used later for watering various crops and vegetation.

c) Expanding the river

The Okatana river that separates Oshakati East, and West, time and again, gets flooded due to heavy flood waters and the river siltation, thus, expanding the river will increase the river's carry capacity and reduce the chance of flooding to the adjacent area by moving the flood water upstream. River infrastructure such as levees, walls and bridges can be used to harness water that can be used for recreational activities as in the case of the Thames River in London. The Thames River is the cultural icon of the city and has become a tourist destination with many recreational activities such as bird watching, boat riding and is home to many historic monuments, art galleries museum and restaurants. If this can be done for Ehenye, it can possibly boost the economy (Wilcox et al., 1998).

d) Recreational activities

Opportunities to see and engage with the river can increase residents' consciousness of the river and to motivate them to protect it. The local municipality can create various recreational activities such as outdoor dining in parks, bird watching and hunting, and select spots for fishing and canoeing during the time

when water level is high. This can also serve as a local, national, and international tourist attraction.

e) Restoration of flood plains

Floodplains provide a buffer from the river in case of floods. They protect people and property by slowing down the flood waters, they are also known for creating fertile soils, nurturing plant species and wildlife and serve as nurseries for many fish species. They are also good for recreation such as paddling, exercising, and fishing. Restoration of the floodplain will ensure that ecosystem services obtained through the flood plain are maintained.

If the community is to derive benefits from floods, they need to adapt to risk in imaginative and innovative ways. Oshakati town is also strategically located near the Ruacana Falls and the Etosha National Park and this can be used to the advantage of the town. The Colorado River Basin in the United States of America for example, is a uniquely human dominated ecosystem that provides water to seven states and has been managed through natural and green infrastructure and this has helped in reducing vulnerability and increased resilience to the changing climate (Sullivan, 2014).

By being intentional about the above, the local economy can be boosted and the quality of life of the people around can improve. This, however, requires transformative collaborations between governments and communities.

## **4.5 Objective 4- Conceptual model**

Objective 4 of the study was to develop and validate a conceptual model for resilience in the Cuvelai-Etосha Basin. The purpose of this objective was to develop a guide that can be followed by developmental planners to increase their capacity for protecting communities in an unstable and changing climate. Key components of a framework for resilience within the context of the Cuvelai- Etosha Basin was developed.

The results of the literature review revealed that resilience is possible if there are strong, active, and engaging developmental and planning systems, which work in an integrated format. In this study, the researcher isolated the variables that were under investigation to unveil the reason why the case area was flooding. Two main reasons were identified are that firstly, that the rainfall intensity patterns had changed within the last 50 years, especially between the year 2008 and 2018 as depicted by the results of objective 1. Secondly, there are many gaps within the developmental town planning system that were uncovered.

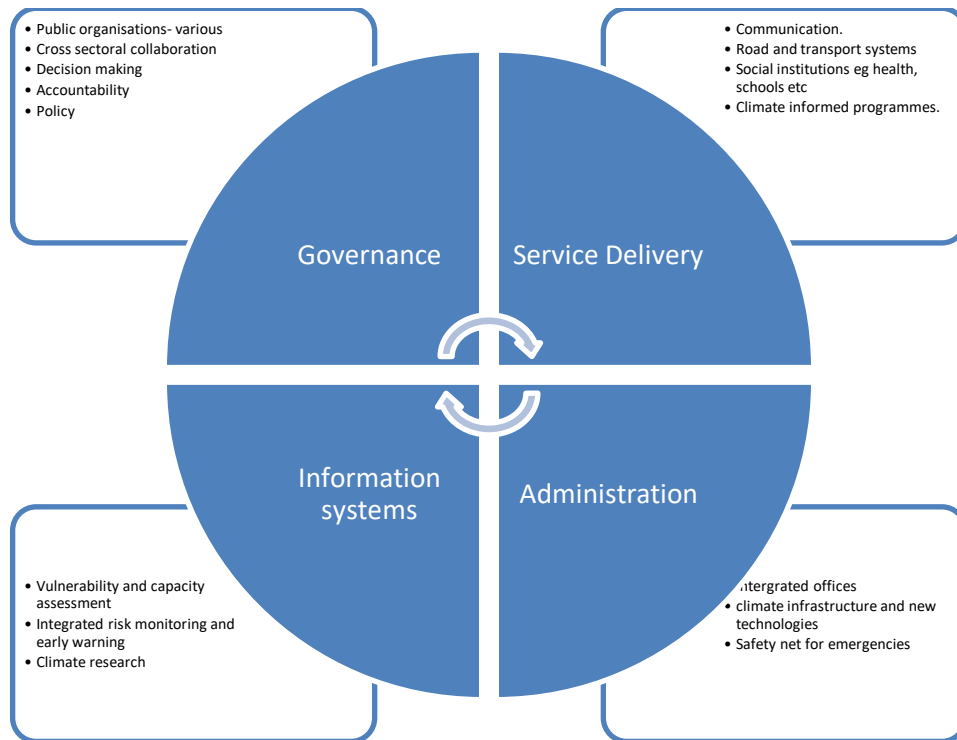
The gaps identified are discussed under objectives 2 and 3 and the results of the discussion form the basis of the starting point of developing the preliminary stage of the proposed conceptual model. The main synthesis is that if communities are adequately planned and supported through their town authorities, even if there are exposed to climate stressors, there is a greater chance of being cushioned from adverse effects and thus be able to recover from the impacts while leveraging on opportunities that may come along because of the phenomenon.

### **4.5.1 Enablers of resilience**

In this research though, the major gaps identified were linked to inadequate capacity building from a developmental planning standpoint and because it is such an important component of the conceptual model, the researcher outlined the pertinent components required to enable community resilience. The enablers of community resilience address

the basic environment that a community needs to survive. The components are outlined in Figure 4.14 and narrated below:

- i. Effective governance
- ii. Knowledge and information
- iii. Administration
- iv. Service delivery



**Figure 4. 14 Enablers of community resilience.**

Source: Author's own construct.

#### Component 1: Governance

This component refers to the strategic management and ability to take ownership and do what is best for the country and local councils for effective governance. The governing environment which the town falls under cannot be ignored when considering plans for the town in question. This includes public organisations

(political, administrative, and legislative) that contributes to the functions of the community. The environment also includes the decision-making process of institutions as well as channels and mechanisms through which the community can use to exercise legal rights and articulate interests. The governance system must enable the people to demand accountability, meaning the people can either push forward or deter any town plans. Effective leadership and governance and the willingness to address the risks of climate change are essential to ensure implementation across the government departments.

This can be achieved through:

- a) Ensuring that legal and regulatory systems, which support climate resilience are implemented accordingly and are regularly monitored.
- b) Institutional mechanisms, capacities and structures and allocation of responsibilities to address climate change.
- c) Cross sectoral collaboration and coordination between divisions and across the departments, to ensure that decisions taken in other sectors are considered.
- d) Accountability at all levels as well as active engagement amongst and between government departments and all who are in decision making positions.

#### Example of measurable outputs

- i. Auditing cross sectoral focal units and individuals (especially in key decision-making positions) for timed response turnaround if information is required.
- ii. .

#### Component 2: Knowledge and information systems

If the leadership and governance environment is conducive, it then allows for the functioning and support of research and information systems that will place the communities in informed positions. The provision of information will allow the community to plan for, prepare and respond to climate stressors in a coordinated and ready format. Under this component, 3 key tenets are considered. They are listed below:

- i. Vulnerability and capacity assessment
- ii. Integrated risk monitoring and early warning
- iii. Climate research

Development of capacities especially for climate resilience should build upon and support the more general effort to ensure adequate baseline levels of climate research, policy and management and delivery. A range of assessments can be instituted to generate policy relevant evidence at the scale and nature of climate risks considering the local circumstances.

Climate risks will vary depending on nature of exposure and therefore vulnerability assessments need to be conducted. The results will then be used as an essential tool policy and programmatic planning and interventions. These vulnerability assessments must be continuous, iterative processes to keep updated information and communication.

#### Examples of measurable outputs

- i. Early warning detection tools: these can be used to identify and monitor changes in incidences so that early action can be triggered (for example., early warning systems)
- ii. Risk mapping reports: periodic reviews of community vulnerability assessments can be used to determine if there are improvements or deterioration.

#### Component 3: Administration

Community resilience to climate change risks builds on the provision of support technologies that can be used to assist in reducing climate risks. Ideally, the integrated offices that work on adaptation and resilience have to be supported by requisite financial resources as well as current technologies for better delivery of interventions.

In this component, the following tenets are considered:

- i. Integrated offices
- ii. Climate financing
- iii. Climate infrastructure and new technologies.

Support systems require funding for them to be successful. Resources requirements can be assessed through budgeting for interventions. The financial resources can be raised through various means such as national budgets, donor funds and fund raising. Once financial resources are raised, infrastructure and technologies used to run the offices and programmes can then be instituted.

#### Examples of measurable outputs

- i. Climate investment plans
- ii. Budget reviews

#### Component 4: Service delivery

For any climate programme to succeed, it needs to be supported by existing and new programmes found in that environment. The existing programmes and systems need to be part of the normal function of the community, for example., a good network of roads, communication systems such as mobile networks and disaster and emergency preparedness plans. Service delivery should be proactive and not happening only when a disaster has occurred. Resilience is not a onetime event, but a series of adjustments to a changing climate that leverages also on the opportunities brought out by climate change. The programmes should also be able to collaborate across sectors to facilitate a timely response.

#### Examples of measurable outputs

- i. Communication: outline the scope of information to diverse audience; responsibility of communication as well as allowing for community feedback.

- ii. Emergency plans: disaster and contingency plans and delivery of interventions in the event of an extreme event.
- iii. Turnaround time for requests and queries submitted to offices.

## **4.5.2 Model Context**

This proposed conceptual is herewith referred to as 'Model for Building Climate Resilient Basin Communities'. The model has been designed considering the evidence of flood hazards in basin communities. The overall objective is to provide a guide that can be used to determine resilience and potential resilience of communities in an unstable and changing climate. As a prerequisite, the four components outlined in part 4.4.1 are essential so that decision makers in sectors such as construction, civil and water engineering, town planning, policy planners and others will be better placed to guide development in the area.

This conceptual model responds to the increasing calls and policy mandates at global, regional and at the local Namibian level to address climate risks and can be used in combination with other interventions. It also acknowledges and considers the annual Conference of Parties' (CoP) resolutions on climate action to strengthen adaptation and leverage on opportunities that climate change presents. The development of the framework was guided by components found in the United Nations Climate Action Pathway 2021.

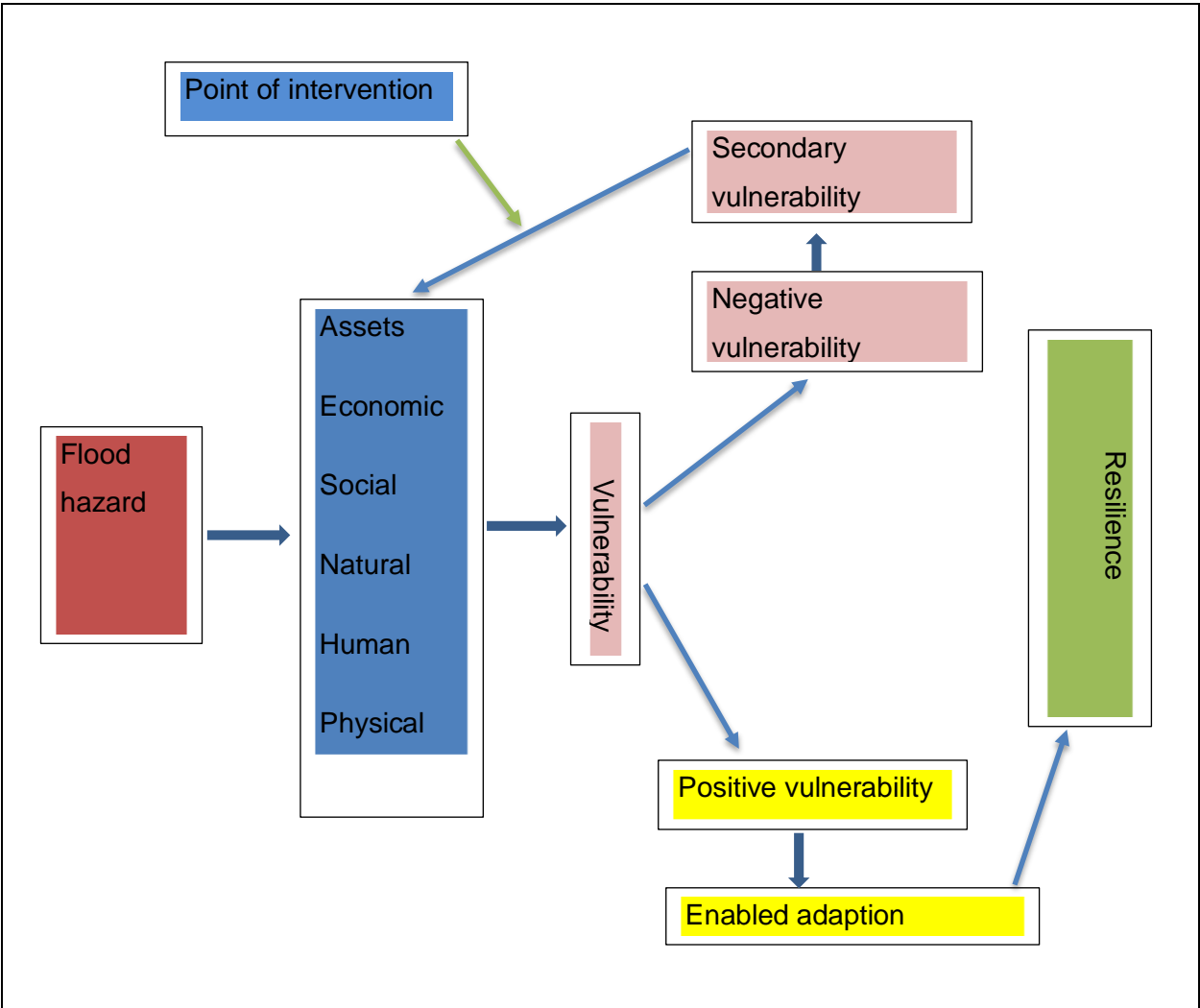
### **4.5.2.1 Conceptual model goals and objectives**

The overall aim is to identify the key functions that need to be strengthened to provide a comprehensive response to climate change in basin communities. The following objectives will help attain this goal:

#### **Objectives**

- a) Identify the main areas that need to be strengthened to build climate resilience and use these as a basis for developing a comprehensive plan.
- b) Guide professions working in the development sector to understand and prepare for climate risks through a resilience assessment.

The model can be used before a flood hazard by town authorities to determine resilience by taking stock of assets and simulating a scenario. The results can be used to build and determine if a community is resilient or not and those results can help in improving preparedness and early warning systems. The model also can be used after a flood hazard to determine understand the strengths and weaknesses preparedness response and also determine level of resilience. Building climate resilience is a process of ensuring that communities adapt to a changing climate mainly through reducing vulnerability and developing system capacities. The proposed conceptual model is depicted and in Figure 4.15.



**Figure 4. 15 Conceptual model for building climate resilient basin communities'**

Source: Developed by author.

#### Definition of framework terms as used in the conceptual model

1. Flood hazard:

A physical process or event that can harm human health, livelihoods, and natural resources for example., floods (Baky et al., 2020).

2. Community

A social group coming from the same geographic location who share the same government, culture, and heritage (Cobigo et al., 2016).

3. Community assets

These are the components that form the background in which a community operates in and used to improve the quality of life (Ahearne, 2010).

a) Physical assets

These include different kinds of structures used for providing goods and services in the community, housing, roads, water systems etc (Walker, 2010).

b) Social assets

These are the networks of organisations and institutions that exist within a community. For example., health centres, education, support networks, livelihoods, and safety net programmes (Maguire & Cartwright, 2008).

c) Economic assets

These are GDP reserves that support and affect the economy of the community. For example., employment levels, economic diversification, insurance, inflation and FDI (Petit & Kingsley, 2006).

d) Natural

Physical geography of the region where the community is located, which includes for example., climate, water quality, air, geology, vegetation, and climate (Shanker, 2004).

#### 4. Vulnerability

##### 4.1 Negative vulnerability

The circumstance of a community system that make it susceptible to the damaging effects of a hazard.

##### 4.1a Secondary vulnerability

The effects that accrue because of the inability of a system to adjust to effects of a climate stimuli/hazard.

##### 4.2 Positive vulnerability

The ability of a community system to adjust, quickly bounce back from the damaging effects of a hazard despite being susceptible.

#### 5. Adaptation

The process human and natural systems use to adjust to as a response to an actual and or expected climatic stimuli (IPCC, 2012).

#### 6. Resilience

This is the ability to use available resources or assets to respond to, withstand and recover from adverse effects of a hazard (Moench et al., 2011).

#### **4.6. Explanation of the conceptual model**

The effects of climate change on a society are differential due to the complex social groups, who have different access to resources. The ability to derive benefits from natural

and other man-made resources, influences vulnerability by either augmenting or reducing exposure and sensitivity. The resources also referred to as assets in the diagram above, include tangible and intangible goods and services, such as private and public capital, liquid assets, alternative accommodation in the event of an exposure to hazard, various insurance and transport and communication networks. All these and more, need to be available and accessible so that they can be used to reduce vulnerability.

When a community is exposed to a hazard, for example., a flood event, it directly impacts the assets of the community. The damage caused by the direct impact will be determined by the general status of the community before the occurrence of the hazard event. The status includes the physical, social, economic, and natural environment collectively, and this forms the asset base.

The direct impacts from the climatic hazard added with the assets, will determine how vulnerable the community will be. If the assets and recovery capacity are weak, it will lead to negative vulnerability, meaning the system will struggle to recover from the impact of the hazard. Inversely, if the assets and recovery capacity are of good standing, then the community will face positive vulnerability, where the community despite the effects, will use the asset base to adjust and respond to, and recover from the effects of the hazard at the same time, taking advantage of opportunities by being innovative and creative to further buttress their asset base leading to community resilience.

If the community assets are weak, the effects of the hazards will lead to susceptibility to the consequences, causing negative vulnerability. The negative vulnerability will lead to secondary vulnerability or indirect consequences, which serve to further exacerbate or worsen the conditions, making it very difficult for the community to adjust and respond to the hazard effects. It then becomes a cycle, if no intervention is found, and the community asset base remains weak, with limited defence, leaving the community exposed to any other hazard that may come their way. If this continues and the asset base is not

reinforced, the community remains vulnerable and exposed, and it will experience the same effects repeatedly. If after realisation of vulnerability holistic interventions are done in the community, the components of the asset base will improve thereby strengthening the resources and institutions available to support the community in the event of exposure to a hazard. This will move the community from the path of vulnerability to resilience.

It must be emphasised that resilience is not a destination as resilience requires continuous strengthening and reinforcement to always function at optimal. Thus, monitoring and evaluation of the systems in the community need to be done even when there is no threat to ensure system readiness.

#### 4.6.1 Flood hazard management

Flood hazard measurement is a prerequisite to managing flood risk. The estimation requires careful consideration of several factors that contribute to the flood hazards. In this research, the flood hazard measurement criterion is guided and adapted for use by the Flood Level Classification as proposed by the Australian Government National Weather Services and is tabulated below.

**Table 4. 8: Flood classification levels**

Flood Depth/ m	Intensity	Impact interpretation
≤ 0.2	Low	Causes inconvenience, low lying areas next to water courses inundated. Minor roads may be closed.
0.3- 0.5	Medium	Some inundation of structures and roads near streams necessitating some evacuation of people and property to higher elevations.
≥1.0	High	Extensive inundation of structures and roads requiring significant evacuation of people and property to higher elevations.

#### 4.6.2 Determining resilience

To be able to determine resilience, key indicators of the components of the asset base need to be reviewed and weighted by ascribing a numerical value as depicted below:

**Table 4. 9 Asset base weights - TOOL A**

Components	Definition	SD	D	N	A	SA
		1	2	3	4	5
Physical	<b>Are the following available and functioning?</b>					
	Roads and transport.					
	Service institutions (water infrastructure, electricity)					
	Housing – appropriate for climate					
	Flood/ hazard infrastructure					
	Reference:(Petit & Kingsley, 2006)					
Economic	Access to private capital by community					
	Government funding availability					
	Various industry availability (public and private)					
	Availability of safety net programmes					
	Reference:(Fey et al., 2006)					
Social	Support organisations and institutions					
	Culture					
	Education (schools etc)					

	Health care centres					
	Reference: (Walker, 2010)					
Natural	Natural resource stocks (minerals, land quality of air and land etc)					
	Does the community have rights and access to these?					
	Ecosystem services useful for livelihoods and resource flows					
	How prepared are they for the prominent climate hazard.?					
	Reference: (Qin et al., 2020)					
Human capital above 50% of total population	Level of education					
	Employment					
	Technical skills					
	Youthful population					
	Reference (Son, 2010)					
TOTAL						

KEY

SD: Strongly disagree

D: Disagree

N: Neither agree nor disagree

A: Agree

SA: Strongly agree

Once the rating scale has been completed by the user, the total weights are calculated, and the result will allow for estimation and categorization of vulnerability using the scale below:

**Table 4. 10 Vulnerability and resilience scale - TOOL B**

Weight	Definition
81-100	Very positive vulnerability (systems and institutions are in place and are working effectively, and opportunity to innovate is possible)
61-80	Positive vulnerability (some systems are in place and working, new opportunities exist)
41-60	Adaptation (the community can recover from hazard effects slowly to its former state before the exposure to the hazard)
21-40	Vulnerable (community struggles to bounce back to its former state before exposure)
0-20	Negative vulnerability (consequences are dire and community is very susceptible, with chance of secondary impacts)

As depicted in the table, any score between 0 and 20, indicates that the community has very weak systems in place, rendering it vulnerable even before exposure to a hazard. A score between 21 and 30, denotes the availability of active adaptive capacity that can enable the system to adjust to a climatic disturbance. Scores of 31 to 40 and 41 to 50, are an indication of strong systems in place that will allow the community not only to recover but to become resilient to the climate hazard. The community can bounce back after exposure and be able to live with the hazard.

A resilient community is one that enables to continue functioning while there are effects of exposure to hazards are still being felt but however the community can adapt to changes in the environment and take advantage of the potential to transform and take advantage of opportunities presented. Simply put, a resilient community can continue functioning and be self-sufficient for some time especially if external assistance or intervention is limited or delayed.

Cartwright & McGuire (2008), state that a resilient community takes a positive response to change by moving from concentrating on the deficiencies of the system to focusing on the opportunities presented by the change.

**Table 4. 11 Resilience scale -TOOL C**

Weight	Resilience scale		Definition
81-100	Optimal	5	Community asset base is strong; systems are in place and programs implemented accordingly. Institutions are functioning optimally. Safety culture exists and resilience is embedded in planning, policy making, practice, attitude, and behaviour.  Also, consistent monitoring and evaluation of the flood management cycle even without any hazard threat. The community is prepared.
61-80	High	4	Community base is fairly strong, institutions exist, and capacity building, implementation and integration of solutions are evident in the whole flood risk management cycle. Proactive response is extensively implemented covering main aspects and coherent with long term strategy of sustainable living. Challenges exist but active system allows for correcting, addressing, and readdressing.
41-60	Medium	3	Community base is fair, institutions exist, albeit challenged with implementation, solutions are evident in parts of the risk management cycle, but likely limited by one challenge or the other. Response action is meant to return the system to its status quo so that community can continue existing.

			Outside assistance to recuperate is required in the event of exposure to a hazard.
21-40	Low	2	Community asset base is weak, institutions exist but capacity building remains limited although it can be improved. Interventions are enabled in the system but are not fully implemented. Actions can go beyond crisis response; they are discussed but implementation is limited.
0-20	Very low	1	The community asset base and institutions are weak. The flood risk management activities are known but weakly implemented both at institution and community level. Motivation is low to address challenges due to poor flood risk management. Actions implemented are mainly limited to crisis response.

In the end, to determine resilience, average flood levels and asset base strength must be known or at least simulated. The severity of the flood cannot be completely ascertained as weather conditions are unpredictable. However, human systems can adequately prepare for flood eventualities especially, where the floods recur frequently so that consequences may not be extensive as systems are already enabled and already anticipating the hazard eventuality.

**4.7 Model evaluation**

The model was internally evaluated by the academic supervisors using the themes listed below:

- a) Clarity of the conceptual model and its identified guiding enablers?  
 The conceptual model is clear and easy to understand. It provides a holistic method of understanding relationships between different societal components required for a community to be resilient.

i) How relevant are the different aspects of the developed model?

The developed model identifies pertinent enablers of resilience in a community and the key assets that support the community and are all relevant in the overall function and implementation of the model. Without identifying the different aspects, the model will not be implementable.

ii) Is it easy to understand?

Yes, the model is explained in a stepwise manner.

b) Is the model implementable/achievable?

Yes. Following the steps and tools provided, the weighted asset base, implementation of the model can be done with ease.

c) Can the model be applied to other environments/ situations?

Yes. Even though the conceptual model was created for least developed countries, different determining criteria for the asset bases can be used and substituted and used for middle income countries and for developed economies. The developed tools can be used not only for flood hazards, but for other climatic threats experienced around the world.

d) How significant is the suggested model to climate change resilience?

The developed model is important as it allows for baseline tracking of vulnerability even before the community is exposed to the hazard. The results can be used as a decision-making tool and if decisions are taken in time and implemented accordingly, the community can move from being vulnerable to being resilient.

### 4.7.1 Pilot Test

As part of the evaluation of the model proposed, the tools developed were pilot tested in the case area of this research to see if it could work and where it could be improved.

The score card of the results is depicted below:

Instructions: tick/check what applies.

**Table 4. 12 Use of tool A**

Components	Definition	SD	D	N	A	SA
		1	2	3	4	5
Physical	<b>Are the following available and functioning?</b>					
	Roads and transport.		x			
	Service institutions (water infrastructure, electricity)			x		
	Housing – appropriate for climate			x		
	Flood/ hazard infrastructure	x				
	Reference:(Petit & Kingsley, 2006)					
Economic	Access to private capital by community		x			
	Government funding availability		x			
	Various industry availability (public and private)			x		
	Availability of safety net programmes		x			
	Reference:(Fey et al., 2006)					
Social	Support organisations and institutions				x	
	Culture			x		
			x			

	Education (schools etc)					
	Health care centres			x		
	Reference: (Walker, 2010)					
Natural	Natural Resource stocks (minerals, land quality of air and land etc)				x	
	Does the community have rights and access to these?		x			
	Ecosystem services useful for livelihoods and resource flows		x			
	How prepared are they for the prominent climate hazard.?	x				
	Reference: (Qin et al., 2020)					
Human capital above 50% of total population	Level of education		x			
	Employment		x			
	Technical skills		x			
	Youthful population			x		
	Reference (Son, 2010)					
TOTAL	48					

**DATE:** 23 January 2023

**COMMUNITY NAME:** Ehenye (Oshakati)

**COUNTRY:** Namibia

**CLIMATE THREAT:** Floods

**FLOOD DEPTH:** 0.3

**INTERPRETATION:** MEDUIM

**FLOOD VELOCITY** (If known) 20m<sup>3</sup>/s

**DATA COLLECTED:** (Tick Appropriate) Before:  During:  After:

**ASSET RATING SCALE:** 48

**VULNERABILTY SCORE:** 41-60 Explanation: (Adaptation)

**RESILEINCE SCORE:** 3 - Explanation: Medium

**COMMENTS:** The community is deemed to be adaptive to the climatic hazard, yearly floods occur, systems in place allow for limited recovery to pre-exposure state. There is a chance to move from adaptation to resilience if weaknesses identified are addressed. Physical assets as assessed require urgent attention to reduce the flooding challenge, they should be given priority in developmental planning of the community.

If that is done, opportunities for resilience exist and these many benefit the community immensely. If, however, minimal interventions are made to reduce vulnerability, the community can move from the current stage to that of being vulnerable. Thus, system inadequacies need to be addressed with urgency as level of floods are unpredictable.

#### 4.7.2 Strengths and weaknesses of the developed tools

Data collection is not without its challenges and the tools developed may have had advantages and disadvantages when using them. In the conceptual model proposed

above, the asset base rating tool is the key tool of determining vulnerability, however, the following disadvantages were acknowledged.

- i) It is subjective – the rating may be subject to individual bias.
- ii) The asset base is in summative form. More data is required to make an informed decision e.g., on information on related to climate, there may need for the data collector to have prior information on trends.

#### Advantages

- i) The tool is holistic – major community components that determine vulnerability and resilience are considered in the asset base rating.
- ii) The rated asset base allows for degrees of opinions that can be further investigated for clarity.

To allay fears with the disadvantages highlighted above, it was recommended that the person using the tool should be one, who is knowledgeable or familiar with the climate hazard investigated. Secondly, individual data on the components of the asset base need to be sought beforehand, in preparation to the data collection using this tool. For example., trend data on climate for instance., can be sought from the responsible authorities before the tool is used, so that an accurate rating is given.

## 4.8 Conceptual Model Validation

The overall purpose of the study was to develop and validate a conceptual framework for resilience to climate change that can be used in basin communities. A multi phased approach was utilised to validate the framework using (i) internal evaluation through presentation to academics' supervisors and colleagues (ii) presentation to research and policy experts, who included academia, government, and those experts working in non-governmental organisations specifically linked to issues of climate change. The presentation allowed for the review of the components of the draft model to obtain inputs to improve it while also assessing usability and adoptability at municipal level. The validation process presented an opportunity to ascertain the accuracy of the information underpinning the framework and identified key points for framework refinement from diverse expert opinion.

- The model was verified using the strategies recommended by Richey, Klein, & Nelson, (2004). The strategies are as follows:
  - ✓ Does the framework highlight/include the key components?
  - ✓ To what extent does the framework address the relevant environmental factors.
  - ✓ To what extent is the framework usable to a wide range of settings?
  - ✓ Is the framework cost effective?

The experts listed below took part in the validation and the letters of validation are attached in the appendages.

1. Academia – Namibia University of Science and Technology
2. Higher education association - Southern African Regional Universities Association
3. Non-governmental organisation - Environmental Buddies
4. Private environmental planners – WSP Australia

## **CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 Summary and conclusions**

Flood events are both naturally occurring and man-made and therefore, best practices need to be considered and adopted to ensure that the flooding is avoided, where possible, mitigatory measures instituted and limits observed were necessary. The main aim of this study was to investigate reasons why floods were reoccurring Ehenye community in the Cuvelai-Etosha basin in Namibia. The intention was to find an upstream solution to flooding to through a conceptual model of resilience to a change in climate that could then be used when considering any land use development.

To be able to investigate flooding, 40-year historical precipitation data was analysed to determine if there was an increasing or decreasing trend. Initially, the research intended to analyse 50-year rainfall data however data available had missing information and no extrapolation could be done as the 10-year gap was too large. Data wrangling techniques were then employed, and the data set was split into 2 to allow for effective manipulation. The objective was achieved, and results of the precipitation trend observed over the 40-year period did not provide a definitive indication of whether the rainfall pattern is following a specific trajectory. However, the trend graph did reveal that the precipitation levels from 1977 to 1992 were consistently below the average of 410mm, save for seasons 1979 and 1986. The trend changed between the year 2008 and 2012, as the average precipitation per year moved beyond the average and this tallies with the flooding reported in the case study. The trend depicted, prompted further investigation to understand why there was flooding, especially in the years 2008-2018 despite rainfall amounts received by Ehenye on the average, being generally low. The researcher then had to unpack and scrutinize daily rainfall data to check for intensity. The results revealed that the rainy season had not changed over the period. The rainfall season officially starts in November with a few rain days and intensifies between the months of January through to March and ends in April with the month of January having the highest recorded rainfall. This suggests that

these 3 months should be the primary focus of resilience efforts. Despite this, the reason behind the recurrent flooding in the Ehenye community remained unresolved as the mean monthly and yearly amounts were generally low. In summary, the results indicated that the rainfall, except for the year 2011, was not significant enough to explain the frequent flooding in the area. To delve deeper into the flooding issue and identify any problematic areas, a ground truthing exercise was carried out under objective 2 of the study.

The second objective was to identify risk areas, categorise them so that flooding hotspots could be mapped out. This objective was also achieved through a combination of ground truthing exercises that involved a general evaluation of the environmental landscape and physical analysis to check if there was anything on the actual ground that predisposed or contributed to the cause of floods in the area. Several risk factors were uncovered, which included the absence of municipal storm drainages, flood drainages and buffers as well as the absence of tributary storm drains from the embankment to harness and channel the water away from the residential plots. The roads in the community were without flood dewatering drainages and most roads were uneven. The residential houses were also situated lower than the roads themselves and this created an environment conducive to flooding.

Furthermore, various Namibia - Oshakati water feature shapefiles were obtained, and these were used to create 2 maps that depicted firstly the different physical features and then the different land use in the area. The water feature map revealed that there were depressions/oshana's in Ehenye that were likely overlooked during allocation of land for residential development. Secondly, proximity of the Okatana river to Ehenye meant that during intense rain, the river could potentially flood as it was silting. The river was mapped, and the Ontario flood guidelines were adapted and used to create 100 m and 200 m flood buffer zones, and these were used to determine the flood way and flood fringe respectively. For the 100 m, any land use within this distance was deemed to be in the flood way, meaning the risk of flooding was at its highest and development is not advisable. Any development within the 200 m (flood fringe) could be permitted provided

risk reduction measures are instituted. In Ehenye community, parts of Extensions 4, 5 and 6 encroached onto the flood plain and were categorized as high risk to flooding whilst Extensions 1,2,3, 7 and 8 were categorized as medium risk only because of the absence of storm drainages. Lastly desk research on flood waters emanating from southern Angola was done to understand the efundja phenomenon. The research revealed that flood waters from Angola drain into Namibia yearly and fill up the depressions whilst bringing with it, various fish species and soil and water nutrients. However, in cases of extreme weather events, the flood water drains in large amounts thus causing extensive flooding in Oshakati. In summary, due to the results of objectives 2 and 3, the whole of the Ehenye community was considered at risk of flooding, even with the normal to heavy rainfall that would ideally not cause floods.

### Objective 3

Objective 3 of the study was to assess the vulnerability risk factors. The purpose of this objective was to identify what makes the community vulnerable to floods and what adaptive capacity was available to ensure that the system had the ability to reduce risk and cope with consequences resulting from exposure (communities, institutions, and public). Qualitative secondary data was collected from the census demographic survey of Oshakati, the Oshakati Town Master Plan 2008 and the Oshakati Strategic Plan 2015-2020 and various Acts of Parliament. The legal environment and critical support factors were investigated. The assessment unveiled that the development of Ehenye was commissioned in 2006 and a total of 500 houses were constructed to provide affordable low-cost housing for the purpose of alleviating the housing challenge that was affecting Oshakati. The residential development was commissioned, completed, and occupied on land that was not fully serviced as critical storm water drainages had not been constructed at the time of occupancy, and years beyond that. Scrutiny of legally binding Acts of Parliament and Town Plans revealed that the local authority as stated in the Local Authority Act of 1992 as amended had the sole mandate to construct, maintain and carry on a system of sewerage and drainage including sewerage works, public sewers and

storm water drains whether within or outside its area. Furthermore, the local authority had the mandate also to construct and maintain roads and its associated drainages. All this was not done accordingly due to budgetary constraints as outlined in the Oshakati town planning report. Part of the plan also included deepening of the Okatana river to mitigate against floods unfortunately, this was affected by limited funding and could not be implemented at once. With respect to resourcing of projects, the Government of Namibia is the major funder of flood prevention, climate mitigation, and disaster management projects and if the money is not released for whatever reason, the infrastructural projects cannot continue.

The final objective was to develop and validate a conceptual model for resilience to climate change in the Cuvelai-Etoshia Basin. This objective was achieved through analyzing results of objectives 1-3 and drawing conclusions on what would be the pertinent components of a framework for resilience within the context of the Cuvelai-Etoshia Basin. The results indicated that, for resilience to occur, a comprehensive approach must take place within the context of the community. Climate change cannot be tackled on a piecemeal approach as, too often, adaptation and resilience are a result of a well-supported and functioning society. The components highlighted in the developed model include sound leadership and governance that would ensure that climate resilience is supported through legal and regulatory systems as well as robust information systems that will ensure that research and development capacities are maintained to keep information updated. Other key components include availability of administrative technologies such as offices specifically made for climate change and financial resources to support any climate programme and lastly, good service delivery needs to be part of the normal function of the community. As part of the model output, tables that can be used to determine if a community is likely at risk were developed, pilot tested and validated by various industry and academic experts. Resilience to climate change cannot exist without sound service, delivery for example., a good network of roads, communication systems such as mobile networks and disaster and emergency

preparedness plans. Service delivery should be proactive and should not happen only when disaster has occurred. Resilience is not a onetime event, but a series of adjustments to a changing climate that leverages also on the opportunities brought out by climate change.

This study revealed that the flooding events in Ehenye community are not necessarily caused by a change in climate, but more of a town planning and land use failure. There were many processes that were ignored and as a result affected the housing development in the area. Rainfall patterns has not changed significantly, although there are years where there are higher amounts. These, however, should not cause significant alarm. Floods will continue to exist, and as far as possible, human interference into the processes of nature should be avoided or reversed, and in the future, even prevented.

## **5.2 Recommendations**

The following recommendations were suggested:

- Flood strategies should not be implemented piecemeal, they should cover the entire basin area to minimise impacts.
- Flooding impacts and trends should be continually studied to ensure that information is readily available for planning purposes and to stay abreast with shifting trends.
- Flood action should consider not only defensive action against hazard but also management of the risk and living with the hazard.
- Human land use development should be adapted to existing hazards and humans should avoid using land that is at risk of flooding without necessary structural

considerations. If development is to occur, appropriate measures should be considered to reduce all flooding related problems such as rising ground water tables and sewerage network disruption.

- The meteorological department should increase efforts in flood forecasting as a prerequisite for successful mitigation of flood damage. The information should be reliable, timely and tailored to meet end user needs and if possible, communicated in local dialects to ensure understanding and comprehension of the message.
- Structural flood defence measures should be the primary focus in protecting the health and safety of communities and they should work in tandem with non-structural measures such as flood hazard policies to reduce human vulnerability.
- The precipitation data can be used in flood forecasting.
- There should be no commencement of any buildings without the necessary flood defence measures.
- The construction of structural defence measures such as the embankment in Ehenye should not lead to the communities to having a false sense of security as flood protection is not absolute. The concept of residual risk including potential failure or breach should be taken into consideration, and the communities need to be always alert.
- Precipitation data should be consistently recorded to avoid cases of missing data.

Several positives were also identified during the research process. Oshakati town is strategically placed as a border town and has sizeable population and traffic between the

two countries. Opportunities exist to turn the town to an attractive tourist destination using the strength of the geographic location and climate.

Key drivers of this would be:

- a) Rivers located in this area.
- b) Ruacanna Falls
- c) Proximity to the Etosha Park and Pan
- d) Biodiversity, fisheries, and wildlife found in this area which connect to the Etosha Park
- e) Agriculture due to available water that can be harnessed for future use.

### **5.3 Limitations**

1. The results of this study and their implications are for only one community in Oshakati. Future research could address this limitation by conducting similar related studies within the Oshana region and in the extended Cuvelai- Etosha Basin as the flooding also occurs in these areas.
2. Research left out human participants from the community and from the town authority, therefore, other research could extend to include the affected people in the community.
3. The tools developed do not measure actual and revealed flood resilience in the event of a flood, the tools only measure vulnerability and likely resilience.

### **5.4 Future research**

Research on climate change and its impacts should be ongoing and iterative to keep updated information as the uncertainties brought about by this phenomenon continuously change.

Key areas to keep researching on include:

- i. Weather patterns (weather variables and the shifting trends) and flood forecasting.
- ii. Impacts of these weather variables on different sectors on society.

## **5.5 Conclusion**

Climate change provides an opportunity to rethink development and to reconfigure strategies to use resources. Any strategy of resilience should recognise the relationship between the environment, development and climate change and manage ongoing trade-offs between them. To build resilience, the risk should be managed by structural and non-structural means, and these should not be static but should evolve to accommodate the change in climate as it is predicted to be happening faster than expected.

## REFERENCES

- Adeyemi, T. O. (2009). Inferential Statistics for Social and Behavioural Research. *Journal of Mathematics and Statistics*, 1(2), 47–54.
- Adger, W. N., Brooks, N., Bentham, G., & Agnew, M. (2004). New Indicators of Vulnerability and Adaptive Capacity. Technical Report. In *Tyndal Center Climate Change, Research University of East Anglia, Norwich*. (Issue January).
- Aerts, J. C. J. H. (2018). A Review of Cost Estimates for Flood Adaptation. In *Institute for Environmental Studies, Amsterdam* (Vol. 10, Issue 11). MDPI AG. <https://doi.org/10.3390/w10111646>
- AFDB. (2012). *Namibia - African Economic Outlook*. <https://doi.org/10.1787/888932602540>
- Africa Climate Policy Centre. (2013). *Africa's Climate Observing Networks: Challenges, Needs and Recommendations*. <http://www.climdev-africa.org>
- African Climate Policy Centre. (2013). Vulnerability to Climate Change in Africa: Challenges and Recommendations for Africa. In *ClimDev-Africa*. <http://www.climdev-africa.org>
- Ahearne, R. (2010). *Understanding Contemporary Development: Tanzanian Life Narratives of Intervention* [Doctorate]. University of Manchester.
- Akbas, F. (2016). The Calm before the Storm. *Journal of Finance*, 71(1), 225–266. <https://doi.org/10.1111/jofi.12377>
- Aktaş, N. K., & Yıldız Donmez, N. (2019). *Effects of urbanisation and human activities on basin ecosystem: Sapanca Lake Basin*. <https://www.researchgate.net/publication/332440726>
- Alahacoon, N., Edirisinghe, M., Simwanda, M., Perera, E. N. C., Nyirenda, V. R., & Ranagalage, M. (2022). Rainfall Variability and Trends over the African Continent using Tamsat Data (1983–2020): Towards Climate Change Resilience And adaptation. *Remote Sensing*, 14(1). <https://doi.org/10.3390/rs14010096>

- Aldardasawi, A. F. M., & Eren, B. (2021). Floods and Their Impact on the Environment. *Academic Perspective Procedia*, 4(2), 42–49. <https://doi.org/10.33793/acperpro.04.02.24>
- Alemu, Z. A., & Dioha, M. O. (2020). Climate Change and Trend Analysis of Temperature: the case of Addis Ababa, Ethiopia. *Environmental Systems Research*, 9(1). <https://doi.org/10.1186/s40068-020-00190-5>
- Alexandre, M., Jussi, L., Redfern Suzanne, Azzu, N., & Gitz Vincent. (2012). Building Resilience for Adaptation to Climate Change in the Agriculture Sector. In *Proceedings of a Joint FAO/OECD Workshop 23–24 April 2012*. <https://doi.org/ISBN 978-92-5-107373-5>
- Allen, J. (2009). Flooding on the Cuvelai River, Namibia. In *NASA Earth Observatory*. <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=37702>
- Antonsen, K. M., Dale, B., & Mayer, S. (2022). “It’s in Our DNA”: Climate Change and Perceived Resilience and Adaptive Capacity in Nature-Based Tourism in Lofoten, Norway. *Weather, Climate, and Society*, 14(1), 177–190. <https://doi.org/10.1175/WCAS-D-21-0026.1>
- Aranda, J. Á., Beneyto, C., Sánchez-Juny, M., & Bladé, E. (2021). Efficient Design of Road Drainage Systems. *Water (Switzerland)*, 13(12). <https://doi.org/10.3390/w13121661>
- Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bülow Gregersen, I., Madsen, H., & Nguyen, V. T. V. (2013). Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems: A review. In *Water Science and Technology* (Vol. 68, Issue 1, pp. 16–28). <https://doi.org/10.2166/wst.2013.251>
- ARUP. (2015). *City Resilience Framework. 100 Resilient Cities* (1; 2). [www.arup.com/climate change/building-resilient-net-zero-cities](http://www.arup.com/climate-change/building-resilient-net-zero-cities)
- Auguste, G. (2018). How Do We Measure Rainfall? *Frontiers for Young Minds*, 6. <https://doi.org/10.3389/frym.2018.00038>
- Awojobi, O. (2017). The Impacts of Climate Change in Africa. *Journal of International Academic Research for Multidisciplinary*, 5(11), 4–8.

- Awumbila, M. (2017, September 3). *Drivers of Migration and Urbanization in Africa: Key Trends and Issues*. United Nations Expert Group Meeting on Sustainable Human Mobility and International Migration. [www.undp.or/desa/pd/sites/presentation\\_anumbila\\_final.pdf](http://www.undp.or/desa/pd/sites/presentation_anumbila_final.pdf)
- Baky, M. A. Al, Islam, M., & Paul, S. (2020). Flood Hazard, Vulnerability and Risk Assessment for Different Land Use Classes Using a Flow Model. *Earth Systems and Environment*, 4(1), 225–244. <https://doi.org/10.1007/s41748-019-00141-w>
- Balasubramanian, A. (2016). Floods as Natural Hazards. *ResearchGate*, 2–9. <https://doi.org/10.13140/RG.2.2.18898.96962>
- Barredo, J. I., de Roo, A., & Lavallo, C. (2007). Flood risk mapping at European scale. *Water Science and Technology*, 56(4), 11–17. <https://doi.org/10.2166/wst.2007.531>
- Becker, D., Othmer, F. J., & Greiving, S. (2022). Climate Impact Assessment for Sustainable Structural Change in the Rhenish Lignite Mining Region. *Land*, 11(7). <https://doi.org/10.3390/land11070957>
- Bernstein, L., Bosch, P., Canziani, O., Chen, Z., Christ, R., Davidson, O., Hare, W., Huq, S., Karoly, D., Kattsov, V., Kundzewicz, Z., Liu, J., Lohmann, U., Manning, M., Matsuno, T., Menne, B., Metz, B., Mirza, M., Nicholls, N., ... Barker, T. (2007). *IPCC Fourth Assessment Report: Climate Change*.
- Carvalho, P. (2014). *Rainfall: Measurements, Variability and Laboratory Simulations*. [Doctorate]. University of Coimbra.
- Chapungu, L., & Nhamo, G. (2021). *The increasing risk of floods and Tornadoes in Southern Africa* (1st ed., Vol. 1). Springer Cham. <https://doi.org/http://doi.org/10.1007/978-3-030-74192-1>
- Charles, A., Challa, R., & Tong, K. (2022). *Delivering Climate-Resilient Cities Using a Systems Approach*. *Future of Cities Report* 1/4. [www.3weforum.org/docs/WEF\\_C4IR\\_GFC\\_on\\_Cities\\_Climate\\_Resilience\\_2022\\_pdf](http://www.3weforum.org/docs/WEF_C4IR_GFC_on_Cities_Climate_Resilience_2022_pdf)

- Chattopadhyay, S., & Edwards, D. R. (2016). Long-term trend analysis of precipitation and air temperature for Kentucky, United States. *Climate*, 4(1). <https://doi.org/10.3390/cli4010010>
- Cinner, J. E., & Barnes, M. L. (2019). Social Dimensions of Resilience in Social-Ecological Systems. In *One Earth* (Vol. 1, Issue 1, pp. 51–56). Cell Press. <https://doi.org/10.1016/j.oneear.2019.08.003>
- Cobigo, V., Martin, L., & Mcheimech, R. (2016). Understanding Community. *Canadian Journal of Disability Studies*, 5(4), 181. <https://doi.org/10.15353/cjds.v5i4.318>
- De Graaf, G., Born, B., Uddin, K. A., & Marttin, F. (2001). *Floods, Fish and Fisherman pilot project, Bangaldesh* (M. Ahmed, Ed.; 1st ed.). University Press Limited.
- Debnath, J., Sahariah, D., Mazumdar, M., Lahon, D., Meraj, G., Hashimoto, S., Kumar, P., Singh, S. K., Kanga, S., Chand, K., & Saikia, A. (2023). Evaluating Flood Susceptibility in the Brahmaputra River Basin: An Insight into Asia's Eastern Himalayan Floodplains Using Machine Learning and Multi-Criteria Decision-Making. *Earth Systems and Environment*, 7(4), 733–760. <https://doi.org/10.1007/s41748-023-00358-w>
- Der Sarkissian, R., Al Sayah, M. J., Abdallah, C., Zaninetti, J. M., & Nedjai, R. (2022). Land Use Planning to Reduce Flood Risk: Opportunities, Challenges and Uncertainties in Developing Countries. *Sensors*, 22(18). <https://doi.org/10.3390/s22186957>
- Dinku, T. (2019). Challenges with availability and quality of climate data in Africa. In *Extreme Hydrology and Climate Variability: Monitoring, Modelling, Adaptation and Mitigation* (pp. 71–80). Elsevier. <https://doi.org/10.1016/B978-0-12-815998-9.00007-5>
- Doswell, C. (2003a). Floods as a Direct Result of Precipitation. *Elsevier*, 769–776.
- Doswell, C. (2003b). *Floods as a Direct Result of Precipitation*.
- Douglas, I., Garvin, S., Lawson, N., Richards, J., Tippett, J., & White, I. (2010). Urban pluvial flooding: A qualitative case study of cause, effect and nonstructural mitigation. *Journal of Flood Risk Management*, 3(2), 112–125. <https://doi.org/10.1111/j.1753-318X.2010.01061.x>

- du Plessis, L., & Viljoen, M. (1999). Determining the benefits of flood mitigation measures in the lower Orange River: A GIS application. *Water SA*, 25(2).
- Duncan, G. (1988). The Volatility of Family Income over the Life Course. In P. Baltes & D. Featherman (Eds.), *Life-Span Development and Behavior* (9th ed., Vol. 9, pp. 11–12). Lawrence Erlbaum Associates.
- Easterling, D., Rusticucci, M., Semenov, V., Alexander, L. V, Allen, S., Benito, G., Cavazos, T., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C., ... Midgley, P. (2012). *3 - Changes in Climate Extremes and their Impacts on the Natural Physical Environment*. Cambridge University Press.
- Ebi, K. L. (2016). Adaptation and resilience. *Public Health Reviews*, 37(1), 1–6. <https://doi.org/10.1186/s40985-016-0032-5>
- Eccles, R., Zhang, H., & Hamilton, D. (2019). A review of the effects of climate change on riverine flooding in subtropical and tropical regions. In *Journal of Water and Climate Change* (Vol. 10, Issue 4, pp. 687–707). IWA Publishing. <https://doi.org/10.2166/wcc.2019.175>
- Eckstein, D., Hutfils, M., & Wings, M. (2019). *Global Climate Risk Index 2019. Who Suffers Most from Extreme Weather Events?* (19-1–01e; 1). [www.germanwatch.org/en/cri](http://www.germanwatch.org/en/cri)
- Eine, S., & Tshilunga, X. (2014). *A Study of the 2011 Floods on Human Security in Namibia: A Case study of the Oshoopala Informal Settlement in Oshakati* [Masters]. University of Namibia.
- Elago, M. (2017). *Oshana Strategic Plan*. Oshana Regional Council.
- Elasha, O. (2006). *Background paper on Impacts, vulnerability and adaptation to climate change in Africa* (1; 10).
- El-ashry, M., & Zeidler, J. (2009). *Adaptation to Climate Change: Building Resilience and Reducing Vulnerability* (1; 2). [www.globalclimateaction.org](http://www.globalclimateaction.org)

- Fellmann, T. (2012). The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. *Building Resilience for Adaptation to Climate Change in the Agricultural Sector*, *i*, 37–62. <https://doi.org/10.1016/B978-0-12-398529-3.00003-8>
- Fey, S., Bregendahl, C., & Flora, C. (2006). The Measurement of Community Capitals through Research. *Online Journal of Rural Research & Policy*, *1*(1). <https://doi.org/10.4148/ojrrp.v1i1.29>
- Forbes, H., Ball, K., & McLay, F. (2015). *Natural Flood Management Handbook* (Vol. 1). [www.sepa.org.uk](http://www.sepa.org.uk)
- Foudi, S., Osés-Eraso, N., & Galarraga, I. (2017). The effect of flooding on mental health: Lessons learned for building resilience. *Water Resources Research*, *53*(7), 5831–5844. <https://doi.org/10.1002/2017WR020435>
- Fraser, J., Fahlman, D., Arscott, J., & Guillot, I. (2018). Pilot Testing for Feasibility in a Study of Student Retention and Attrition in Online Undergraduate Programs. In *International Review of Research in Open and Distributed Learning* (Vol. 19).
- Füssel. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, *17*(2), 155–167. <https://doi.org/10.1016/j.gloenvcha.2006.05.002>
- Füssel, H.-M. (2010). Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts. *World Development Report*, *34*. <https://doi.org/10.1016/j.gloenvcha.2010.07.009>
- GAO. (2019). *Disaster Resilience Framework* (D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, & B. C. Stewart, Eds.). <https://doi.org/10.7930/NCA4.2018>
- Garmestani, A., Craig, R. K., Gilissen, H. K., McDonald, J., Soininen, N., van Doorn-Hoekveld, W. J., & van Rijswick, H. F. M. W. (2019). The Role of Social-Ecological Resilience in Coastal

- Zone Management: A Comparative Law Approach to Three Coastal Nations. *Frontiers in Ecology and Evolution*, 7. <https://doi.org/10.3389/fevo.2019.00410>
- Global Climate Action. (2021). *Climate Resilience* (pp. 6–8). United Nations Climate Change.
- Gofa, F., Mamara, A., Anadranistakis, M., & Flocas, H. (2019). Developing gridded climate data sets of precipitation for Greece based on homogenized time series. *Climate*, 7(5). <https://doi.org/10.3390/cli7050068>
- Government of Namibia. (2009). *Post Disaster Needs Assessment (PDNA)*.
- Government of Namibia. (2010). *Post Disaster Needs Assessment- Floods 2009*.
- Government of Namibia. (2021). *Fourth Biennial Update Report (BUR4) to the United Nations Framework Convention on Climate Change*.
- Granberg, T. A. (2013). *Preparedness Measures for Emergency and Disaster Response* (pp. 59–75). [https://doi.org/10.1007/978-1-4614-7007-6\\_4](https://doi.org/10.1007/978-1-4614-7007-6_4)
- Grant, C., & Osanloo, A. (2014). Understanding, Selecting, and Integrating a Theoretical Framework in Dissertation Research: Creating the Blueprint for Your “House.” *Administrative Issues Journal Education Practice and Research*, 4(2). <https://doi.org/10.5929/2014.4.2.9>
- Grassl, H., & Menzel, L. (2007). Precipitation trends and shifts of rainfall regimes in Africa since 1951. *Water and Climate Change*, 3(1), 191–194. [www.klima-warnsignale.uni-hamburg.de](http://www.klima-warnsignale.uni-hamburg.de)
- Gravitiani, E., Fitriana, S. N., & Suryanto. (2018). Community livelihood vulnerability level in northern and southern coastal area of Java, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 202(1). <https://doi.org/10.1088/1755-1315/202/1/012050>
- Gray, S. (2008). Long-term health effects of flooding. In *Journal of Public Health* (Vol. 30, Issue 4, pp. 353–354). <https://doi.org/10.1093/pubmed/fdn092>
- Greve, A. I., & Boswell, M. R. (2014). Climate change adaptation. *Elgar Companion to Sustainable Cities: Strategies, Methods and Outlook*, 320–335. <https://doi.org/10.4337/9780857939999.00022>

- Guillaumont, P., & Simonet, C. (2011). To what extent are African Countries Vulnerable to Climate Change? Lessons from a New Indicator of Physical Vulnerability to Climate Change. In *Ferdi* (1; 3).
- Hango, L. (2017). Flood management in Namibia: Hydrological linkage between the Kunene River and the Cuvelai Drainage System: Cuvelai-Etосha Basin. *UNESCO-IHP Regional Workshop, Langkawi, Malaysia, July, 10–11*.
- Harrison, L., Funk, C., & Peterson, P. (2019). Identifying changing precipitation extremes in Sub-Saharan Africa with gauge and satellite products. *Environmental Research Letters*, 14(8). <https://doi.org/10.1088/1748-9326/ab2cae>
- Harsha, S. (2017). Role of Statistics in Monitoring Rainfall. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 11(03), 07–19. <https://doi.org/10.9790/2402-1103030719>
- Hegerl, G. C., Brönnimann, S., Cowan, T., Friedman, A. R., Hawkins, E., Iles, C., Müller, W., Schurer, A., & Undorf, S. (2019). Causes of climate change over the historical record. In *Environmental Research Letters* (Vol. 14, Issue 12). Institute of Physics Publishing. <https://doi.org/10.1088/1748-9326/ab4557>
- Hegga, Salma & Siyambango, N. (2015). Commemorating 20 Years of Tackling Climate Change in Namibia 1995-2015. *Republikein, Namibian Sun, Allgemeine Zeitung*.
- Heldsinger, N., Mackinnon, J., & Peddle, S. (2018). *A COMMUNITY GUIDE TO FLOOD RISK COMMUNICATION Promoting Personal Preparedness*. <https://uwaterloo.ca/partners-for-action/>
- Hickey, J. T., & Salas, J. D. (1995). *Environmental effects of extreme floods*. <https://www.researchgate.net/publication/255593265>
- Hickford, A. J., Blainey, S. P., Ortega Hortelano, A., & Pant, R. (2018). Resilience engineering: theory and practice in interdependent infrastructure systems. *Environment Systems and Decisions*, 38(3), 278–291. <https://doi.org/10.1007/s10669-018-9707-4>

- Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K. L., Engelbrecht, F., Guiot, J., Hijikata, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., & Zhou, G. (2018). Impacts of 1.5 degrees of Global Warming on Natural and Human Systems. *IPCC Report*, 175–311. <https://doi.org/10.1002/ejoc.201200111>
- Hoffmann, A. A., Chown, S. L., & Clusella-Trullas, S. (2013). Upper thermal limits in terrestrial ectotherms: How constrained are they? *Functional Ecology*, 27(4), 934–949. <https://doi.org/10.1111/j.1365-2435.2012.02036.x>
- Holling, C. S. (1973). *Resilience and Stability of Ecological Systems* (pp. 9–10). ILASA.
- Hooli, L. J. (2016). Resilience of the poorest: coping strategies and indigenous knowledge of living with the floods in Northern Namibia. *Regional Environmental Change*, 16(3), 695–707. <https://doi.org/10.1007/s10113-015-0782-5>
- Houston, D., Werritty, A., Bassett, D., Geddes, A., Hoolachan, A., & Mcmillan, M. (2011). *Pluvial (rain-related) flooding in urban areas: the invisible hazard*. [www.jrf.org.uk](http://www.jrf.org.uk)
- Huber, D., & Gullege, J. (2011). *Extreme Weather and Climate Change. Understanding the link and managing the risk*. Centre for Climate and Energy Solutions. [www.c2es.org/publications/extreme-weather-and-climate-change](http://www.c2es.org/publications/extreme-weather-and-climate-change)
- Huddleston, N. (2016). *Climate Change. Evidence, Impacts and Choices* (2nd ed.). National Research Council. <http://dels.nas.edu/basc>
- Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African climate change: 1900–2100. *Climate Research*, 17(2 SPECIAL 8), 145–168. <https://doi.org/10.3354/cr017145>
- IEMA. (2015). *Climate Change Resilience and Adaptation* (Issue November, p. 32). DEFRA. [https://www.iema.net/assets/templates/documents/iema\\_guidance\\_documents\\_eia\\_climate\\_change\\_resilience\\_and\\_adaptation\(1\).pdf](https://www.iema.net/assets/templates/documents/iema_guidance_documents_eia_climate_change_resilience_and_adaptation(1).pdf)
- lita, W. (2015). *Strategic Plan*. Oshakati Town Council.
- Institute of Risk Management. (2018). *A Risk Practitioners Guide to ISO 31000* (p. 20). IRM.

- IPCC. (2012). IPCC: Glossary of Terms. *Cambridge University Press*, 403–424. <https://doi.org/10.1002/9783527612024.oth1>
- IRI. (2007). *Flood Management in Mozambique*. [www.wmo.int](http://www.wmo.int)
- Jaffrés, J. B. D., & Gray, J. L. (2023). Chasing rainfall: estimating event precipitation along tracks of tropical cyclones via reanalysis data and in-situ gauges. *Environmental Modelling and Software*, 167. <https://doi.org/10.1016/j.envsoft.2023.105773>
- Jain, S. K., Mani, P., Jain, S. K., Prakash, P., Singh, V. P., Tullos, D., Kumar, S., Agarwal, S. P., & Dimri, A. P. (2018). A Brief review of flood forecasting techniques and their applications. *International Journal of River Basin Management*, 16(3), 329–344. <https://doi.org/10.1080/15715124.2017.1411920>
- Jianguo, W., & Tong, W. (2013). Ecological Resilience as a Foundation for Urban Design and Sustainability. In B. McGrath & K. Hill (Eds.), *Resilience in Urban Ecology and Design* (1st ed., Vol. 1).
- Jonkman, S. N., & Dawson, R. J. (2012). Issues and challenges in flood risk management- Editorial for the special issue on flood risk management. In *Water (Switzerland)* (Vol. 4, Issue 4, pp. 785–792). <https://doi.org/10.3390/w4040785>
- Kang, S. J., Lee, S. J., & Lee, K. H. (2009). A study on the implementation of non-structural measures to reduce urban flood damage -Focused on the survey results of the experts-. *Journal of Asian Architecture and Building Engineering*, 8(2), 385–392. <https://doi.org/10.3130/jaabe.8.385>
- Keenan, J. (2014). Material and Social Construction: A Framework for the adaptation of Buildings. *ARCC Journal*, 11(1).
- Kern, S. (2013). Inferential statistics, power estimates and design formalities continue to suppress biomedical innovation. *Forum for Nordic Dermato-Venerology*, 18(1), 12.

- Kim, D., & Lee, J. (2016). Development of a web-based tool for climate change risk assessment in the business sector. *Sustainability (Switzerland)*, 8(10). <https://doi.org/10.3390/su8101013>
- Kintziger, K., & Jagger, M. (2013). *Building Resilience Against Climate Effects ( BRACE ) Increasing Public Health Planning , Adaptation , Sea Level Rise Summit Impact of Climate on Environmental Risk Factors.*
- Koivisto, J. (2020). *NAVIGATING IN THE MIDST OF UNCERTAINTIES: CHALLENGES IN DISASTER RISK GOVERNANCE IN MOZAMBIQUE.*
- Kotir, J. H. (2011). Climate change and variability in Sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, 13(3), 587–605. <https://doi.org/10.1007/s10668-010-9278-0>
- Kristianssen, A. C., & Granberg, M. (2021). Transforming local climate adaptation organization: Barriers and progress in 13 swedish municipalities. *Climate*, 9(4). <https://doi.org/10.3390/cli9040052>
- Kropp, J., & Scholze, Michael. (2009). *Climate Change Information for Effective Adaptation* (p. 58). GTZ.
- Kuliwoye, E. K. (2010). Flood Hazard Assessment by means of Remote Sensing and Spatial analyses in the Cuvelai Basin. Case Study Ohangwena Region – Northern Namibia. In *Seminar Series Nr. 218* (Issue 218).
- Langsdorf, S., Löschke, S., Möller, V., Okem, A., Officer, S., Rama, B., Belling, D., Dieck, W., Götze, S., Kersher, T., Mangele, P., Maus, B., Mühle, A., Nabiyeva, K., Nicolai, M., Niebuhr, A., Petzold, J., Prentzler, E., Savolainen, J., ... Weyer, N. (2022). *Assessment Report of the Intergovernmental Panel on Climate Change* (2nd ed., Vol. 2). IPCC. [www.environmentalgraphiti.org](http://www.environmentalgraphiti.org)
- Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R., & Myeong, S. (2012). Climate change: new dimensions in disaster risk, exposure, vulnerability, and

- resilience. *Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, 25–64. <https://doi.org/10.1017/CBO9781139177245.004>
- Lazarus, S., Taliep, N., & Naidoo, A. V. (2017). *Community Asset Mapping as a Critical Participatory Research Method* (pp. 45–59). [https://doi.org/10.1007/978-3-319-63489-0\\_5](https://doi.org/10.1007/978-3-319-63489-0_5)
- Le Coz, C., & Van De Giesen, N. (2020). Comparison of rainfall products over sub-saharan africa. *Journal of Hydrometeorology*, 21(4), 553–596. <https://doi.org/10.1175/JHM-D-18-0256.1>
- Leveson, N., Dulac, N., Zipkin, D., Cutcher-Gershenfeld, J., Carroll, J., & Barrett, B. (2006). *Engineering Resilience into Safety-Critical Systems* \*.
- Little, R. J. A., & Rubin, D. B. (2019). Statistical analysis with missing data. *Statistical Analysis with Missing Data*. <https://doi.org/10.1002/9781119482260>
- Liu, J., Yu, Y., Zhang, L., & Nie, C. (2011). An overview of conceptual model for simulation and its validation. *Procedia Engineering*, 24, 152–158. <https://doi.org/10.1016/j.proeng.2011.11.2618>
- Liu, X., & Zhou, J. (2021). Assessment of the continuous extreme drought events in namibia during the last decade. *Water (Switzerland)*, 13(20). <https://doi.org/10.3390/w13202942>
- Lorant, I. and, & Dillion, M. M. (2002). *River and Stream Systems: Flooding Hazard Limit*. Ontario Ministry of Natural Resources.
- Madden, C. (2017). *Enhancing Resilience within Vulnerable Communities Affected by Flooding* (Issue July) [Masters]. Institute of Technology Carlow.
- Magnuszewski, P., Jarzabek, L., Keating, A., Mechler, R., French, A., Laurien, F., Arestegui, M., Etienne, E., Ilieva, L., Ferradas, P., Mcquistan, C., & Mayor, B. (2019). *Journal of Integrated Disaster Risk Management The Flood Resilience Systems Framework: from Concept to Application*. 1, 9. <https://doi.org/10.5595/idrim.2019.0348>
- Maguire, B., & Cartwright, S. (2008). *Assessing a community's capacity to manage change: A resilience approach to social assessment*. <http://www.ag.gov.au/cca>.

- Mamombe, V., Kim, W. M., & Choi, Y. S. (2017). Rainfall variability over Zimbabwe and its relation to large-scale atmosphere–ocean processes. *International Journal of Climatology*, 37(2), 963–971. <https://doi.org/10.1002/joc.4752>
- Marinucci, G. D., Luber, G., Uejio, C. K., Saha, S., & Hess, J. J. (2014). Building resilience against climate effects-a novel framework to facilitate climate readiness in public health agencies. *International Journal of Environmental Research and Public Health*, 11(6), 6433–6458. <https://doi.org/10.3390/ijerph110606433>
- Markkanen, S., & Anger-Kraavi, A. (2019). Social impacts of climate change mitigation policies and their implications for inequality. *Climate Policy*, 19(7), 827–844. <https://doi.org/10.1080/14693062.2019.1596873>
- Mbah, E. E., & Ayegba, M. (2013). Proper Dissemination of Information on Climate Change: A Comparative study of the roles of official and indigenous language in Nigeria. In *International Journal of Physical and Human Geography* (Vol. 1, Issue 2). [www.ea-journals.org](http://www.ea-journals.org)
- Mcbean, G. A., Kovacs, P., Voogt, J. A., Kopp, G. A., & Guilbault, S. (2021). *Building climate resilient communities: Living within the earth's carrying capacity* (70; 3).
- Mendelsohn, J., & Beat, W. (2011). The Cuvelai Basin, it's water and people in Angola and Namibia. In *Water and Peoples* (Vol. 8).
- Mendelson, J., & Beat, W. (2022). *Informal settlements in Namibia: their nature and growth*. Namibian Chamber of Environment.
- Mensah, H., & Ahadzie, D. K. (2020). Causes, impacts and coping strategies of floods in Ghana: a systematic review. In *SN Applied Sciences* (Vol. 2, Issue 5). Springer Nature. <https://doi.org/10.1007/s42452-020-2548-z>
- Mika, J. (2011). *Weather and Climate Extremes in Light of the IPCC SREX (2011) and beyond*. IPCC.

- Ministry of Environment & Tourism. (2015). *Third National Communication to the United Nations Framework Convention on Climate Change* (Issue November). National Planning Commission.
- Moench, Marcus., Tyler, Stephen., & Lage, Jessica. (2011). *Catalyzing urban climate resilience: applying resilience concepts to planning practice in the ACCCRN program (2009-2011)* (p. 292). Institute for Social and Environmental Transition, International.
- Mohanty, M. P., & Simonovic, S. P. (2022). A Comprehensive Approach for Floodplain Mapping through Identification of Hazard Using Publicly Available Data Sets over Canada. *Water (Switzerland)*, 14(14). <https://doi.org/10.3390/w14142280>
- Molua, E. L., Mendelsohn, R. O., & Akamin, A. (2020). Economic vulnerability to tropical storms on the southeastern coast of Africa. *Jàmhá Journal of Disaster Risk Studies*, 12(1). <https://doi.org/10.4102/jamba.v12i1.676>
- Morbidelli, R., Saltalippi, C., Dari, J., & Flammini, A. (2021). A review on rainfall data resolution and its role in the hydrological practice. In *Water (Switzerland)* (Vol. 13, Issue 8). MDPI AG. <https://doi.org/10.3390/w13081012>
- Moses, E. (2020). *Long and short-distance internal migration motivations in post-apartheid Namibia: a gravity model approach*. [www.ekon.sun.ac.za/wpapers/2020/wp112020](http://www.ekon.sun.ac.za/wpapers/2020/wp112020)<http://resep.sun.ac.za>[www.ekon.sun.ac.za/wpapers](http://www.ekon.sun.ac.za/wpapers)
- Moss, R. H., Brenkert, A. L., & Malone, E. L. (2001). *VULNERABILITY TO CLIMATE CHANGE A Quantitative Approach*. <http://www.ntis.gov/ordering.htm>
- Mu, L., Fang, L., Liu, Y., & Wang, C. (2020). Identifying barriers and enablers for climate change adaptation of farmers in semi-arid North-Western China. *Sustainability (Switzerland)*, 12(18). <https://doi.org/10.3390/su12187494>
- Muche, G., Kruger, S., Hillmann, T., Josenhans, K., Ribeiro, C., Bazibi, M., Seely, M., Nkonde, E., de Clercq, W., Strohbach, B., Kenabatho, P., Vogt, R., Kaspar, F., Helmschrot, J., & Jürgens, N. (2018). SASSCAL WeatherNet: present state, challenges, and achievements of

- the regional climatic observation network and database. *Biodiversity & Ecology*, 6, 34–43. <https://doi.org/10.7809/b-e.00302>
- Müller, A., Reiter, J., & Weiland, U. (2011a). Assessment of urban vulnerability towards floods using an indicator-based approach—a case study for Santiago de Chile. *Natural Hazards and Earth System Sciences*, 11(8), 2107–2123. <https://doi.org/10.5194/nhess-11-2107-2011>
- Müller, A., Reiter, J., & Weiland, U. (2011b). Assessment of urban vulnerability towards floods using an indicator-based approach—a case study for Santiago de Chile. *Natural Hazards and Earth System Sciences*, 11(8), 2107–2123. <https://doi.org/10.5194/nhess-11-2107-2011>
- Mwazi, O. (2010). *An Atlas of Namibia's Population*. Central Bureau of Statistics.
- Nakale, A. (2022, February 17). Oshakati scrambles to prevent flooding. *New Era*, 1.
- Nam, K. M., Martinez-Corra, R., & Gunawardena, J. (2022). The linear framework: Using graph theory to reveal the algebra and thermodynamics of biomolecular systems. In *Interface Focus* (Vol. 12, Issue 4). Royal Society Publishing. <https://doi.org/10.1098/rsfs.2022.0013>
- Namibia Statistics Agency. (2011). Namibia 2011 Population and Housing Census Main Report. In *Population Census Report*.
- Nampa, E. (2006, October 20). Oshakati and NHE housing agreement. *The Namibian* .
- National Academy of Science. (2011). *Climate Change Evidence & Causes*. <http://nas-sites.org/americasclimatechoices/>
- National Oceanic and Atmospheric Administration. (2005). *Why Should I Be Concerned About Flooding?* <http://www.redcross.org/http://www.fema.gov/>
- National Planning Commission. (2017). *Namibia's Development Journey* (Vol. 148).
- National Policy on Climate Change for Namibia, Pub. L. No. 1, 1 (2010). <https://doi.org/10.1007/s13398-014-0173-7.2>
- Nembwaya, H. (2014, July 9). Oshakati mass housing underway. *The Namibian*.

- Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2015). Climate Change 2014: Impacts, Adaptation and Vulnerability. In *Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. <https://doi.org/10.1017/CBO9781107415386.002>
- Niehoff, D., Fritsch, U., & Bronstert, A. (2002). Land-use impacts on storm-runoff generation: Scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. *Journal of Hydrology*, 267(1–2), 80–93. [https://doi.org/10.1016/S0022-1694\(02\)00142-7](https://doi.org/10.1016/S0022-1694(02)00142-7)
- Niipare, A. –Marie, Jordaan, A., & Siyambango, N. (2020). Flood Impacts in Oshana Region, Namibia: A Case Study of Cuvelai River Basin. *Journal of Geography and Geology*, 12(1), 8. <https://doi.org/10.5539/jgg.v12n1p8>
- Nuusita, A. (2018, August 20). Envisioned dyke shelved. *New Era*.
- OCCAR. (2019). Vulnerability Assessment in Climate Change Adaptation. OCCAR.
- Olanrewaju, O. (2019). Effect of Rainfall Variations on Economic Growth in Africa. *Journal of Economics and Sustainable Development*, 10(8). <https://doi.org/10.7176/JESD>
- Oluwagbemi, O. O., Hamutoko, J. T., Fotso-Nguemo, T. C., Lokonon, B. O. K., Emebo, O., & Kirsten, K. L. (2022). Towards Resolving Challenges Associated with Climate Change Modelling in Africa. *Applied Sciences (Switzerland)*, 12(14). <https://doi.org/10.3390/app12147107>
- Osti, R. P. (2018). *Integrating Flood and Environmental Risk Management Principles and Practices* (15; 3.0). [www.adb.org](http://www.adb.org)
- Parker, D., Tunstall, S., & Wilson, T. (2005). Socio-Economic Benefits of Flood Forecasting and Warning. *International Conference on Innovation Advances and Implementation of Flood Forecasting Technology*.

- Pearce, W., Brown, B., Nerlich, B., & Koteyko, N. (2015). Communicating climate change: Conduits, content, and consensus. *Wiley Interdisciplinary Reviews: Climate Change*, 6(6), 613–626. <https://doi.org/10.1002/wcc.366>
- Pereira, J., Revi, A., Rose, S., Sanchez-Rodriguez, R., Lisa Schipper Sweden, E. F., Schmidt, D. U., Schoeman, D., Shaw, R., Singh, C., Solecki, W., & Stringer, L. (2022). Salvador Lluch-Cota (Mexico), Sina Loeschke (Germany). *Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 7–10. <https://doi.org/10.1017/9781009325844.001>
- Persendt, F. C., & Gomez, C. (2016). Assessment of drainage network extractions in a low-relief area of the Cuvelai Basin (Namibia) from multiple sources: LiDAR, topographic maps, and digital aerial orthophotographs. *Geomorphology*, 260, 32–50. <https://doi.org/10.1016/j.geomorph.2015.06.047>
- Petit, R., & Kingsley, P. (2006). *The Role of Assets in Community-Based* (M. Oliver, Ed.; 1st ed.). Urban Institute.
- Phillipe, T. (2022). *The Importance of Riverine and Floodplain Fisheries for Livelihood Resilience in Africa* (pp. 8–9). Africa Natural Resources Management and Investment Center.
- Pilkington, C., & Prestorius, L. (2015). A Conceptual Model of the Research Methodology Domain. With a focus on Computing Fields of Study. *7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (ICK3K 2015)*, 96–107.
- Pottier, N., Penning-Rowsell, E., Tunstall, S., & Hubert, G. (2005). Land use and flood protection: Contrasting approaches and outcomes in France and in England and Wales. *Applied Geography*, 25(1), 1–27. <https://doi.org/10.1016/j.apgeog.2004.11.003>
- Poussin, C. (2016). *The Role of Land-Use Planning in Flood Management*. Global Water Partnership. [www.lamenagerie.net](http://www.lamenagerie.net)
- Prokić, M., Savić, S., & Pavić, D. (2019). Pluvial flooding in Urban Areas Across the European Continent. *Geographica Pannonica*, 23(4), 216–232. <https://doi.org/10.5937/gp23-23508>

- Qin, H., Bass, M., Ulrich-Schad, J. D., Matarrita-Cascante, D., Sanders, C., & Bekee, B. (2020). Community, natural resources, and sustainability: Overview of an interdisciplinary and international literature. In *Sustainability (Switzerland)* (Vol. 12, Issue 3). MDPI. <https://doi.org/10.3390/su12031061>
- Rahm, E., & Hong, H. (2012). *Data Cleaning: Problems and Current Approaches*. Leipzig Germany.
- Rahman, M. I. (2013). Climate Change: a Theoretical Review. *Interdisciplinary Description of Complex Systems*, 11(1), 1–13. <https://doi.org/10.7906/indecs.11.1.1>
- Reisinger, A., Howden, M., Vera, C., Garschagen, M., Hurlbert, M., Kreibiehl, S., Mach, K. J., Mintenbeck, K., O'Neill, B., Pathak, M., Pedace, R., Pörtner, H.-O., Poloczanska, E., Rojas Corradi, M., Sillmann, J., Van Aalst, M., Viner, D., Jones, R., Ruane, A. C., & Ranasinghe, R. (2020). *The concept of risk in the IPCC Sixth Assessment Report*.
- Renschler, C. S. (2013). *The PEOPLES Resilience Framework-An Integrated Quantitative Measure and Modeling of Sustainable Development and Disaster Risk Reduction*.
- Richey, R. C., Klein, J. D., & Nelson, W. (2004). Developmental research: Studies of instructional design and development. *Handbook of Research for Educational Communications and Technology, January 2004*, 1099–1130. [https://doi.org/10.1007/978-1-4614-3185-5\\_12](https://doi.org/10.1007/978-1-4614-3185-5_12)
- Rigolini, J., & Bank, W. (2021). *Social Protection and Labor: A key enabler for Climate Change adaptation and mitigation*. [www.worldbank.org](http://www.worldbank.org)
- Ristic, D. (2013). A Tool for Risk Assessment. *Safety Engineering*, 3(3). <https://doi.org/10.7562/SE2013.3.03.03>
- Ritvik, V. (2020). Data Wrangling- A Goliath of Data Industry. *International Journal of Engineering Research And*, V9(08). <https://doi.org/10.17577/IJERTV9IS080122>
- Robinson, S., Arbez, G., Birta, L. G., Tolk, A., & Wagner, G. (2016). Conceptual modeling: Definition, purpose and benefits. *Proceedings - Winter Simulation Conference, 2016-February*, 2812–2826. <https://doi.org/10.1109/WSC.2015.7408386>

- Rogers, P. (2020). *Real-Time Evaluation. Monitoring and Evaluation for Adaptive Management Working series*. <https://www.betterevaluation.org/monitori>
- Rözer, V., Müller, M., Bubeck, P., Kienzler, S., Thieken, A., Pech, I., Schröter, K., Buchholz, O., & Kreibich, H. (2016). Coping with pluvial floods by private households. *Water (Switzerland)*, 8(7). <https://doi.org/10.3390/W8070304>
- SASSCAL. (2020). *SASSCAL WeatherNet promoting science for sustainable development*. [www.sasscal.org](http://www.sasscal.org)
- Schneiderbauer, S. (2007). *Risk and Vulnerability to Natural Disasters-from Broad View to Focused Perspective* [Doctorate]. United Nations University.
- Schneiderbauer, S. & Ehrlich, D. (2013). *Risk and Vulnerability to Natural Disasters - from broad view to focused perspectives*.
- Schneiderbauer, S., Calliari, E., Eidsvig, U., & Hagenlocher, M. (2020). *Understanding Disaster Risk: Risk assessment methodologies and examples*.
- Selod, H., & Shilpi, F. (2021). *Rural-Urban Migration in Developing Countries Lessons from the Literature*. <http://www.worldbank.org/prwp>.
- Serdeczny, O., Adams, S., Coumou, D., Hare, W., & Perrette, M. (2016). *Climate Change impacts in Sub Saharan Africa: from physical changes to their social repercussions*. JANUARY. <https://doi.org/10.1007/s10113-015-0910-2>
- Seregina, L. S., Fink, A. H., van der Linden, R., Elagib, N. A., & Pinto, J. G. (2019). A new and flexible rainy season definition: Validation for the Greater Horn of Africa and application to rainfall trends. *International Journal of Climatology*, 39(2), 989–1012. <https://doi.org/10.1002/joc.5856>
- Shaamhula, L., & van Rooy, G. (2019). Here comes the water: Risk assessments, observation and knowledge of Ompundja village. *Jàmbá Journal of Disaster Risk Studies*, 11(1), 1–9. <https://doi.org/10.4102/jamba.v11i1.507>

- Shammin, M. R., Haque, A. K. E., & Faisal, I. M. (2022). A Framework for Climate Resilient Community-Based Adaptation. In *Climate Change and Community Resilience* (pp. 11–30). Springer Nature Singapore. [https://doi.org/10.1007/978-981-16-0680-9\\_2](https://doi.org/10.1007/978-981-16-0680-9_2)
- Shanker, R. (2004). Community Based Natural Resources Management- Experiences from Africa. In *CRD Gandhinagar*. [www.tve.org](http://www.tve.org)
- Sherbinin, A. De. (2014). *Spatial Climate Change Vulnerability Assessments : a Review of Data , Methods , and Issues*. August, 1–70. <https://doi.org/10.13140/2.1.1888.0002>
- Shukla, P. R., Skea, J., Reisinger, A., Slade, R., Fradera, R., Pathak, M., Al, A., Malek, K., Renée Van Diemen, B., Hasija, A., Lisboa, G., Luz, S., Malley, J., Mccollum, D., & Some, S. (2022). *Climate Change 2022 Mitigation of Climate Change Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Summary for Policymakers Edited by*. [www.ipcc.ch](http://www.ipcc.ch)
- Silva-Villanueva, P. (2019). What Is Human Resilience and Why Does It Matter? *Psychopathology in Women*, April, 27–53. [https://doi.org/10.1007/978-3-030-15179-9\\_2](https://doi.org/10.1007/978-3-030-15179-9_2)
- Smith, M., Ricker, M., Prutz, R., Anand, M., Lehner, B., Florke, M., Wimmer, F., Mann, H., Weller, D., Mucke, P., & Pfliegner, K. (2021). *Global Riverine Flood Assessment-Technical Report Global assessment of current and future river flooding and the role of nature-based solutions for risk management*.
- Smith, Schellnhuber, H. J., & Mirza, M. M. Q. (2001). Vulnerability to Climate Change and Reasons for Concern: A Synthesis. *Climate Change 2001: Impacts: Adaptation and Vulnerability*, 913–970.
- Soleimani-Alyar, M., Ghaffari-Hadigheh, A., & Sadeghi, F. (2016). Controlling Floods by Optimization Methods. *Water Resources Management*, 30(12), 4053–4062. <https://doi.org/10.1007/s11269-016-1272-3>
- Son, H. H. (2010). *Human Capital Development* (No. 225).

- Song, M. K., Lin, F. C., Ward, S. E., & Fine, J. P. (2013). Composite variables: When and how. *Nursing Research*, 62(1), 45–49. <https://doi.org/10.1097/NNR.0b013e3182741948>
- Spachinger, K., Dorner, W., Metzka, R., Serrhini, K., & Fuchs, S. (2008). Flood Risk and Flood hazard maps – Visualisation of hydrological risks. *IOP Conference Series: Earth and Environmental Science*, 4, 012043. <https://doi.org/10.1088/1755-1307/4/1/012043>
- Spaliviero, M., De Dapper, M., & Maló, S. (2014). Flood risk analysis of the Limpopo River basin Flood risk analysis of the Limpopo River basin through past evolution reconstruction and geomorphological approach Flood risk analysis of the Limpopo River basin. *Nat. Hazards Earth Syst. Sci. Discuss*, 2, 1367–1404. <https://doi.org/10.5194/nhessd-2-1367-2014>
- Steytler, J., & Kafidi, L. (2011). *Namibia 2011 population and housing census main report*.
- Sullivan, L. (2014). *Building Resilience in Changing River Basins: A Comparative analysis of management practices in the Colorado and Okavango river basins*. [Masters]. Boston University.
- Tariq, M. A. U. R., Farooq, R., & van de Giesen, N. (2020). A critical review of flood risk management and the selection of suitable measures. In *Applied Sciences (Switzerland)* (Vol. 10, Issue 23, pp. 1–18). MDPI AG. <https://doi.org/10.3390/app10238752>
- The World Bank Group. (2021). *NAMIBIA CLIMATE RISK COUNTRY PROFILE*. [www.worldbank.org](http://www.worldbank.org)
- Thies, B., & Bendix, J. (2011). Satellite based remote sensing of weather and climate: Recent achievements and future perspectives. In *Meteorological Applications* (Vol. 18, Issue 3, pp. 262–295). John Wiley and Sons Ltd. <https://doi.org/10.1002/met.288>
- Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: A review. *Global Change Biology*, 20(11), 3313–3328. <https://doi.org/10.1111/gcb.12581>
- Thulkanam, M. (2010). *Response to the 2009 floods emergency in Namibia Preventing diseases, saving lives*. World Health Organisation.

- Tilford, K. A., Sene, K. J., & Khatibi, R. (2007). Flood forecasting model selection: A structured approach. In *Advances in Natural and Technological Hazards Research* (Vol. 25, pp. 401–416). Springer Netherlands. [https://doi.org/10.1007/978-1-4020-4200-3\\_21](https://doi.org/10.1007/978-1-4020-4200-3_21)
- Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research*, 47(1–2), 123–138. <https://doi.org/10.3354/cr00953>
- Twigger-Ross, C. (2005). *The impact of flooding on urban and rural communities*. Environment Agency.
- UCLA. (2020). *Asset Mapping*.
- UN Environment. (2017). Climate change vulnerability assessments. *Water Adaption Technology Brief*.
- UNFCCC. (2012). NAP LEG Guidelines National Adaptation Plans. *LDC Expert Group, December*, 1–4.
- UNFCCC. (2019). *Ethiopia's Climate Resilient Green Economy National Adaptation Plan*.
- van Elst, H. (2013). *Foundations of Descriptive and Inferential Statistics*. <http://arxiv.org/abs/1302.2525>
- Van Zyl, S. , Carstens, E. , Saayman, C. , Husselman, E. , Muir, C. , & Simon, E. (2012). *Proposed Flood Mitigation Measures for the Oshakati/ Ongwendiva Area Scoping Report* (Issue May). [http://www.envirod.com/pdf/proposed\\_flood\\_mitigation\\_measurements/OFM\\_scoping\\_report\\_01\\_05\\_2012\\_to\\_public.pdf](http://www.envirod.com/pdf/proposed_flood_mitigation_measurements/OFM_scoping_report_01_05_2012_to_public.pdf)
- Vasseur, L., & Jones, M. (2015). *Adaptation and resilience in the face of climate change : protecting the conditions of emergence through good governance*. [https://sustainabledevelopment.un.org/content/documents/6579124-Vasseur-Adaptation and resilience in the face of climate change.pdf](https://sustainabledevelopment.un.org/content/documents/6579124-Vasseur-Adaptation_and_resilience_in_the_face_of_climate_change.pdf)
- Wahab, M. A. (2017). *Interpolation and Extrapolation*. <https://www.researchgate.net/publication/313359516>

- Walker, J. R. (2010). *Understanding Community Capacity and Assets*.  
<https://agrillifebookstore.org/>
- Wang, & Sebastian, A. (2021). Community flood vulnerability and risk assessment: An empirical predictive modeling approach. *Journal of Flood Risk Management*, 14(3).  
<https://doi.org/10.1111/jfr3.12739>
- Welborn, L. (2018). Africa and climate change Projecting vulnerability and adaptive capacity. *Institute for Security Studies*, November, 1–24.  
<https://issafrica.s3.amazonaws.com/site/uploads/ar14.pdf>
- Wilcox, I., Quinlan, C., Dool, D., & Heagy, E. (1998). *The Thames River watershed : a background study for nomination under the Canadian Heritage Rivers System*. Upper Thames River Conservation Authority for the Thames River Coordinating Committee.
- Wilhelm, M. (2012). *The Impact of Climate Change in Namibia- A Case Study of Omusati Region* [Masters]. Polytechnic of Namibia.
- WMO. (2011). Guide to Climatological Practices. In *Naturaweb.Net* (Issue 100).  
<https://doi.org/10.11369/jji1950.27.129>
- Wolff, E., Fun, I., Hoskins, B., Mitchell, J., Palmer, T., Santer, B., Shepherd, J., Shine, K., Solomon, S., Trenberth, K., Walsh, J., & Wuebbles, D. (2014). Climate Change Evidence & Causes. *National Acedemy of Sciences*, 36. <https://doi.org/10.17226/18730>
- Woods, E., Hollnagel, H., & David, D. (2016). *Resilience Engineering Concepts* (W. Karl, Ed.; 3rd ed.). Fischhoff.
- Yunianta, A., Suripin, & Setiadji, B. H. (2018). Sustainable road drainage system: Experimental model. *MATEC Web of Conferences*, 181. <https://doi.org/10.1051/matecconf/201818111005>
- Zambuko, C. (2011). *Zimbabwe Meteorological Services Department Climate Issues and Facts: Zimbabwe*. Meteorological Services Department.
- Zeidler, J., Kandjinga, L., & David, A. (2010). *Study on the effects of Climate Change in the Cuvelai Etosha Basin and possible adaptation measures*.

Zhang, A., Gao, R., XixiWang, Liu, T., & Fang, L. (2020). Historical Trends in Air Temperature , Precipitation ,. *Water*, 12(74).

## **Appendix 1- Permission letters**

As part of the requirements of the research, permission needs to be sought for research from the designated organisations. The researcher also had to undergo ethics training before an Ethics approval letter was granted. All permission and validation letters are listed below, and the evidence follows in the preceding pages.

1. Research Permit NCRST
2. Ethics Permission Letter- NWU
3. Validation Letters
  - a) NUST Namibia
  - b) SARUA
  - c) WSP Planners -Australia
  - d) SASSCAL- Namibia



## NATIONAL COMMISSION ON RESEARCH, SCIENCE AND TECHNOLOGY


RESEARCH, SCIENCE AND TECHNOLOGY ACT, 2004

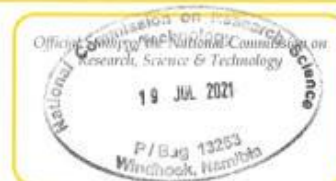
RESEARCH PERMIT  
OF  
NON-NAMIBIAN-BASED RESEARCH  
INSTITUTE/PERSON

(Section 21 and Regulation 22)

Permit Number  
RPIV01042031

Name of Non-Namibian-based Research Institute/Person: Buhlebenkosi Fiona Mpofu	Physical Address: 80 Kleine Palace Kleine Kuppe Windhoek.		
Issue Date: 19 July 2021	Commence Date: 19 July 2021		
Termination Date: 31 July 2022	Sample Collection Authorised:	YES	NO
Type of Research Authorised Developing a conceptual model of resilience of communities to climate change in the Cuvelai-Etoshia basin. Non-Commercial research and the use of the resources must be limited to what is specified in the research proposal.			
Type and Size of Sample Collection Authorised N/A			
Locations Authorised for Research and/or Sample Collection Oshakati, Ehenye community (Okatana)			
Intended Use of Samples N/A			
Responsible Person: Buhlebenkosi Fiona Mpofu	Contact No: +264 61 2072086		

  
 Signed on behalf of the National  
 Commission on Research, Science &  
 Technology



#### Research / Sample Collecting Permit Conditions

1. You must report to the Park Chief warden and / or Regional Office of the Ministry of Environment and Tourism prior to arrival in fieldwork area, and must present your permit.
2. This permit does NOT entitle the holder to free entry to the protected areas or state land outside protected areas.
3. For Field work in National Parks you have to make arrangement with park management in advance prior to arrival in fieldwork area.
4. Voucher specimens should be deposited with National Museum of Namibia.
5. If you would like to export samples of specimens you must loan them from the National Museum of Namibia.
6. To conduct research work in the rhinos and elephants range all persons listed on the permit must be in possession of a police clearance certificate.
7. The permission of the land owner is required to work/collect on private lands.
8. The permission of the concession holder is required to work/collect in concession areas.
9. The permission of the communal authority is required to work/collect in communal areas.
10. No commercial filming will be permitted without prior approval by the Ministry of Environment and Tourism under this permit.
11. Duplicates of publications and / or final report should be made available to the Ministry of Environment and Tourism and also the final report.
12. The specimens and their derivatives may be used for the purposes of this study only and may not be patented, commercialised, donated or sold to a third party without the written consent of the Ministry of Environment and Tourism.
13. All results (raw materials) or technology derived directly or indirectly from this research must be made available free of charge without reservations to the Ministry of Environment and Tourism.
14. A report on the work conducted under this permit must be submitted to the Ministry of Environment and Tourism not later than one month after the expiry of this permit as well as to regional office in whose area research was conducted.
15. Applications for renewal of this permit must reach this office at least three months prior to the expiry of this permit.
16. Habitat destructive collecting methods must not to be used.
17. Veterinary restriction may apply in the case of movement of samples and it is the applicants' responsibility to obtain such permits.
18. Foreign (or destination) wildlife import, and veterinary import permits may be required.
19. CITES import permit from the country of the destination is required for the application of export permit for CITES -listed species.
20. All field teams must be in possession of the permit and permit copy must accompany the transport of specimens.
21. You are subject to all conditions listed on the entry permit to any of the protected areas, unless specifically exempted.
22. Failure to adhere to the conditions will lead to cancellation of the research permit.
23. It is your responsibility to make the necessary contacts and arrangements as specified above.
24. Applicant to obtain permission from the Traditional Authority (Oshakati) area.



Private Bag X1290, Potchefstroom  
 South Africa 2520  
 Tel: 018 299-1111/2222  
 Fax: 018 299-4910  
 Web: <http://www.nwu.ac.za>  
**Senate Committee for Research Ethics**  
 Tel: 018 299-4849  
 Email: [nkosinathi.machine@nwu.ac.za](mailto:nkosinathi.machine@nwu.ac.za)

## ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Faculty of Natural and Agricultural Sciences Ethics Committee (FNASF REC)**, the Faculty of Natural and Agricultural Sciences Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-SCRE) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

<b>Study title: Developing a conceptual model of resilience of communities to climate change in the Cuvelai-Etosha Basin</b>				
<b>Study Leader/Supervisor: Prof SJ Piketh</b>				
<b>Student: BF Mpofo</b>				
<b>Ethics number:</b>	<b>N</b>	<b>W</b>	<b>U</b>	<b>- 0 0 4 7 1 - 2 1 - A 9</b>
	Institution	Study Number		Year Status
Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation				
<b>Application type: Single</b>	<b>Risk Category:</b>		<b>Minimal</b>	
<b>Commencement date: 01/04/2021</b>				
<b>Expiry date: 01/07/2022</b>				
<b>Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.</b>				

Special in process conditions of the research for approval (if applicable):

- The following documentation are archived by FNASREC and should be complete and kept up to date:
  - Research proposal
  - Signed approval from the scientific committee indicating the proposed risk category
- All researchers involved in the study should submit signed NWU code of conduct statements annually.
- All researchers of low risk studies should submit proof of relevant ethics training every two years.
- All researchers that take part in activities that pose a safety and security threat to the researchers or the environment should submit a risk assessment form annually.
- All research involving human interaction should follow best ethical practise and keep documents as proof. This includes informed consent, questionnaires, incorporation of risk-benefit, and responsible data management.
- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the FNASREC. Ethics approval is required BEFORE approval can be obtained from these authorities.



**NAMIBIA UNIVERSITY  
OF SCIENCE AND TECHNOLOGY**

**Faculty of Health, Natural  
Resources and Applied  
Sciences**

School of Health Sciences

Department of Preventative  
Health Sciences

13 Jackson Kaujeua Street  
Private Bag 13388  
Windhoek  
NAMIBIA

T: +264 61 207 2012  
F: +264 61 207 9012  
E: [dphs@nust.na](mailto:dphs@nust.na)  
W: [www.nust.na](http://www.nust.na)

13 Jackson Kaujeua Street,  
Windhoek West,  
Windhoek, Namibia

24 March 2023

#### **TO WHOM IT MAY CONCERN**

This letter serves to inform that I was involved in the validation exercise of the conceptual framework of the research project developed by Ms Buhlebenkosi Fiona Fuyane-Mpofu as part of her studies towards doctoral qualification. The title of her project is **'Developing a conceptual model of resilience of communities to climate change in the Cuvelai-Etoshia Basin'**.

The framework was evaluated based on fundamental validation principles of (i) reliability, (ii) appropriateness, (iii) simplicity, and (iv) useability. The framework and tools developed are relevant to the study, applicable with clear, unambiguous, and easy to follow stages. Importantly, the step-by-step application process allow for ease of revalidation during utilisation by researchers in similar and related studies.

From the above, the conceptual framework and the developed tools are recommended for use.

Sincerely,

Prof O Awofolu  
Associate Dean  
School of Health Sciences  
Tel: +264 (0) 61-207-2500  
Email: [oawofolu@nust.na](mailto:oawofolu@nust.na)



ServiceStream

27 March 2023

Dear Sir/ Madam

**REF: CONCEPT VALIDATION**

This letter is written as confirmation that I the undersigned, have evaluated Ms Buhlebenkosi Fiona Fuyane (Mpofu)'s thesis titled "**Developing a conceptual model of resilience of communities to climate change in the Cuvelai-Etsha Basin**". The purpose of the evaluation was to assess the applicability of the developed conceptual model and its instruments.

The developed model can distinguish the properties of differing attributes of the subjects that influence vulnerability and resilience. The developed instruments are framed clearly, and weights attached minimise errors. Overallly, the instruments can generate data that will be of value and practical use to sectors concerned.

I confidently validate the conceptual model and its instruments in respect of accuracy and completeness.

Sincerely,

**Jovial Matshazi**  
**SAED Town Planner**  
**Telecommunications Services**



ServiceStream

Level 1, 129 Pilbara Street  
Welshpool, WA 6106  
M: +61 487 949 301  
[jo.matshazi@servicestream.com.au](mailto:jo.matshazi@servicestream.com.au)  
[www.servicestream.com.au](http://www.servicestream.com.au)

ServiceStream Limited ABN 46 072 369 870

HEAD OFFICE Level 4, 357 Collins Street, Melbourne VIC 3000 | Mailing Address: PO Box 14570, Melbourne VIC 8001  
T +61 3 9677 8888 | F +61 3 9677 8877 | E [info@servicestream.com.au](mailto:info@servicestream.com.au) | [www.servicestream.com.au](http://www.servicestream.com.au)

Page | 1

Southern African Regional Universities A  
43 Andringa Street Eikestad Mall,  
3rd Floor Stellenbosch, 7600

24 March 2023

**REF: VALIDATION OF CONCEPT MODEL FOR A DOCTORAL THESIS: DEVELOPING A CONCEPTUAL  
MODEL OF RESILIENCE OF COMMUNITIES TO CLIMATE CHANGE IN THE CUVELAI-ETOSHA BASIN**

---

To whom it may concern

This communique serves as a report of a review and validation exercise of the conceptual model and the instruments developed as an output of the doctoral research work by Buhlebenkosi Fiona Fuyane-Mpofu.

The model was evaluated and found that it relates to variables under investigation; easy to follow and practically implement because of the numerical weighting given. The key elements on resilience were noted while the identified paucities are highlighted on the recommendations attached. The instrument developed can provide unbiased data for investigation and they can be applied in a wide range of hazards that communities may be exposed to. This therefore gives the framework applicability and an opportunity to be adapted to different communities. Therefore, I can confirm that the framework/model can be used in a wide range of settings and is cost effective.

For any further clarity please do not hesitate to contact me at [nomazile.chicho@baisago.ac.bw](mailto:nomazile.chicho@baisago.ac.bw) or [nomazilechicho@yahoo.com](mailto:nomazilechicho@yahoo.com) and at +267 71667065.

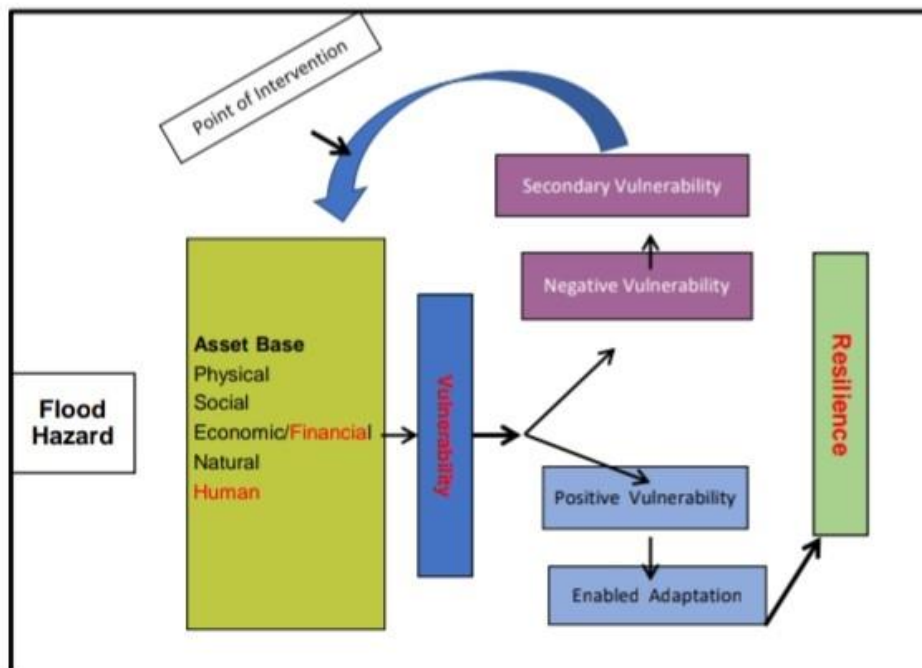
Yours sincerely,



Dr Nomazile Chicho (Ph.D)  
Curriculum Coordinator  
Southern African Regional Universities Association (SARUA)

### Recommendations for consideration for inclusion on the Conceptual Framework

- Upon review, it was noted that human capital had not been included as part of the asset base; however, it is imperative that when addressing vulnerability, resilience and capacity to cope with exposures, people are included as they are at the core of these assessments (see figure attached). As such, it is recommended that they be included on the pictorial presentation and discussion of assets.
- Further, for easy understanding and elaboration, the figure may be reconsidered by including a box 'VULNERABILITY' after the box indicating asset base where the arrows showing either positive or negative vulnerability will emanate or exit from as shown in colour on the figure attached.



11 April 2023

TO WHOM IT MAY CONCERN

This letter serves to inform that I the undersigned participated in the validation of the conceptual model developed by MsBuhlebenkosi Fiona Fuyane-Mpofu as part of her studies towards a doctoral qualification titled ' **Developing a conceptual model of resilience of communities to climate change in the Cuvelai-Etосha Basin**'.

The model developed builds a foundation in understanding the major causes of vulnerability and key determinants of resilience in communities affected by climate change. The developed tools allow for practical implementation, and they are easy to follow and understand. The results obtained from the use of the tools allow for critical data generation that can be then used to improve preparedness and ensure societal readiness to the effects of climate.

The conceptual framework and the tools developed are recommended for use.

Sincerely,

**Shamiso Winnet Mupara**



**(FOUNDER and Executive Director) 0777 559 426**

[treeplanterzim@gmail.com](mailto:treeplanterzim@gmail.com)

[shamiso@ebtrust.org](mailto:shamiso@ebtrust.org)

## Appendix 4 – Flooding Variables

Physical Analysis		
Variable	Relevance	Reference
Construction Material of Houses	<p>Determines the physical fragility towards flood events and indicates resistance to damage.</p> <p>Some of the construction material allow humidity to remain in the walls or floor after flood events which lead to health problems.</p>	Clark et al (1998); Cutter et al (2003); Taubenbock (2007) and Schneiderbauer (2007)
Position of buildings in relation to street level	<p>Determines the likelihood of constructions to suffer damage in case of flood event.</p> <p>People that live below or at street level show a much bigger exposure to the floods.</p>	Schneiderbauer (2007)
<p>Availability of flood protection infrastructure?</p> <p>3. Municipality constructed.</p> <p>4. Community constructed.</p> <p>Green spaces</p> <p>Number and proportion</p>	<p>Flood protection infrastructure reduce chances of flooding.</p> <p>The higher number of green spaces the lower the flood hazard</p>	<p>Schneiderbauer (2007)</p> <p>Niehoff et al (2002)</p>
<p>Are there any depressions? If so, how big? How many?</p> <ul style="list-style-type: none"> <li>• Distance between the depressions/inundations</li> <li>• Distance from the depression to the nearest settlements/houses.</li> </ul>	<p>The higher number of depressions the higher the possibility of flooding</p> <p>Size determines water retention.</p>	Niehoff et al (2002)

<ul style="list-style-type: none"> <li>Distance of the depression from the local Okatana river.</li> </ul> Other?	Distance between the depressions and river determine flooding possibilities.	
Type of soil	Soil type determines soil water retention? drainage	
Distance of house from nearest water body	Determines risk of flooding in case of heavy rain.	Niehoff et al (2002)

### Social Vulnerability

Gender	<p>The young and the elderly are both vulnerable to natural hazards because of physical condition and financial independence. Vulnerability of the elderly is minimised by the experience.</p> <p>Women are generally described as more vulnerable to natural hazards than men because of their stronger involvement in family life, sector specific jobs and lower wages.</p>	<p>Schneiderbauer (2007)</p> <p>Clark et al (1998);</p>
Level of education	Better knowledge about knowledge of extreme events and their origins and about methods to reduce and mitigate the hazards.	<p>Wisner et al (2004)</p> <p>Haki et al (2004)</p>
Average size of household	The higher the household size the lower social status	

	and the higher amount of people affected.	
Main form or livelihood/ employment status	Indicates the regularity of income and the possibilities of a household to save money for flood mitigation measures or to cope with negative effects.	Dwyer et al., 2004)
Experience with floods  Knowledge of hazards	Increases community sensitivity to the problem, leads to the generation of private flood mitigation measures, positive influence on preparedness.  The knowledge and information available, the lower the vulnerability.	Cardona (2003) Birkmann (2005a) Wisner et al (2004)
Expert Perspective		

Critical

Communication and Emergency Operations		y	no	comments
	Are there any forms of government emergency telecommunication? Between and among agencies? Does the community have emergency operations? Mobile network coverage? Satellite Commands systems Mass notification systems (SMS alert? And others) Is there a formalised emergency plan?			

Roads	Availability of alternatives De-routing possibilities			
Hospitals	Capacity Integrated communication Emergency plan arrangements			
Police station	Capacity Integrated communication Emergency plan arrangements			
Fire station	Capacity Integrated communication Emergency plan arrangements			
Town Council	Planning and disaster unit Past flood issues/frequency Mitigation taken or planned.			

## Appendix 5 Images of Ehenye



Figure 5.1 Ehenye Flooding- No drainages.  
Source: <https://neweralive.na/posts/oshakati-mayor-to-put-skills-to-the-test>



Figure 5.1 Embankment  
Source: <https://imdc.be/en/reference/oshakati-flood-protection>

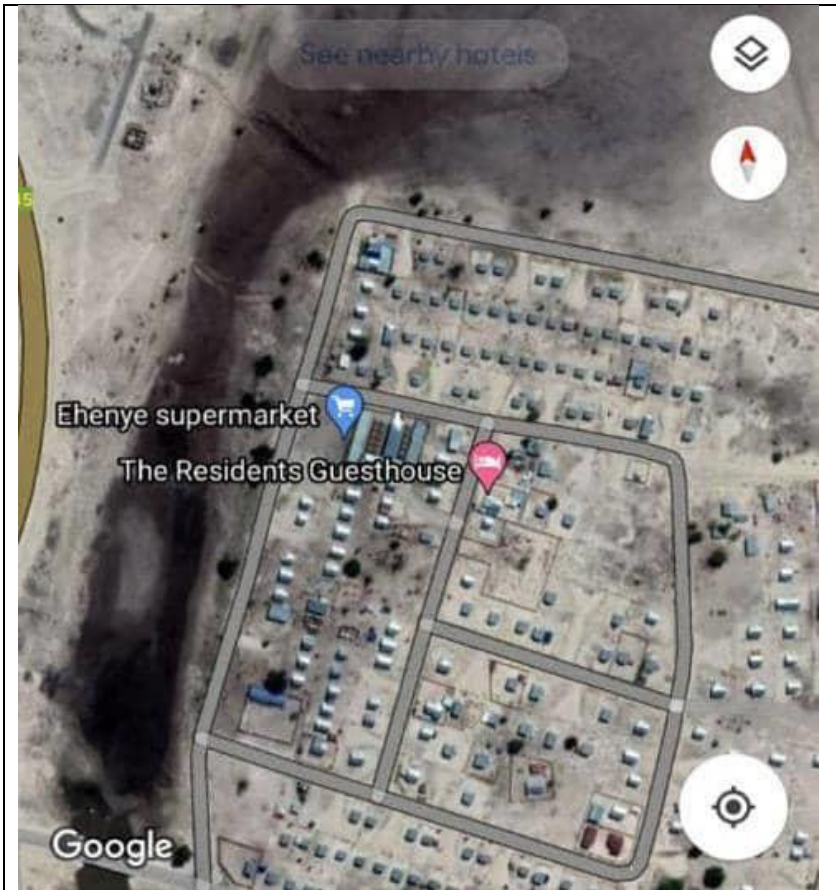


Figure 5.2 Aerial Photograph showing Ehenye community.  
Source: Google



Figure 5.4 Image of Ehenye  
Source: Authors own