Czech University of Life Sciences Prague

Dissertation Thesis

Analysis of the Effects of Climate Change on Forest Ecosystem Services: Effects on Socio-Economic Benefits in the North-Central Region of Namibia

A dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in the Faculty of Forestry and Wood Sciences, Department of Forestry Technologies and Construction of the Czech University of Life Sciences, Prague

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Thesis title

Analysis of the impacts of climate change on forest ecosystem services: effects on socio-economic benefits in the North-Central Region of Namibia

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Objectives of thesis

The aim is this study aims to investigate the socio-economic benefits of forest ecosystems in a changing climate in rural communities and the implementation of policy instruments for climate change adaptation actions in northern Namibia. The study will focus on the following specific objectives:
- To analyse the socio-economic benefits of forest ecosystems in a changing climate at the local community level in northern Namibia;
- To assess trends in temperature and precipitation in forest ecosystems in northern Namibia;
- To investigate the implementation of policy instruments for climate change adaptation actions in mopane woodlands in northern Namibia.

Methodology

The study will focus on forest products of forest ecosystems in two regions in northern Namibia – Omusati and Kunene regions in northern Namibia. The study duration will be delimited to 11 years (2011-2021) due to the lack of historical data for forest products and climate change variables. The second part of the study will focus on the existing policy instruments for climate change adaptation actions in forest ecosystems in northern Namibia and on the national level. A mixed approach combining both quantitative and qualitative will be used. The quantitative approach will be used to quantify the use of forest products in a changing climate in mopane woodlands, specifically, for socio-economic benefits. The qualitative approach will focus on perceptions from multiple stakeholders such as forestry experts, local communities, traditional authorities, and local farmers concerning climate change policy instruments to improve forest ecosystem services regarding rural community livelihoods. A descriptive design will give an overview of the changes in effects of climate variables and their potential impacts on forest ecosystem services with a special focus on socio-economic benefits and demands through the yield model. Quantitative data will be entered, organized, and analysed in Statistical Package for the Social Science (SPSS) software (IBM SPSS version 26, IBM Corp., Armonk, NY, USA) with a p-value less than 0.05 ($p < 0.05$). ATLAS.ti version 22.2 and Thematic Content Analysis (TCA). The results will be presented in form of tables, charts, graphs, and texts (themes).

The proposed extent of the thesis

At least 80 standard pages.

Keywords

Socio-economic benefits; local rural communities; livelihoods; forest products; forest ecosystems; northern Namibia, precipitation; temperature

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DECLARATION

I, ANDREAS NIKODEMUS, hereby declare that this project is my own work and is a true reflection of my research and that this work or any part thereof has not been submitted for a degree at any other institution. No part of this dissertation may be reproduced, stored in any retrieval system, or transmitted in any form, or by means (e.g., electronic, mechanical, photocopying, recording, or otherwise) without the prior permission of the author, or the Czech University of Life Sciences, Prague in that behalf. I grant the Czech University of Life Sciences, Prague the right to reproduce this dissertation in whole or in part, in any manner or format, that the university may deem fit.

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ABSTRACT

Forest resources continue to play an important role in rural communities in developing countries by providing services, products, and incomes. This study aims to investigate the effects of climate change on the provisioning services of *Colophospermum mopane (C. mopane)* woodlands in northern Namibia's Kunene and Omusati regions from 2011-2021. A hybrid approach was used to collect data from forestry, climate change, other relevant experts, and local rural communities through semi-structured questionnaires. All statistical analyses (quantitative) were performed using Statistical Package for the Social Sciences (IBM SPSS version 26, IBM Corp., Armonk, NY, USA) with a p-value less than 0.05 ($p < 0.05$), whereas qualitative analyses were performed in ATLAS.ti version 22.2. The study identified that local communities primarily use firewood, poles, droppers, rafters, and roots for subsistence use. Total changes in annual mean temperature affected the annual mean precipitation over the study period. The most effective policy instruments were Communal Land Reform Act, Forest Act, Namibia National Forest Policy, and Forestry Strategic Plan. Forest ecosystem services such as biodiversity, carbon sequestration, soil conservation, and socio-economic benefits showed statistically significantly effective after the introduction of the National Climate Change for Namibia (NPCC). Biodiversity showed the most significant adaptation actions after the introduction of the NPCC ($p < 0.001$). Challenges such as the dry conditions of Namibia, and the lack of funds for adaptation measures hamper the implementation of policy instruments for climate change adaptation. Emphasis on alternatives for rural communities' reliance on forest resources for their livelihood by improving their awareness of the impacts of climate change should be prioritized. More research is needed to investigate extreme weather events and their effects on goods and services provided by forest ecosystems in the northern regions. Finally, there is also a need for a strengths, weaknesses, threats, and opportunities (SWOT) analysis of the NPCC to appropriately guide the formulation of a framework for forest ecosystem services-based adaptation actions.

Keywords: Socio-economic benefits, local rural communities, livelihoods, forest products, forest ecosystems, northern Namibia, precipitation, and temperature

DEDICATION

This dissertation and my entire Ph.D. accomplishment are a special dedication to my biological parents, Ms. Veronika Nghikufwasha, and Mr. Ananias Nikodemus. Long live mom and dad.

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First of all, I want to give all the glory to my Lord and Saviour, Jesus Christ, for giving me the grace, strength, protection, and good health to pursue my passion and achieve my biggest dream of becoming a Ph.D.

I am grateful to the Czech University of Life Sciences, Prague, for the opportunity to pursue my studies. I would also like to sincerely thank my supervisor, Professor Miroslav Hájek, for his invaluable supervision, unwavering guidance, patience, and encouragement throughout this journey. I would not have completed this work without his support. Long live and God bless you, Professor.

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LIST OF ACRONYMS

FAO	Food and Agriculture Organization
DoF	Directorate of Forestry
GDP	Gross Domestic Products
MEFT	Ministry of Environment, Forestry, and Tourism
MEFT	Ministry of Environment, Forestry, and Tourism
MWARL	Ministry of Agriculture, Water, and Land Reform
NCRST	National Commission on Research Science, and Technology
NPCC	National Policy on Climate Change
NTFPs	Non-timber forest products
ORC	Omusati Region Council
SADC	Southern African Development Community
SASSCAL	Southern African Science Service Centre for Climate Change, and Adaptive Land Management
SPSS	Statistical Package for the Social Sciences
SWOT	Strengths, Weaknesses, Threats, and Opportunities
TCA	Thematic Content Analysis

CHAPTER ONE

BACKGROUND AND LITERARY ANALYSIS

This chapter discusses the background of the study of the effects of climate change on socio-economic benefits of forest ecosystems and policy instruments for adaptation actions in northern Namibia. The chapter further discusses the study's aim, objectives, and significance and a brief literature review.

1.1 Introduction

Forest ecosystems provide multiple services to all life forms, including humans (Kornatowska and Sienkiewicz, 2018). There are seven forest ecosystem services: biodiversity, carbon sequestration, watershed services, soil conservation, recreational and cultural values, social and economic benefits for communities, and high conservation values (Jenkins and Schaap, 2018). Forest ecosystem services can be further classified as supporting, regulating, provisioning, and cultural services (Liagre et al., 2013; Mengist and Soromessa, 2019).

From the perspective of the socio-economic benefits, forests are important for economic development and livelihood security locally and globally (Kumar et al., 2019). However, the dependency on forest resources is higher among local communities in developing countries (Langat et al., 2016). Local communities, particularly in rural areas, consume direct services and products from forests, such as water, food, medicine, wood, and other raw materials (Kornatowska and Sienkiewicz, 2018). Local communities can use forest provisioning services for subsistence and cash income purposes (Ahammad et al., 2019).

The southern African region is part of the developing world, where millions of local rural communities depend on forest resources for their livelihoods (Ryan et al., 2016; Vrabcová et al., 2019). Local communities benefit from forests in various forms in the region, ranging from timber and non-timber forest products (NTFPs) (De Cauwer et al., 2016). The most common forest products in local communities in southern Africa use firewood, construction materials, medicine, and food for marketing and subsistence uses (Langat et al., 2016; Nikodemus et al., 2023).

Although forest ecosystems play an important role in sustaining human communities' livelihoods, the effects of climate change on forest ecosystems and their services around the world are unequivocal (Baciu et al., 2021). In addition, research has proven that the impacts of climate change and climate variability on forest ecosystems are unavoidable, at least in short to

medium term (Gebeyehu, 2019). These effects are manifested by altering the structure and functionality of forest ecosystems, which consequently affects forest ecosystems' output (Xiao-Ying et al., 2013).

The southern Africa region is one of the parts of the world that are extremely vulnerable to the impacts of climate change (Thompson et al., 2010; Tucker et al., 2015). Hence, forest ecosystems in the region are threatened by climate change (Kapuka and Hlásny, 2021). Some of the identified climate risks to forest ecosystems in the region include, for example, altering the growth rates of woodland flora and impacting species composition and productivity (Rohde et al., 2019). As a result, the Food and Agriculture Organization (FAO) highlights that most countries (98%) in southern Africa prioritize climate change adaptation (FAO, 2021).

Namibia is one of the southern African countries that are recognised as most vulnerable to the impacts of climate change (Mupambwa et al., 2019; Shikangalah, 2020). Its vulnerability to climate change is attributed to the fact that it is identified as one of the driest countries in the Sub-Sahara Region of Africa (Crawford and Terton, 2016; Heita, 2018). The average daily temperature ranges between, and the average annual rainfall ranges from about 600 mm in the extreme north-east to less than 50 mm in the extreme south and along the entire coast (World Bank Group, 2021). Namibia's temperature trends have risen by 0.58°C to 1.2°C on average over the past 50 years, with more significant increases in the country's northern parts (Ministry of Environment and Tourism, 2011).

Rainfall trends are less evident than temperature trends over the past 50 years, and there are substantial variations in the direction and magnitude of the changes observed across the region (Daron, 2014). The precipitation trends of Namibia are challenging to discern, given the country's typically erratic rainfall (Lu et al., 2016). In the same view, there is a lack of information concerning long-term rainfall trends and variability across the country (Awala et al., 2019).

In response to the increasing impacts of climate change on life in natural environments and forest ecosystems in particular, policy instruments for climate change mitigation and adaptation have been formulated to govern climate change mitigation and adaptation on the global, regional, and local levels (Yazykova and Bruch, 2018). Policy instruments for climate change are directed by the Paris Agreement (United Nations, 2015).

In the case of Namibia, all policy instruments, including cross-sectoral climate change policies, are governed by the constitution (Ruppel and Ruppel-Schlichting, 2022). The NPCC

is a central force for climate change adaptation and mitigation in Namibia (Ministry of Environment and Tourism, 2010). However, there are multiple policy instruments for climate change adaptation in addition to the NPCC (Nikodemus and Hájek, 2022).

Despite the evidence from research about the severity of the impacts of climate change on forest ecosystems, little is known about its effects on forest products for socio-economic benefits at the local community level in Namibia.

1.2 Overview of the Problem

The socio-economic benefits of forest ecosystems to sustain the livelihoods of the local rural communities in a changing climate, particularly in developing countries that depend on forest products and services for their livelihoods, has attracted research attention over the years (Nunes et al., 2021; Ramsfield et al., 2016). This subject is particularly relevant in southern Africa, a region with the vast majority of the local rural communities depending on forest resources (Gugushe et al., 2008; Nikodemus and Hájek, 2015; Wale et al., 2022a). At the same time, scientific work proves that southern Africa is vulnerable to climate change's effects. However, the impacts of climate change on the socio-economic benefits of the forests have not been fully addressed from a research perspective to date in southern Africa and Namibia in particular.

Namibia is one of the southern African countries with the majority of local rural communities depending on forests to sustain their livelihoods (Nikodemus and Hájek, 2015; Vrabcová et al., 2019). At the same time, it is one of the countries in the region considered vulnerable to the effects of climate change (Mupambwa et al., 2019; Shalumbu-Shivute, 2022). These effects are extended to forest ecosystems and the local communities that depend on forest resources (Vrabcová et al., 2019).

The study focused on *Colophospermum mopane* (*C. mopane* - Kirk ex Benth) because of its good wood quality and adaptability to harsh conditions (Bainbridge, 2012). *C. mopane* is part of the Fabaceae family and can grow into a big tree with a height ranging from 4 m to 18 m (Krug, 2017; Makhado et al., 2014). The species often forms pure stands of two distinct types (Krug, 2017). On favorable sites, the stands are made up of tall trees, ‘cathedral mopane,’ but when the soil conditions are less favorable, the vegetation is referred to as ‘mopane shrub’ (Palgrave, 2002).

C. mopane is considered a natural resource and source of income on a small scale in the daily lives of local people (Teshirogi et al., 2017). Due to its durability and availability, it is a

primary source of products such as poles, firewood, droppers, rafters, and bark ropes for subsistence and commercial uses by local farmers in most northern parts of Namibia (Krug, 2017). Although the species is valuable for the livelihoods of local rural communities, little is known about its socio-economic benefits in a changing climate in southern Africa, especially in northern Namibia.

In addition, policy instruments play a critical role in conserving forest resources while contributing to adaptation actions against climate change. There is a rich literature about the impacts of climate change on various environmental features, mitigation actions, and vulnerability of Namibia (Kapuka and Hlásny, 2020; Mupambwa et al., 2019; Shalumbu-Shivute, 2022). Unfortunately, research focusing on the forest ecosystem services-based adaptation actions supported by the policy instruments on climate change for Namibia is still limited.

1.3 Aim and Objectives

This study aims to investigate the socio-economic benefits of forest ecosystems in a changing climate in rural communities and the implementation of policy instruments for climate change adaptation actions in forest ecosystems in northern Namibia. The study focused on the following specific objectives:

- To analyse the socio-economic benefits of forest ecosystems in a changing climate at the local community level in northern Namibia;
- To assess trends in temperature and precipitation in forest ecosystems in northern Namibia;
- To investigate the implementation of legislation and policy instruments for climate change adaptation actions in mopane woodlands in northern Namibia.

1.4 Hypothesis of the Study

The study tested the following hypotheses to determine whether there is enough statistical evidence about the subject matter:

H1: It is assumed that forest ecosystems continue to provide socio-economic benefits to sustain local community livelihoods in northern Namibia despite a changing climate.

H2: Temperature and precipitation changes could potentially affect the socio-economic benefits of forest ecosystems in northern Namibia.

H3: The implementation of various local legislation and policy instruments for climate change are effective in promoting adaptation actions in mopane woodlands.

1.5 Significance/Contributions of the Study

The justification of the study is that it contributes to the growing literature of similar studies carried out in Namibia and southern Africa about socio-economic benefits of forests in a changing climate. It, therefore, is a twofold approach intended to make contributions to establish an understanding from the research point of view about the socio-economic benefits of forests in a changing climate and the implementation of various forest instruments for climate change adaptation in local rural communities in Namibia. Therefore, it is hoped that findings from this work will contribute to understanding the use of forest products in a changing climate and the effectiveness of adaptation options. Furthermore, the results of the study can be used as a basis for making recommendations for enhancing sustainable management and utilization of forest-related products under the required climate change interventions.

Therefore, the findings of the study are helpful, especially for forestry managers, local rural communities, traditional authorities, cross-sectoral policymakers, researchers, and relevant stakeholders in making decisions regarding the use of forest products in a changing climate. The findings of the study can also be extrapolated in future local studies and other southern African countries with similar conditions. Finally, the research is also helpful for students, scholars, and researchers in the field of forest ecosystem services in a changing climate across Namibia, the southern African region, and other regions with similar climatic and socio-economic conditions.

1.6 Literature Review

There is no doubt about the effects of climate change on forest ecosystems and the services they provide. Arid and semi-arid systems are susceptible to precipitation changes because soil moisture determines ecosystem processes and plant diversity. Climate change is one of the world's most significant challenges and affects forest ecosystems (Gebeyehu, 2019).

Climate change strongly influences ecological functions, such as water use and plant productivity, that critically impact forests (Rustad et al., 2012). For example, warmer winters and a longer growing season will increase forest evaporation and water use. Another critical aspect that is influenced by the changing climates is rainfall. Additionally, climate change will impact rainfall patterns which affect forests (Kirilenko and Sedjo, 2007) and, consequently, the livelihoods of local communities that depend on forests.

1.6.1 Forest Ecosystems in a Changing Climate

The concept of forest ecosystem services refers to the services provided by forest ecosystems, namely, biodiversity, carbon sequestration, watershed services, soil conservation, recreational and cultural values, social and economic benefits for communities, and high conservation values (Jenkins and Schaap, 2018). Forest ecosystems play a multifunctional role in which attempts are made to balance human commodity needs with the production of other goods and services, including the habitat needs of forest-dependent organisms (Martínez Pastur et al., 2018).

In addition, forest ecosystem services can be consumed as direct products: water, food, wood, and other raw materials, or indirectly, as services related to water purification, climate regulation and air quality and a variety of generally intangible assets in the category of cultural services including recreational, scientific, cultural, and religious – all the heritage passed on to next generations (Kornatowska and Sienkiewicz, 2018).

It has been identified that forests provide a wide array of services, ranging from timber production, climate stabilization, water quantity and quality provision, and cultural benefits, such as recreation (Brauman and Daily, 2014). Forests are among the most important providers of ecosystem services for the whole world (Aznar-Sánchez et al., 2018).

The world's forest ecosystems provide critical and diverse services and values to human society (Jenkins and Schaap, 2018). Additionally, the world's forests are one of our greatest natural assets, providing innumerable ecological, social, and economic services (Toochi, 2017). Concurrently, it has been noticed that the importance of forest ecosystem services has been increasingly recognized across the globe (Morin et al., 2018).

Climate change is changing, and the changes in the climate are likely to strongly affect forest ecosystems by altering the growth, mortality, and reproduction of trees (Gebeyehu, 2019). The impact of climate change on forests will result in the influence on forest ecosystem services. However, there are few studies conducted about climate change and forests from this angle.

The unique climate conditions of Namibia and its high vulnerability to climate change call for robust policies to guide climate change adaptation actions at the national level (Keja-Kaereho et al., 2019). Effectively implementing climate change adaptation actions can be a remedy against the degrading utilization of mopane woodlands (Reid et al., 2007). In other

words, sustainable utilization, and management of mopane woodlands through various policy instruments would significantly contribute to climate change adaptation actions.

1.6.2 Socio-economic Benefits of Forests in a Changing Climate

Natural forest resources are the primary source of multiple services and products while offering income generation opportunities for many local rural communities (Wale et al., 2022a). On the global level, it is estimated that between 1.095 billion and 1.745 billion people depend to varying degrees on forests for their livelihoods, and about 200 million indigenous communities are almost wholly dependent on forests (Chao, 2012).

In addition to services such as carbon sequestration and the protection of watersheds and biodiversity (Ryan et al., 2016), forest ecosystems provide goods and services to local communities in various forms in the region, ranging from timber and non-timber forest products (NTFPs) (De Cauwer et al., 2016). Local communities utilize forest products, such as fuel wood, construction materials, medicine, and food, for marketing and household consumption (Langat et al., 2016). Forest ecosystems play an essential role in the livelihood of rural communities where forests are the vital elements of livelihood (Vrabcová et al., 2019).

In southern Africa, for example, forests are critical to the sustainable livelihoods of local communities and ecosystems (Naidoo et al., 2013). Although multiple products are harvested from forests, fuelwood is identified as one of the main forest products utilized by rural communities in the developing world, including Namibia (Nikodemus and Hájek, 2015; Vrabcová et al., 2019). Nearly 2.9 billion people in low and middle-income countries cook and heat their homes by burning solid fuels such as fuelwood (Lindgren, 2021).

However, various previous studies have acknowledged that forest ecosystems in southern Africa are highly vulnerable to climate change (Egoh et al., 2012; Naidoo et al., 2013; Scholes and Engelbrecht, 2021). Some of the identified climate risks to forest ecosystems in the region include, for example, altering the growth rates of woodland flora and impacting species composition and productivity (Rohde et al., 2019; Ryan et al., 2016).

1.6.3 Policy Instruments for Climate Change in Forestry

Forests are naturally capacitated to protect lives and livelihoods and create a base for the earth's sustainable economic and social development from the effects of climate change by protecting people. However, human activities often impede this natural process (Nghogekeh et al., 2020). Therefore, policy instruments are critical in climate change adaptation and the management of forest ecosystems.

Policy instruments are very crucial in guiding adaptation actions against climate change. Several policy instruments are available for governments, companies, and civil society organizations to encourage adaptation (Ulibarri et al., 2022). In addition to the Paris Agreement (United Nations, 2015), different countries implement different policy instruments for climate change at the national level (Yazykova and Bruch, 2018).

However, it is worth pointing out that the success of implementing climate-related policies is linked to how they are integrated with sectorial policies and policies of other government levels (de Oliveira and Antonio, 2009). However, local governments have been busy drawing up policies on climate change and global warming without enlightening the nation about the risk and their influence on the economy or other factors that can change their lives (Keja-Kaereho et al., 2019).

In the context of forest ecosystem services and their value, it is vital to implement effective national development policies (Jenkins and Schaap, 2018). This implies that appropriately addressing the challenges of climate change will require improvements to forest policies and forest management plans and practices.

Considering the climate conditions and their effects on the forest, it is safe to suggest that forest managers and policy developers should consider four main factors when developing forest policies considering climate change: policy, economic, social, and biophysical factors. However, the research gap in this aspect is still huge, especially in the adaptation capacity of the existing actions (Singh et al., 2021). Research on implementing climate change policies in forest ecosystems is crucial to advise forest managers and policy developers to formulate the appropriate strategies.

CHAPTER TWO

SUMMARY OF RESEARCH METHODOLOGY

This chapter summarizes research methods, materials, and procedures used in collecting and analysing data. The chapter is divided into the study area, research approach, population, sampling, instruments and materials, procedures, data analysis, ethical considerations, and limitations.

2.1 Study Area

The study focused on the Kunene and Omusati regions. The two regions form a zone of the northern part of Namibia with the highest distribution of *C. mopane* woodlands. The target regions also fall into the Baikiaea-mopane woodlands zone of southern Africa (Olson et al., 2001). The Kunene and Omusati regions make up 17% of the total area and constitute 13% of the population of Namibia (Nikodemus et al., 2023). However, the Omusati region has the highest species distribution among the two regions (Vrabcová et al., 2019) (Figure 2.1).

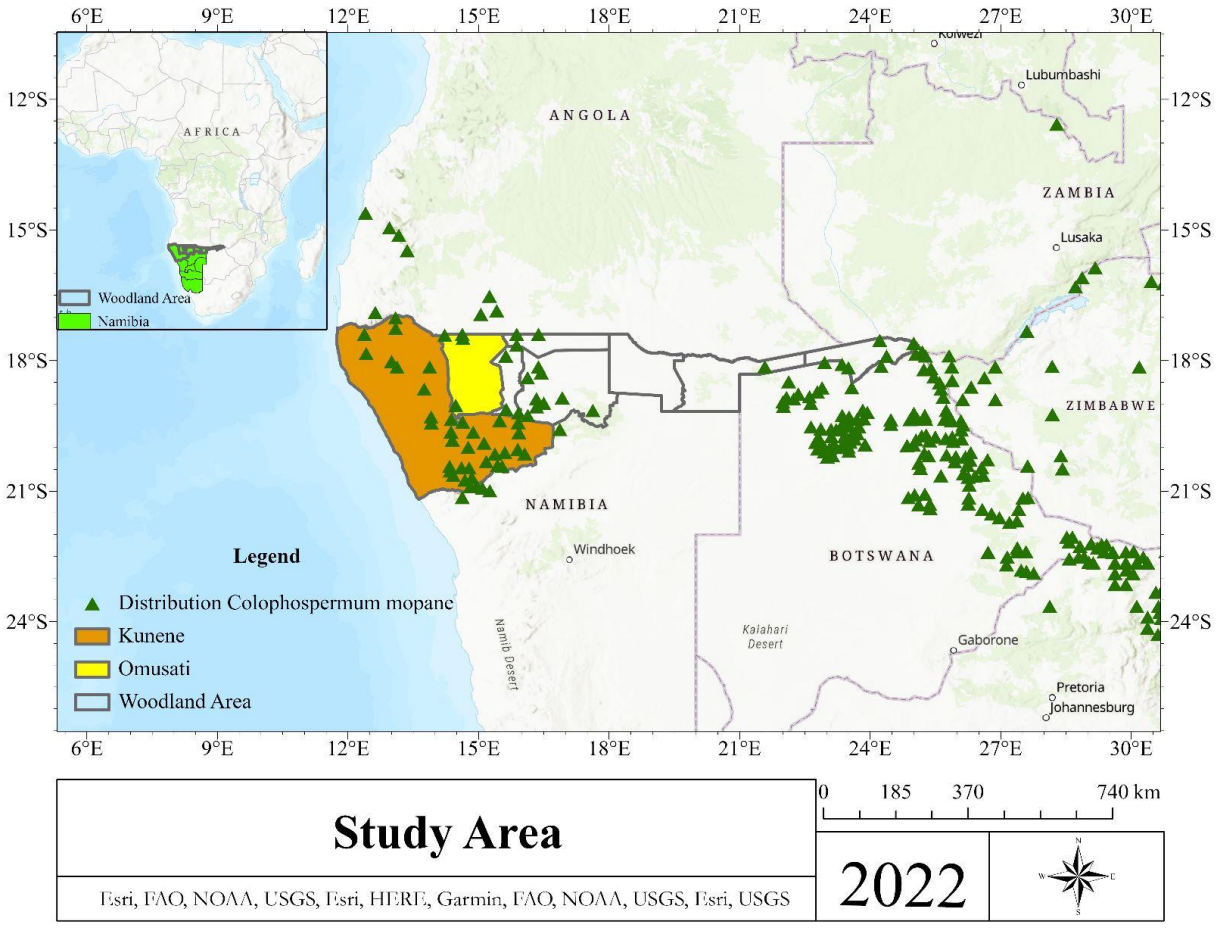

Figure 2.1: Study area and the distribution of *C. mopane*

On the demographic sphere, the northern part of Namibia is primarily rural and is one of the hotspots for climate change-related impacts (Kapuka and Hlásny, 2020; Spear and Chappel, 2018). Rural communities in the two regions mainly rely on subsistence agricultural practices and other forest-related ecosystem services, particularly from the mopane woodlands to sustain their livelihoods (Nikodemus and Hájek, 2022, 2015; Vrabcová et al., 2019). Agricultural practices contribute between 22 and 32% to the livelihoods of local rural communities in Kunene and Omusati regions, respectively (Haukongo, 2017; Kunene Regional Council, 2015; ORC, 2010). Due to demands for agricultural land and other land uses, the area experienced a combined tree cover loss of 302 hectares between 2001 and 2018 (Hansen et al., 2013).

The Kunene region occupies the northwest corner of Namibia and shares borders with Angola to the north, the Omusati region to the east, the Otjozondjupa region to the south-east, the Erongo region to the south, and the Atlantic Ocean to the west (Inman et al., 2020) (Figure 2.2).

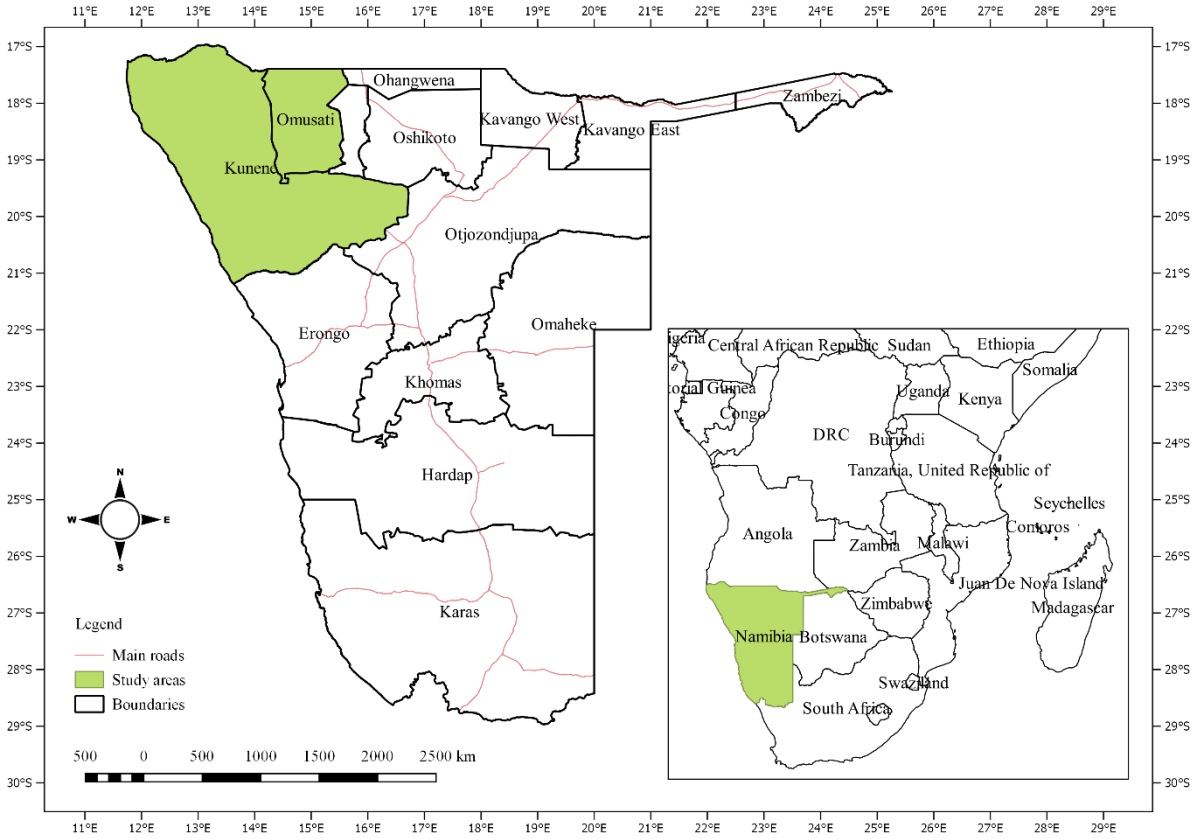

Figure 2.2: The location of the Omusati and the Kunene regions on the Namibian map

The average daily temperatures range from 5°C to 35°C depending on the season (Kunene Regional Council, 2015). Summer day temperatures are often sweltering, reaching up to 35°C with minimum temperatures of 14°C on average. During the winter, the temperatures can range

from an average of 5°C to 26°C (Kunene Regional Council, 2015). The region receives irregular annual rainfall, which increases from the west to the east and ranges from less than 50 mm to 415 mm (Inman et al., 2020).

The Omusati Region is situated in the far north-western part of Namibia, bordered by Angola to the north, the Kunene Region to the west and south, and the Oshana and the Ohangwena Regions to the east. The word *'omusati'* is an Oshiwambo dialect word that is translated into the C. mopane tree species. The yearly rainfall of the Omusati region ranges from 400-500 mm (Haukongo, 2017). The region has high average daily temperatures varying between 6-35°C. However, temperatures vary with the year's four seasons (spring, summer, autumn, and winter). For example, summers are very hot, with a maximum temperature between 30°C and 35°C during the hottest months, according to the Omusati Region Council (ORC, 2010).

Overall, the Kunene and Omusati regions share the same climatic conditions. Furthermore, the two regions are semi-arid and characterized by high temperatures from 5-37°C. The annual average rainfall ranges from 350-500 mm mainly between November and April (World Bank Group, 2021). However, slight differences in weather and climatic conditions are noticeable from season to season.

The main vegetation types of the Kunene and the Omusati regions can be classified as woodlands and savannas (grass cover, trees, and shrubs). More specifically, the woodlands and savannas in the area are characterized by mopane woodlands, mopane sparse shrublands, and grasslands (Giess, 1986; Nikodemus et al., 2022).

2.2 Research Approach

A hybrid approach combining qualitative and quantitative approaches was employed. Although the hybrid (generally referred to as mixed design) requires extensive time, resources, and effort (Molina-Azorin et al., 2018), it has an overall advantage in that it provides directions for the collection and analysis of data from multiple sources in a single study (Dawadi et al., 2021). Therefore, a hybrid approach was employed since the study involved primary data directly from humans and secondary data for climate variables, forest products, and policy instruments.

Furthermore, a descriptive research design was used to describe the phenomenon and its characteristics (identified variables) (Nassaji, 2015). The descriptive design is applied in case

studies, surveys, and naturalistic observations. It allows the researcher to vividly present the problem statement to enable others to understand a study's objectives and significance better. Also, this method ascertains prevailing conditions of facts in a group under study that gives either qualitative or quantitative, or both, descriptions of the general characteristics of the group as results (Rillo and Alieto, 2018).

Quantitative data consisted of climate variables (temperature and precipitation), forest products, uses, permit costs, and the effectiveness of various policy instruments for climate change adaptation actions in forest ecosystems. On the other hand, the qualitative aspect focused on the views expressed about the improvements of the implementation policy instruments.

2.3 Respondents and Key Variables

Key informants involved the local rural communities in the two regions, DoF officials at five forestry offices (Okahao, Onesi, Outapi, Opuwo, and Tsandi) in the two regions, climate change experts, researchers from local academic institutions, and cross-sectoral stakeholders. The study used various variables classified into three sub-categories, socio-economic benefits from *C. mopane,* climate change variables, and the implementation of various legislation and policy instruments for climate change adaptation actions in the context of forest ecosystem services.

Socio-economic benefits data include different types of forest products from *C. mopane* and their uses (commercial and subsistence). Since climate change is generally measured by changes in temperature, precipitation, and windspeed (Barry and Hoyne, 2021), the study used temperature and precipitation to assess climate variability in the area. Wind variables were excluded due to the lack of data.

Data for various forest products were extracted from harvesting permit record books at the five DoF offices, representing 239 villages across the study area. Data included all harvesting permits for products from *C. mopane,* such as firewood, poles, droppers, rafters, and roots. Data also comprised the uses, quantities, permit costs, and harvesting years. Due to limited long-term historical climate change data, data for all variables were confined to 11 years (2011-2021).

The second component of the research was the implementation of various policy instruments for climate change adaptation actions. Data for this component was obtained from cross-sectional experts. The study targeted at least 150 respondents, including local

communities, forestry, climate change, and other relevant environmental experts. However, the study could only collect results from 128 responses, translating into an 85.3% response rate.

Finally, the last component was a follow-up survey which was aimed at investigating the effectiveness of adaptation actions within the framework of the NPCC for Namibia in the context of forest ecosystem services. The research deemed it necessary to investigate adaptation actions supported by the NPCC, specifically in forest ecosystems. The NPCC is the central force for climate change actions at the national level. It provides an institutional framework and overarching national strategy for developing, implementing, monitoring, and evaluating climate change mitigation and adaptation activities in Namibia (Ministry of Environment, Forestry, and Tourism, 2021).

The target population for this component was 40 cross-sectional experts. However, the study could only obtain 36 responses, translating to 90%. The small target population in this aspect was because Namibia has a small population. Based on the national census of 2011, Namibia's population was estimated at 2.5 (Destatis, 2022; Kapuka and Hlásny, 2020). The forestry sector is one of the smallest sectors in the country. On the other hand, climate change is still a new and least emphasized subject at the local level. Hence, there was a small population for the last component of the study was relatively small.

2.4 Sampling

Since this study used a mixed method, two sampling techniques were combined—a purposive mixed-probability sampling continuum combined with a simple random method.

In the case of the local communities, respondents were chosen through simple random sampling. Each member of the study population was given an equal chance to be selected (probability). Simple random sampling allows for the selection of the members of the sample by equal chance (Bhardwaj, 2019). As a result, the quality of the sample is not affected.

In the case of the experts, a purposive-mixed-probability sampling continuum method was used. This method involves choosing multiple sampling strategies and comparing the results emerging from both samples (Onwuegbuzie and Collins, 2015). A mixed purposive-probability sampling, also referred to as judgment sampling, was chosen because it is the deliberate choice of an informant due to the qualities the informant possesses.

The study covered 239 villages where local communities harvest forest products for socio-economic benefits in the study area (manuscript 3). For policy instruments (manuscripts 1 and

2), the study reached involved local communities, forestry, climate change, and other relevant environmental experts through an online semi-structured questionnaire. That is 128 respondents (local communities, forestry, climate change, and other relevant environmental experts {manuscript 2}) and 36 experts (manuscript 3).

2.5 Data Collection Tools and Procedures

The study used primary and secondary data. As a result, the study used different methods and tools to collect primary and secondary data.

2.5.1 Primary Data

In this study, primary data was used to address the third objective on the implementation of policy instruments for climate change adaptation actions in mopane woodlands in northern Namibia. Primary data was collected using a semi-structured online questionnaire (Survio 2022 version).

Online questionnaires are commonly used nowadays because they collect substantial quantitative and qualitative data (Dewaele, 2018). Furthermore, online questionnaires require minimal input from the researcher. Once they are distributed, they keep count of the number of responses until sufficient data have been collected and the analysis can start (Dewaele, 2018). In this study, an online questionnaire was used due to its attributes, such that it is less costly, less time-consuming, flexible, and convenient to complete. Additionally, online questionnaires were used because they reach many respondents, and data entry and analysis are easy (Evans and Mathur, 2005).

Structured questionnaires and semi-structured interviews are generally used in mixed-method studies to generate confirmatory results despite differences in data collection, analysis, and interpretation methods (Harris and Brown, 2010). Therefore, a semi-structured questionnaire was employed for collecting the required quantitative data because it consists of open and closed-ended questions.

Structured questions consisted of multiple options and Likert scales (e.g., extremely ineffective, very ineffective, ineffective not sure, effective, very effective, extremely effective). This approach gave respondents categories from which they could choose to indicate their opinions, attitudes, or feelings about a particular issue (Nemoto and Beglar, 2014).

Furthermore, a questionnaire was used because of its several advantages. For example, it is generally used for limited resources because it can be inexpensive to design and administer

(Roopa and Rani, 2012). Additional advantages of using a questionnaire include protecting the privacy of the respondents and using less time. Finally, a questionnaire can be a helpful confirmation tool when combined with other data collection strategies (Roopa and Rani, 2012).

Careful consideration was given to the design of the questionnaire to ensure valuable and relevant data. Therefore, the following stages adopted from (Roopa and Rani, 2012) were followed in the design of the questionnaire (Figure 2.3).

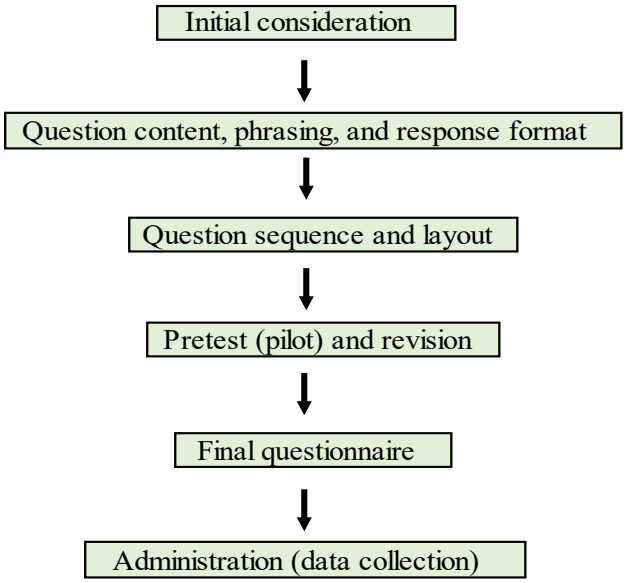

Figure 2.3: Stages of designing a questionnaire

The questionnaire was distributed to the respondents (experts and local communities) from 27 August 2022 to 30 September 2022. The survey took 35 days, including weekends and public holidays. The link to the questionnaire was shared with target respondents via email, WhatsApp, and LinkedIn. The study used these platforms because they are user-friendly, cheap, and commonly used by most professionals daily.

2.5.2 Secondary Data

The first research objective focused on the evidence of the utilization of forest products in the Kunene and Omusati regions. Data from the harvesting permit books at forestry offices were entered, organized, and analysed using statistical tools to achieve this objective.

Data for forest products were extracted directly from harvesting permits record books at forestry offices in the two regions. For convenient data processing, copies were made from permit record books (Appendix A). Permit books provided data such as the types of products

(firewood, poles, droppers, rafters, and roots), uses, quantities, permit costs, and harvesting years.

The second objective was about trends in annual mean temperature and annual mean precipitation. It was addressed by obtaining data from the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) weather stations surrounding and within the study area. Annual mean temperature and annual mean precipitation data were derived from various the SASSCAL weather stations (Figure 2.4).

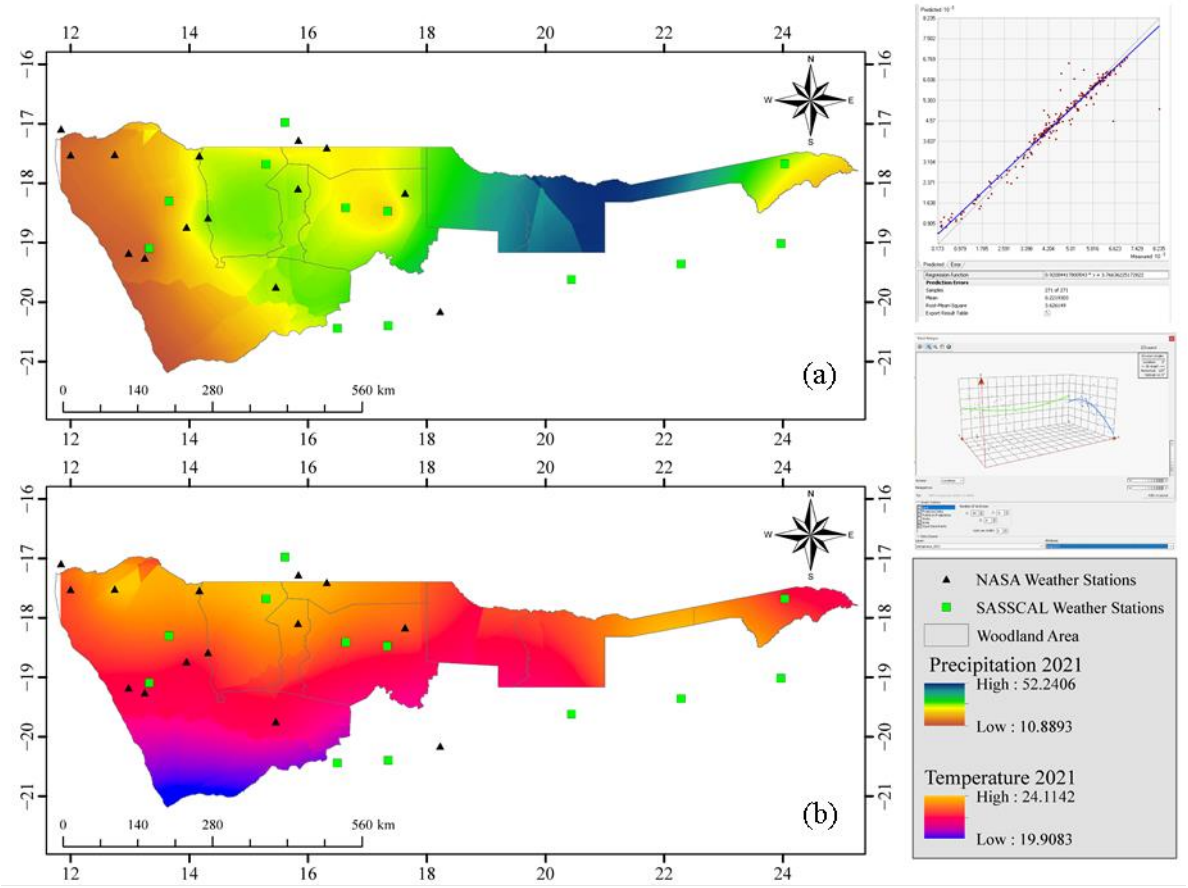

Figure 2.4: The SASSCAL weather stations surrounding and within the study area

For converting the point layer containing the climatic data to countifies maps, the geostatistical analyst toolbar in ArcGIS Pro V2.7.2 was used.

2.6 Data Analysis

Since this study is descriptive, a descriptive statistics method was employed to generate frequencies, mean, percentage, and p-values of statistical variables.

According to the permit system of the DoF, forest products are recorded in different units. For example, poles, droppers, and rafters are measured in pieces, whereas firewood and roots

are in tons. Therefore, units were ultimately standardized to tons. The authors developed estimates of the local weights of different wood products harvested by the local communities (Ngheendekwa, 2019). On average, a bundle of firewood/root is 0.013 tons, whereas poles are approximately 0.0094 tons, droppers are 0.001 tons, and rafters are 0.001 tons per piece.

To determine the distribution of climate variabilities and forest products utilization across the study area, the corresponding coordinates was linked to the 239 villages. Then, information was extracted from the continuous maps in Python Spyder 3.9 using the following packages; i) geopandas, ii) os, iii) scipy.sparse, iv) rasterio, v) pandas, vi) numpy. After the extraction, the correlation between mean annual temperature and precipitation was analyzed in the area.

2.6.1 Statistical Analysis

Quantitative analyses focused on the data for the forest products, climate change variables, and effectiveness of policy instruments. All statistical analyses were performed using IBM SPSS version 28 (IBM Corp., Armonk, NY, USA). A p-value of less than 0.05 ($p < 0.05$) was deemed statistically significant in all analyses in this study.

The independent t-test for non-categorical data for the statistical analysis was used to compare mean scores of the implementation of various climate change adaptation actions in forest ecosystems. The independent samples t-test can be represented using the functions below:

$$t = \frac{\bar{x_1} - \overline{x_2}}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

With:

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

Where:

$\bar{x_1}$ = Mean of first sample

$\bar{x_2}$ = Mean of second sample

n_1 = Sample size (i.e., number of observations) of first sample

n_2 = Sample size (i.e., number of observations) of second sample

s_1 = Standard deviation of first sample

s_2 = Standard deviation of second sample

s_p = Pooled standard deviation

2.6.2 Qualitative Analyses

Qualitative analyses focused on the data for the implementation of policy instruments. All qualitative analyses were performed using ATLAS.ti Scientific Software Development GmbH version 22.2.4 (Berlin, Germany) combined with the Thematic Content Analysis (TCA) approach. TCA is a method of presenting qualitative data descriptively (Anderson, 2014). This approach is used to categorize and exhibit the data's narrator themes or data patterns.

Since ATLAS.ti software does not perform automated data analysis, all the relationships created during the analysis process were based on the researcher's decision (Soratto et al., 2020). The procedure flow of the TCA was performed, which is depicted in Figure 2.5.

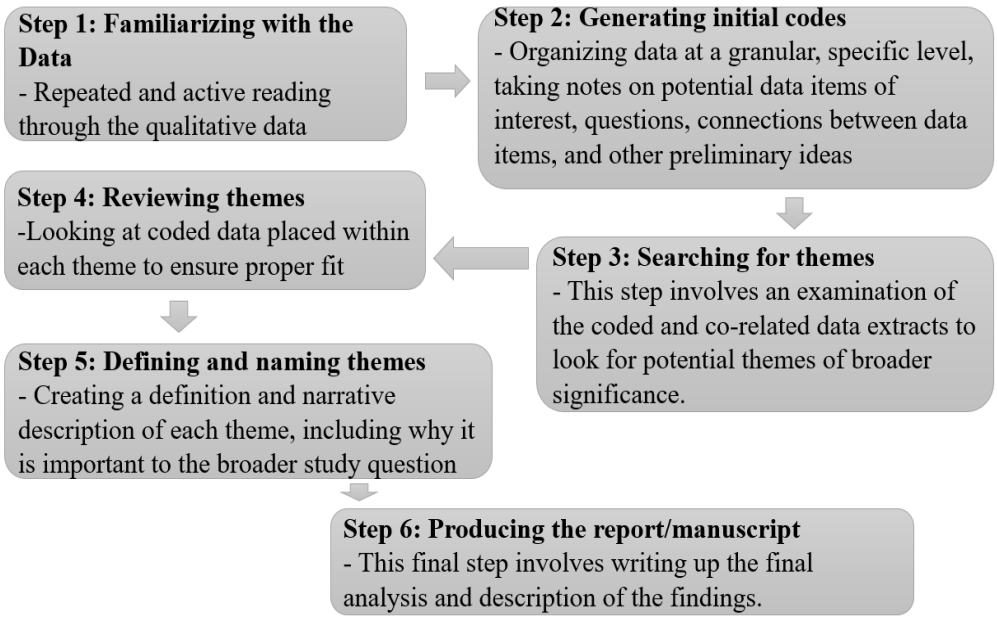

Figure 2.5: The procedure flow of the TCA according to (Kiger and Varpio, 2020)

During the data analysis process, qualitative data were coded according to relevant themes (codes), mainly derived from the proposed improvements for the existing policy instruments, i.e., the effectiveness of the NPCC in forest ecosystem services.

2.7 Limitations of the Study

This is the pioneering research on the effects of climate change on forest ecosystem benefits in Namibia. Therefore, there were several limitations regarding the limited literature and long-term historical data. Secondly, climate change is not fully emphasized in forest ecosystems in Namibia. Several aspects, such as correlational analysis between forestry productivity, forest status (growth rates, mortality rates, and stand structure), and climate change variables, would

be helpful to this study. However, this approach requires long-term data from permanent sample plots, which is currently unavailable.

Regarding the limited data, the study focused on the available data combined with surveys to achieve its aim. Ultimately, this study is critical because it serves as a baseline for formulating strategies for the necessary actions, including awareness creation for local communities, forestry managers, and policymakers about the effects of changing climatic conditions on forest ecosystems and livelihoods of local communities in northern Namibia.

2.8 Ethical Considerations

The study was conducted in accordance with the ethical conduct of the National Commission on Research Science and Technology (NCRST), issued on 13 December 2022 (Appendix B), and the ethical clearance by MEFT of Namibia, and approved by DoF, dated 18 August 2022 (Appendix C). The study ensured complete privacy by giving assurance of confidentiality of the information to be obtained. Furthermore, the researcher strictly used the collected data for this academic research and not for other ambitions. The researcher also ensured that no part of the information obtained during the study was released to outside individuals where it would cause any damaging consequences. All the data used in this study will be stored in the researchers' office's safe locker and destroyed after five years.

CHAPTER THREE

RESULTS SYNTHESIS

This chapter presents the findings of the study. The findings were arranged according to three publications. The publications focus on socio-economic benefits of forest ecosystems, various legislation, and policy instruments, and the NPCC.

Publications

Manuscript 1

Authors: Nikodemus, A., Hájek, M.

Title: Implementing Local Climate Change Adaptation Actions: The Role of Various Policy Instruments in Mopane *(Colophospermum mopane)* Woodlands, Northern Namibia

Journal: Forests, (2022), 13, 1682. https://doi.org/10.3390/f13101682

Personal Contributions: Conceptualization (98%), study design (100%), dataset compilation (100%), data processing and analysis (100%), manuscript writing and artwork (100%), corresponding author.

Publication certificate for article 1

forests

MDPI

Article

Implementing Local Climate Change Adaptation Actions: The Role of Various Policy Instruments in Mopane (*Colophospermum mopane*) Woodlands, Northern Namibia

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Abstract: The impacts of climate change are severe in rural communities because of their proximity to forest ecosystems. *Colophospermum mopane* woodlands are vital in supporting the livelihood of the rural communities in the mopane woodlands while contributing to biodiversity conservation. There is limited research regarding implementing policy instruments for climate change adaptation in rural areas of the mopane woodlands in northern Namibia. This study aims to investigate this subject from the mopane woodlands' point of view to understand the implementation of policy instruments for climate change adaptation in the mopane woodlands. We conducted an online survey focusing on multiple stakeholders, experts in different sectors, and local communities. Major challenges such as a limited general understanding of climate change, its impacts, dry conditions of Namibia, and lack of funds for adaptation measures hamper the implementation of policy instruments for climate change adaptation in mopane woodlands. Policymakers and relevant stakeholders should emphasize altering rural communities' reliance on forest resources for their livelihood by improving their awareness of the impacts of climate change. Future research should evaluate climate change policy instruments' framework and strategies in the context of forest ecosystems at the rural area level of Namibia.

Keywords: adaptation; climate change; forest ecosystem services; mopane woodlands; northern Namibia; policy instruments; rural communities

Citation: Nikodemus, A.; Hájek, M. Implementing Local Climate Change Adaptation Actions: The Role of Various Policy Instruments in Mopane (*Colophospermum mopane*) Woodlands, Northern Namibia. *Forests* **2022**, *13*, 1682. https://doi.org/10.3390/f13101682

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1. Introduction

Climate change affects natural environments, including forest ecosystems and local communities. Rural communities are typically vulnerable to the impacts of climate change due to their dependency on forest ecosystems for their livelihoods [1–3]. Implementing policy instruments minimizes the effects of climate change on rural communities.

With so much emphasis on climate change policy and regulatory framework development to enhance adaptation measures, it is still unclear how efficient the existing instruments are in rural communities [3]. The ambiguity of the effectiveness of existing policy instruments is prevalent, specifically in the context of forest ecosystems in rural communities. Although forest ecosystems play a crucial role in the livelihood of rural communities [4,5], most local communities in rural areas have a limited understanding of the impacts of climate change and adaptation measures [6,7]. Therefore, emphasis on implementing policy instruments for climate change adaptation measures in rural communities requires special attention [8].

On a global level, the efforts to minimize the impacts of climate change have moved from understanding vulnerabilities to climate change adaptation [9]. In addition to the Paris Agreement [10], different countries implement different policy instruments for climate change at the national level [11]. The same need to build such policy activities upon cross-sector dialogue and actions has also been recognized in southern Africa [12]. In

South Africa, for example, the local government has been developing the municipal climate protection program since 2004 [13].

The constitution of Namibia lays the foundation for all policies and legislation in Namibia and contains three vital environmental clauses relevant to the sustainable use of natural resources [14]. Therefore, climate change adaptation policy instruments are mainstreamed across multiple sectors and in concurrence with other related policy instruments [12]. Thus, Namibia's National Climate Change Policy [15] is consistent with different policy instruments. There are various policy instruments for climate change adaptation in Namibia. The most significant ones include the National Climate Change Policy for Namibia, Namibia's Climate Change Strategy and Action Plan, Namibia National Forest Policy, Forestry Strategic Plan, the Forest Act, National Environmental Education and Education for Sustainable Development Policy, and the Communal Land Reform Act contribute to climate change adaptation [14].

Studying the use of different policy tools to adapt and mitigate climate change is a critical research gap [16]. Therefore, the phenomena of climate change and forest ecosystem services have attracted the attention of researchers and scholars all around the world [3,16] to southern Africa [17] and Namibia [18,19]. However, significant research gaps still exist regarding the implementation of policy instruments and their impacts on adaptation in the context of forest ecosystem services in rural communities in the mopane woodlands in northern Namibia.

While a considerable amount of literature focuses on climate change adaptation [18,20], the implementation policy instruments for adaptation to climate change, their effectiveness, and the challenges faced implementing them in rural communities of the mopane woodlands remain under-researched and misunderstood. Implementing policy instruments in rural communities, especially in the mopane woodlands in northern Namibia, are highly vulnerable to the impacts of climate change [21]. Furthermore, forest ecosystems in this area have become degraded due to the dense population, poor vegetation cover [22], and low and erratic rainfall patterns [23,24]. In addition, forest ecosystems in the mopane woodlands in northern Namibia, where tree species of high socio-economic value, such as *Colophospermum mopane* (Kirk ex Benth.) Kirk ex J.Léonard, commonly known as mopane, are threatened by the demands from local communities and by the ever-changing harsh climatic conditions, are no exception [25].

Mopane woodlands, which provide multiple forest services, including socio-economic benefits, are essential to the livelihoods of rural communities in northern Namibia [26]. Effectively implementing climate change adaptation actions can be a remedy against the degrading utilization of mopane woodlands [27]. There is little scientific work about the impacts of climate change and policy instruments in the context of forest ecosystems in Namibia. Hence, although mopane woodlands are valuable in terms of socio-economic values and biodiversity, there is little emphasis on implementing policy instruments for climate change adaptation in mopane woodlands in northern Namibia. Consequently, there is no clear evidence about the extent of the implementation of policy instruments in mopane woodlands. This situation might affect the adequacy of management strategies and the adequacy of the existing policy instruments for climate change adaptation in the mopane woodlands. Bridging this gap would contribute to formulating a practical framework and approach for effectively implementing adaptation policy instruments in the highly vulnerable yet socio-economically valuable mopane woodlands.

The paper aims to investigate the implementation of policy instruments for climate change adaptation actions in mopane woodlands. Our study focuses on the knowledge, effectiveness, and challenges of implementing various policy instruments for climate change adaptation and, finally, possible improvement proposals for policy instruments for climate change adaptation in mopane woodlands.

2. Materials and Methods

2.1. Study Area

Namibia consists of fourteen (14) political regions [28]. We focused on the Omusati and Kunene regions (Figure 1). These regions also form part of the *Baikiaea-mopane* woodlands of southern Africa and represent areas with the highest distribution of *C. mopane* species in Namibia, with the Omusati region having the highest concentration of the species among the two [29]. The species is a valuable natural resource and an income source for the local inhabitants [30]. It is mainly used for poles, fuelwood, droppers, rafters, and bark rope by local communities in the mopane woodlands in northern Namibia [31].

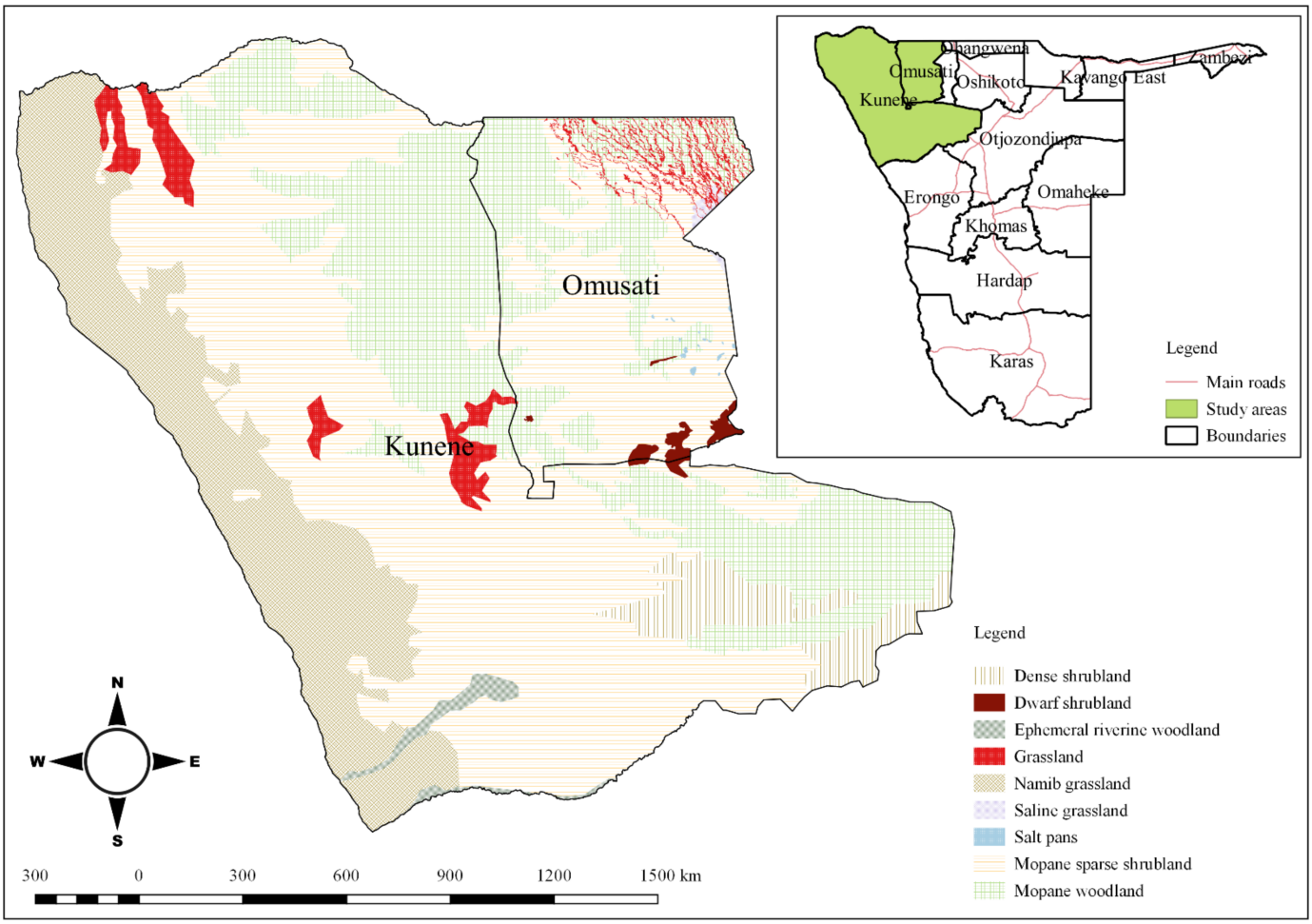

Figure 1. The location of the Omusati and Kunene regions on the map of Namibia and the distribution of mopane woodlands in northern Namibia.

Due to the quality wood of *C. mopane*, mopane woodlands are disappearing despite their role in providing forest ecosystem services such as being crucial to livelihoods, carbon sequestration, and biodiversity [26]. Increases in local populations have increased tree harvesting in the area over the years.

Eight countries in southern Africa are reported to have *C. mopane* vegetation [31]. *C. mopane* is predominately found in areas with little to moderate rainfall, hot temperatures, low altitudes, and various soil types [31]. As a result, the *C. mopane* savanna extends over a large area, reaching as far south as Brandberg mountain, Namibia's highest point, between southwestern Angola and Namibia [5,32]. Fine-grained sand and clay-loam sites made of basalt, alluvial material, and lime are ideal for *C. mopane* [31]. Hence, *C. mopane* has mitigative and adaptation values to the impacts of climate change.

Covering about 17% of the total area and constituting 13% of the total population of Namibia, these two regions are situated in the north-central geographical zones of Namibia [33]. The study area is semi-arid and characterized by high temperatures ranging from 5–37 °C, whereas the annual average rainfall is about 350–500 mm between November and April [34]. Due to its dry climatic conditions, the area is considered prone to severe effects of climate. Communities in the northern and northeastern parts of the country have experienced more severe flooding, which has caused significant hardship to local communities [35].

Most of Namibia's population, approximately 70%, lives in rural areas that depend heavily on forest ecosystems [35]. These rural areas, which are frequently underdeveloped and marginalized, are more severely affected by the effects of climate change [36]. Most of the Omusati and Kunene residents live in rural areas. As a result, forest ecosystems play a crucial role in supporting the livelihood of the local communities in these two regions [4,37]. Agricultural activities at a subsistence level are customary in these regions [37,38].

2.2. Survey

We collected data using a semi-structured online questionnaire (Survio 2022 version, see Appendix A). Given the fact that Namibia is vulnerable to the impacts of climate change, especially in the rural communities [23], all Namibians, especially senior managers, policy-makers, and decision-makers across all sectors, are commissioned to assume responsibility for adaptation given the forecast that weather conditions will worsen over the coming decades [39].

Therefore, we focused on eight of the main cross-sectoral policy instruments that are directly integrated into the protection and conservation of forest ecosystems in Namibia, namely the National Policy on Climate Change for Namibia, Namibia's Climate Change Strategy and Action Plan, National Environmental Education and Education for Sustainable Development Policy, Nature Conservation Ordinance No. 4 of 1975, the Communal Land Reform Act, Namibia National Forest Policy, Forestry Strategic Plan, and the Forest Act. These policy instruments systematically complement climate adaptation activities within Namibia's National Policy on Climate Change framework and the United Nations Framework Convention on Climate Change (UNFCCC) [40].

Given that the existing policy instruments are executed at the national level, we administered the semi-structured questionnaire to experts at different ranks representing professions with varying experience levels in the environmental sciences and natural resources management, including forestry and climate change. This included experts from public, private, and academic institutions. The cross-sectoral experts were involved based on their expertise and experiences in policy instruments, rural community development programs, research, and forest resources management.

Since we delimited our study to rural communities within mopane woodlands, particularly the Omusati and Kunene regions, we also tried to involve local communities from these two regions. Local communities depend on mopane woodlands for their livelihoods [4,5]. Local communities are also involved in implementing policy instruments for climate change adaptation, both directly and indirectly. The implementation of policy instruments also affects their livelihoods to some extent. Hence, we involved them in our study to give their views and experience concerning implementing various policy instruments in mopane woodlands.

Due to the limited understanding of climate change [20], we targeted 150 respondents representing private, public, academia, research, and local community members in the Omusati and Kunene Regions. We achieved a response rate of 128, which translates to 85.3%. The most significantly represented institution was public (n = 50, 39.2%), followed by the private (n = 31, 24.5%) and academia and research (n = 26, 20.3%). There were few local community members (n = 15, 11.9%) due to their low literacy level and poor internet access. In addition, other institutions, such as students and Non-governmental Organizations (NGOs), comprised (n = 5) 4.1% of the respondents.

For the local communities, we limited the survey to the literate members of the community. Another reason for selecting the literate local community members was that most illiterate local community members do not comprehensively understand the subject of climate change, policy instruments, and forest ecosystem services.

For public institutions, we focused on the top, middle, and lower management staff of the Ministry of Environment, Forestry, and Tourism (MEFT) and the Ministry of Agriculture, Water, and Land Reform (MAWRL). Regional and global public institutions operating in Namibia, such as the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL), Deutsche Gesellschaft für Internationale Zusammenarbeit/the German Agency for International Cooperation (GIZ), and the Environmental Investment Fund (EIF) were also involved.

In the case of private institutions, we focused on the Namibia Nature Foundation (NNF), the Desert Research Foundation of Namibia (DRFN), the Namibian Association of Community Based Natural Resource Management (NACSO), Namibia Scientific Society, and the Integrated Rural Development and Nature Conservation (IRDNC). Such private institutions are actively involved in managing and conserving natural environments, including forest ecosystems in Namibia. For academic institutions, we focused on the teaching and research staff representing fields such as natural resources management, forestry, and environmental sciences at the Namibia University of Sciences and Technology (NUST), the University of Namibia (UNAM), and the International University of Management (IUM).

Collected data were entered, coded, cleaned, and analyzed using the Statistical Package for Social sciences (IBM SPSS, version 28; IBM Corp., Armonk, NY, USA) [41] (Appendix B). Qualitative data were coded according to relevant themes using the Thematic Content Analysis (TCA) approach. TCA is a method of presenting qualitative data descriptively [42]. This tool is used to categorize and exhibit the data's narrator themes or data patterns. The approach is less suitable for investigating unique meanings or experiences from a particular person or data item because it is programmed to look for shared or common meanings [43].

Figure 2 shows our procedure flow of the TCA according to [43].

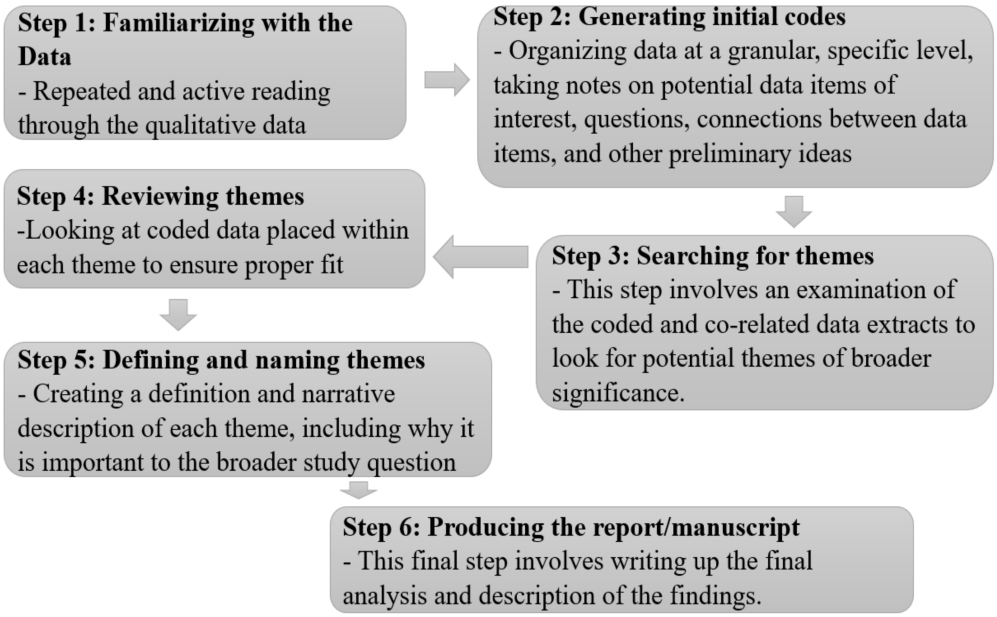

Figure 2. The procedure flow of the TCA that was performed for qualitative data.

3. Results

3.1. Level of Education

The level of education plays a vital role in the knowledge and implementation of adaptation actions for climate change [44]. Most of the respondents across different sectors were educated (Figure 3).

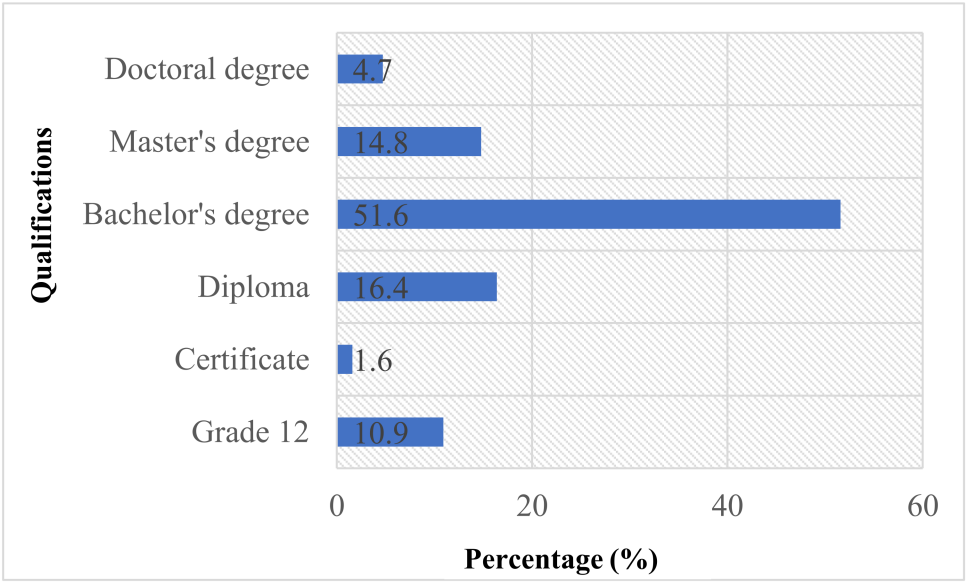

Figure 3. Level of education ranging from a grade 12 to a doctoral degree among the respondents from various sectors.

Most of the respondents were in possession of bachelor's degrees (51.6%). In addition to the bachelor's degree, there were many respondents with diplomas (16.4%) compared to master's degrees which constituted 14.8% of all the respondents. Although the level of education assessed was not limited to the field of climate and forestry, it is believed that general education can be a powerful tool in enabling effective adaptation to climate change [44].

The implementation of policy instruments is expected to be more effective where communities are educated. Educated communities can easily understand the concept of policy instruments and their implementation and spearhead adaptation actions among uneducated local communities.

3.2. Knowledge of Policy Instruments for Climate Change

The level of general and scientific knowledge about various policy instruments for climate change adaptation among climate change experts, stakeholders, and local communities plays an essential role in implementing its policy and associated policy instruments [45]. In this context, the level of knowledge about the various policy instruments for climate change adaptation in mopane woodlands is essential in determining their effectiveness. Our results revealed the level of understanding of the respondents about implementing multiple policy instruments as interventions made in mopane woodlands to promote adaptation (Figure 4).

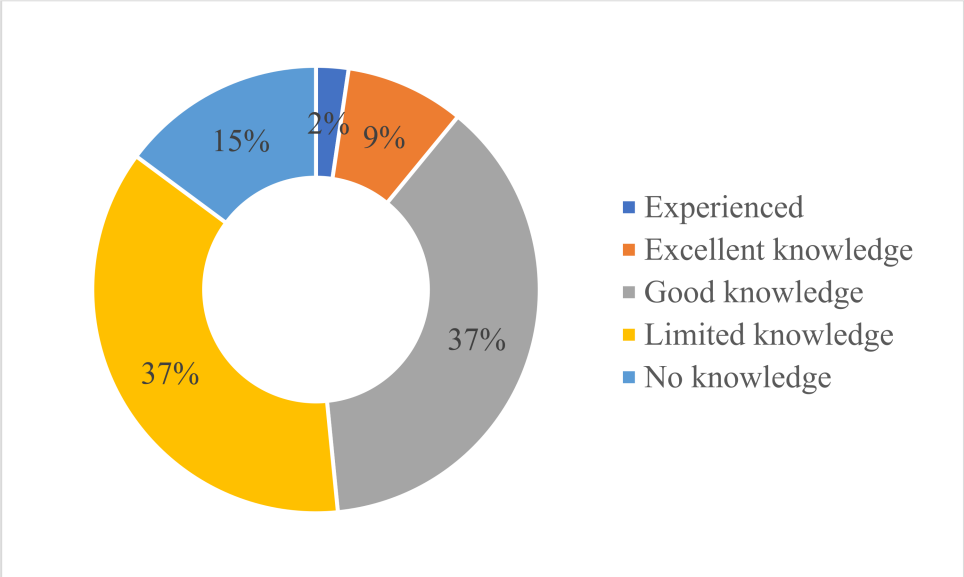

Figure 4. Knowledge of implementing various policy instruments for climate change adaptation in mopane woodlands.

Although most of the respondents in our study were experts, the results show that the level of knowledge about climate change and policy instruments ranged from good knowledge (n = 48, 37%) to no knowledge at all (n = 19, 15%). In addition to the category of respondents who indicated that they had good knowledge about climate change and associated policy instruments, another group of respondents in the same measure showed that they had limited knowledge (n = 48, 37%). About 9% (n = 11) of the respondents had excellent knowledge. Only relatively few respondents had an experience in climate change and implementing policy instruments (n = 3, 2%).

It is clear from the results that the implementation of climate change actions in the mopane woodlands is not fully understood among different stakeholders. The results coincide with [20], who highlighted that limited knowledge of climate change adaptation is one of the main limiting factors in the effectiveness of adaptation actions—in Namibia. Limited knowledge of policy instruments for climate change adaptation in mopane woodlands could be attributed to many factors that need to be identified and addressed appropriately. The issue of limited knowledge about climate change and associated policy instruments is worse in rural areas where most residents are illiterate or do not have access to media [6]. Thus, this situation could hamper the implementation of policy instruments for climate change adaptation [7,8].

3.3. The Implementation of Policy Instruments

Our survey results on implementing policy instruments for climate change adaptation in the mopane woodlands provide a good picture of the various policy instruments associated with climate change adaptation (Table 1).

Our survey results show that most of the policy instruments were on a scale ranging from active to very active. This implies that multiple policy instruments for climate change adaptation are active within the Namibia National Forest Policy, rated the most active instrument (n = 51, 40%), followed by the Communal Land Reform Act (n = 47, 37%).

Although the National Policy on Climate Change for Namibia is the central catalyst for adaptation measures, it was rated among the least active instruments (n = 32, 25%) alongside Namibia's Climate Change Strategy and Action Plan (n = 27, 21%). This situation could be attributed to various factors, including a lack of communication [17], a lack of understanding of climate, and the exclusion of rural communities [7].

Table 1. The rating of how active the implementation of various policy instruments for climate change adaptation in mopane woodlands in northern Namibia.

Policy Instruments	Extremely Inactive	Very Inactive	Inactive	Not Sure	Active	Very Active	Extremely Active	Total
Namibia's Climate Change Strategy and Action Plan	4 (3%)	11 (9%)	29 (23%)	50 (39%)	27 (21%)	6 (5%)	1 (1%)	128 (100)
National Policy on Climate Change for Namibia	5 (4%)	7 (6%)	20 (16%)	51 (38%)	32 (25%)	10 (8%)	3 (2%)	128 (100)
National Environmental Education and Education for Sustainable Development Policy	5 (4%)	9 (7%)	22 (17%)	38 (30%)	45 (35%)	8 (6%)	1 (1%)	128 (100)
The Nature Conservation Ordinance No. 4 of 1975	4 (3%)	7 (6%)	8 (6%)	46 (36%)	44 (34%)	15 (12%)	4 (3%)	128 (100)
The Communal Land Reform Act	3 (2%)	7 (6%)	14 (11%)	36 (28%)	47 (37%)	18 (14%)	3 (2%)	128 (100)
Namibia National Forest Policy	2 (2%)	8 (6%)	10 (8%)	36 (28%)	51 (40%)	17 (13%)	4 (3%)	128 (100)
Forestry Strategic Plan	4 (3%)	5 (4%)	15 (12%)	57 (45%)	36 (28%)	7 (6%)	4 (3%)	128 (100)
The Forest Act	2 (2%)	5 (4%)	9 (7%)	43 (34%)	45 (35%)	21 (16%)	3 (2%)	128 (100)

3.4. Effectiveness of the Policy Instruments

Our results further revealed the effectiveness of different policy instruments for climate change adaptation (Table 2). The results indicate that all the listed policy instruments rated effective to very effective. We discovered that the Communal Land Reform Act was the most effective policy instrument (n = 54, 42%), followed by the Forest Act (n = 51, 40%).

The Communal Land Reform Act is crucial for determining land use in rural areas. Forestry and agricultural activities in rural communities of Namibia must comply with the Communal Land Reform Act. The Communal Land Reform Act determines rural forestry ownership (private, communal, and state). Therefore, it plays a significant role in climate change adaptation in the mopane woodlands.

Furthermore, Namibia National Forest Policy (n = 35, 27%) and Forestry Strategic Plan (n = 35, 27%) were identified among the least effective policy instruments. Mopane woodlands consist of sparsely distributed vegetation mixed with mopane shrublands (Figure 1). Local communities predominantly practice agriculture for subsistence purposes, which has led to desertification in the area. These and possibly more factors have influenced the effectiveness of forestry legislative activities in the mopane woodlands.

Table 2. The effectiveness of the policy instruments for climate change adaptation in mopane woodlands in northern Namibia.

Policy Instruments	Extremely Ineffective	Very Ineffective	Ineffective	Not sure	Effective	Very Effective	Extremely Effective	Total
Namibia's Climate Change Strategy and Action Plan	4 (3%)	5 (4%)	23 (18%)	51 (40%)	37 (29%)	5 (4%)	3 (2%)	128 (100)
National Policy on Climate Change for Namibia	4 (3%)	4 (3%)	20 (16%)	49 (38%)	41 (32%)	9 (7%)	1 (1%)	128 (100)
National Environmental Education and Education for Sustainable Development Policy	4 (3.1%)	3 (2%)	24 (19%)	39 (31%)	43 (34%)	10 (8%)	5 (4%)	128 (100)
The Nature Conservation Ordinance No. 4 of 1975	4 (3%)	5 (4%)	14 (11%)	41 (32%)	44 (34%)	16 (13%)	4 (3%)	128 (100)
The Communal Land Reform Act	3 (2%)	2 (2%)	17 (13%)	36 (28%)	54 (42%)	14 (11%)	2 (2%)	128 (100)
Namibia National Forest Policy	3 (2.3%)	2 (2%)	14 (11%)	53 (41%)	35 (27%)	18 (14%)	3 (2%)	128 (100)
Forestry Strategic Plan	4 (3%)	4 (3%)	14 (11%)	58 (45%)	36 (28%)	10 (8%)	2 (2%)	128 (100)
The Forest Act	4 (3%)	2 (2%)	11 (9%)	45 (35%)	51 (40%)	13 (10%)	2 (2%)	128 (100)

3.5. Implementation Strategies

Strategies are essential for implementing policy instruments for climate change adaptation actions in mopane woodlands. Our results show the main implementation strategies for adaptation policy instruments (Table 3).

Table 3. Implementation strategies for policy instruments for climate change adaptation in mopane woodlands in northern Namibia.

Extremely Ineffective	Extremely Ineffective	Very Ineffective	Ineffective	Not Sure	Effective	Very Effective	Extremely Effective	Total
Minimizing deforestation	5 (4%)	8 (6%)	38 (28%)	35 (27%)	31 (24%)	8 (6%)	3 (2%)	128 (100)
Promoting tree planting	4 (3%)	8 (6%)	31 (24%)	33 (26%)	29 (23%)	17 (13%)	6 (5%)	128 (100)
Promoting agroforestry	4 (3%)	5 (4%)	36 (28%)	36 (28%)	35 (27%)	8 (6%)	4 (3%)	128 (100)
Reducing reliance on firewood for energy	10 (8%)	11 (9%)	53 (41%)	23 (18%)	21 (16%)	7 (6%)	3 (2%)	128 (100)
Promoting the use of alternative building materials	8 (6%)	3 (2%)	30 (23%)	32 (25%)	36 (28%)	16 (13%)	3 (2%)	128 (100)
Awareness creation in climate change and forest ecosystem services	6 (5%)	7 (6%)	22 (17%)	32 (25%)	45 (35%)	12 (9%)	4 (3%)	128 (100)
Research, development, and innovation	5 (4%)	2 (2%)	36 (28%)	35 (27%)	39 (31%)	8 (6%)	3 (2%)	128 (100)

Since climate change is a cross-cutting phenomenon, the implementation strategies that our survey discovered cover various sectors but predominantly stem from the forestry and agriculture sectors. Our results reveal that awareness creation was the most effective strategy (n = 45, 35%), followed by research, development, and innovation (n = 39, 31%) and promoting the use of alternative building materials (n = 36, 28%). Promoting tree planting (n = 29, 23%) and reducing reliance on firewood as a source of energy (n = 21, 16%) were listed among the least effective strategy for policy instruments for climate change adaptation. The most ineffective strategies included reducing reliance on firewood for energy (n = 53, 41%) and minimizing deforestation (n = 38, 28%).

3.6. Challenges

Implementing policy instruments for climate change adaptation in the mopane woodlands is faced with several challenges. Our results show some of our main challenges (Table 4).

Table 4. Challenges facing the implementation of policy instruments for climate change adaptation in mopane woodland in northern Namibia.

Challenges	Extremely Insignificant	Very Insignificant	Insignificant	Not Sure	Significant	Very Significant	Extremely Significant	Total
Dry climatic conditions	4 (3%)	5 (4%)	10 (8%)	36 (28%)	37 (29%)	28 (22%)	8 (6%)	128 (100)
High unemployment rates and poverty exert pressure on forest ecosystems	5 (4%)	8 (6%)	12 (10%)	18 (14%)	28 (22%)	34 (27%)	23 (18%)	128 (100)
High demands for land for agricultural practices	4 (3%)	4 (3%)	5 (4%)	19 (15%)	41 (32%)	29 (23%)	26 (20%)	128 (100)
Inadequate awareness creation in rural communities	5 (4%)	5 (4%)	15 (12%)	31 (24%)	34 (27%)	26 (20%)	12 (10%)	128 (100)
Limited research and poor information dissemination	5 (4%)	6 (5%)	9 (7%)	26 (20%)	30 (23%)	38 (30%)	14 (11%)	128 (100)
Lack of funds for climate change adaptation measures	9 (7%)	6 (5%)	4 (3%)	22 (17%)	30 (23%)	40 (31%)	17 (13%)	128 (100)
Inadequate law enforcement officials due to low government budget	6 (5%)	3 (2%)	15 (12%)	22 (17%)	23 (18%)	38 (30%)	21 (16%)	128 (100)

Our results showed that the most significant challenges included high demands for land for agricultural practices (n = 41, 32%) and a lack of funds for climate change adaptation measures (n = 40, 31%). We further discovered limited research, poor information dissemination (n = 38, 30%), and inadequate law enforcement officials due to the low government budget (n = 38, 30%) among the main challenges. In addition, insufficient awareness creation in rural communities (n = 34, 27%) and dry climatic conditions (n = 37, 29%) were listed among the significant challenges in implementing climate change adaptation measures in the mopane woodlands.

We noted that most of the challenges in this study are associated with administrative aspects of climate change policy instruments and forest ecosystems. Only dry conditions can be classified as a natural challenge that can be difficult to control. Therefore, there are plenty of opportunities to improve the implementation and effectiveness of various policy instruments to maximize their potential.

3.7. Possible Improvements

Regarding the status of policy instruments for climate change adaptation in the context of forest ecosystems, opportunities, and challenges faced, our results offer possible improvements to enhance the framework for such various instruments (Figure 5).

The most significant recommended improvement for climate change policy instruments was awareness creation (n = 55, 43%), followed by funds for adaptation and mitigation measures (n = 17, 14%), rural community participatory approach (n = 9, 7%), and research and development (n = 9, 7%). The least recommended strategies included minimized land clearing for agricultural practices (n = 3, 2%), improved implementation (n = 3, 2%), and monitoring and evaluation of the policy instruments (n = 1, 1%).

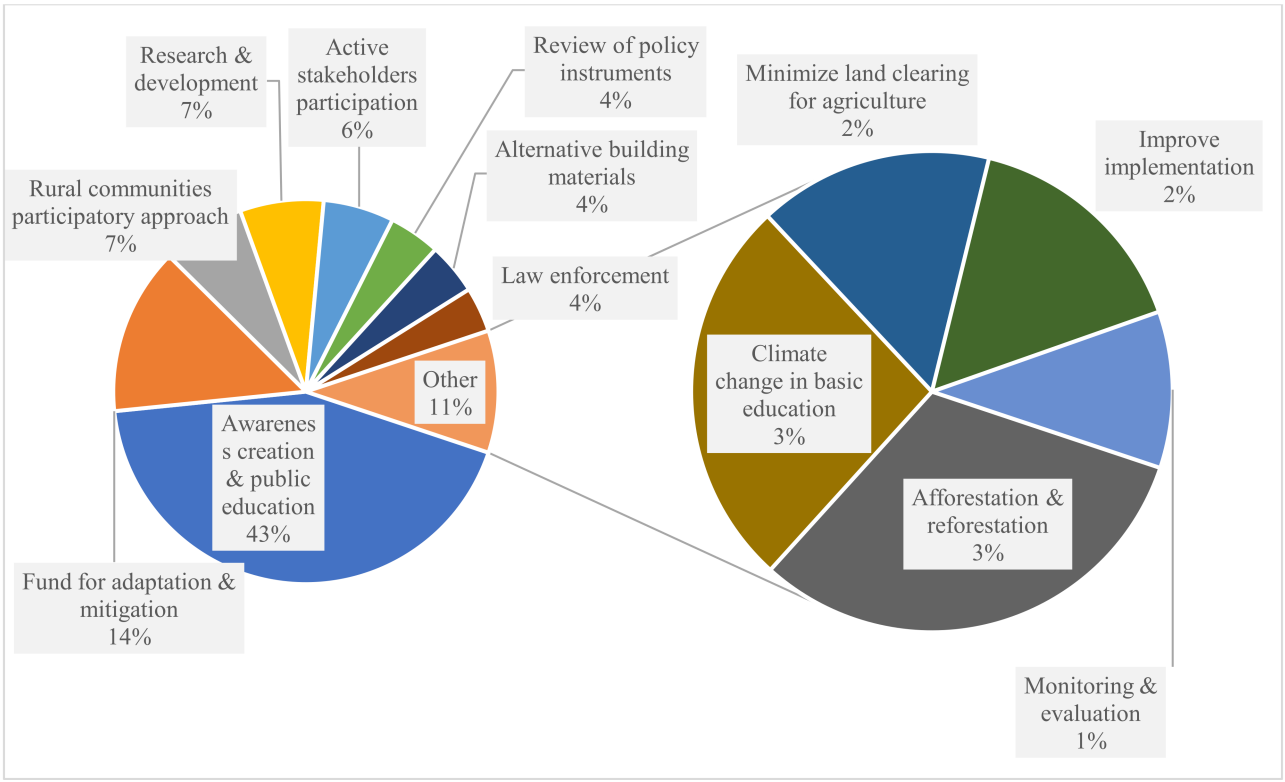

Figure 5. Possible improvements for policy instruments for climate change adaptation in mopane woodlands according to stakeholders from various sectors.

From the recommendations by our respondents, we can conclude that there are plenty of opportunities for integrated policy instruments to effectively contribute to climate change adaptation in rural communities of the mopane woodlands in northern Namibia. However, more emphasis should be on awareness creation about climate change, its impacts, and existing policy instruments. It is worth highlighting that awareness creation and information dissemination are enormous challenges (Table 4) that require funding. Thus, our respondents recommended that funding for climate change policy instruments needs improvement. In view of this, it was suggested that research and development need improvement.

The issue of climate change is cross-cutting. Therefore, improving policy instruments will benefit all affected sectors. We discovered that the status of the implementation of policy instruments, their collective effectiveness, challenges, and recommended improvements are interlinked.

4. Discussion

Although our results were based on the perception of multiple experts representing various sectors in addition to the local communities, it is concerning that most of them revealed a lack of knowledge about climate change (Figure 4) and its existing integrated policy instruments at the rural and national levels. Most of the respondents were educated with a bachelor's degree taking dominance in terms of the level of education. Even though not all the experts, stakeholders, and local communities have qualifications in forestry and climate change, their education level can be a powerful tool to implement climate change actions in mopane woodlands effectively.

Although rural communities in the mopane woodlands in northern Namibia depend on forest resources for their livelihood, escalating desertification has led to the dominance of agricultural practices, mainly subsistence. As a result, the Communal Land Reform Act, which administers land tenure, was rated the most effective policy instrument for

climate change adaptation (Table 2) in Northern Namibia's mopane woodlands. In addition, *C. mopane* is the most valuable in terms of utilization by local communities in the mopane woodlands [5]. Therefore, the Forest Act is important in governing the management and utilization of forest resources. In this case, the Forest Act, in alignment with principles for climate change adaptation, regulates access to forest resources, management of forest ecosystems, and utilization of forest resources in the mopane woodlands. As a result, it was identified among the most effective instruments in promoting climate change adaptation in *C. mopane* woodlands.

The Namibia National Forest Policy was rated the most active instrument along with the Communal Land Reform Act. Rural communities in the mopane woodlands depend on forest ecosystems and agriculture. Thus, these two policy instruments are critical in climate change adaptation in this area. However, Namibia's Climate Change Strategy and Action Plan was the only policy instrument rated inactive. Namibia's Climate Change Strategy and Action Plan is an implementation strategy for the National Policy on Climate Change for Namibia that was active between 2013–2020 [46].

Due to its natural ability to adapt to dry conditions, *C. mopane* is a tree species with high values for both socio-economic and biodiversity [30,31]. Therefore, the mopane woodlands play a critical role in carbon sequestration, supporting livelihood for rural communities, biodiversity, soil conservation, and forest ecosystem services in general [47]. However, mopane woodlands are constantly threatened by high demands for land for agriculture by local communities. Therefore, policy instruments for climate change adaptation in this area are essential. However, for the policy instruments to be effective in the mopane woodlands, various challenges, including a lack of communication [17], a lack of understanding/awareness of climate change, and exclusion of the rural communities from policy instrument formulation [7], need to be addressed.

Implementing policy instruments for climate change adaptation faces various challenges, ranging from natural conditions to legislation and human activities. Natural conditions, arid and erratic conditions, particularly in the mopane woodlands [34,48,49], influence vegetation cover and, consequently, forest ecosystems in the area. Thus, this situation has influenced the effectiveness of policy instruments in the area.

Although there are various policy instruments for adaptation to climate change, policymakers, implementation institutions, and stakeholders do not appear to feel the urgency to prioritize policy instruments in the less forested mopane woodlands. However, it is essential to point out that this attitude is the critical driver of the lack of awareness of climate change and its policy instruments for adaptation in rural areas. Our results agree with previous research that local communities have a limited understanding of the phenomenon in rural areas [6,7]. This situation is concerning because local communities in rural areas are the most vulnerable to the impacts of climate change and will continue to degrade forest ecosystems for their livelihood.

5. Conclusions

A general understanding of the impacts of climate change is that they are severe in rural communities [45] because local communities live close to forest ecosystems [4,5]. In other words, they depend on forest resources for their livelihood. At the same time, rural communities tend to exert enormous pressure on forest ecosystems, which eventually affects forest ecosystem services and their role in climate change mitigation and adaptation, for example, carbon sequestration. Thus, ensuring the effectiveness of policy instruments for climate change in rural communities is essential in building resilience and adaptation to the impacts of climate change in these vulnerable communities. However, this subject did not receive sufficient attention from research in various regions, including southern Africa, especially in the mopane woodlands in northern Namibia.

In the present study, we conclude that the limited understanding of climate change, its impacts, dry conditions, and lack of funds for adaptation measures are significant challenges hampering policy instruments for adaptation. As highlighted earlier, *C. mopane*

ecosystems support livelihood for the rural communities in mopane woodlands in northern Namibia while contributing to biodiversity conservation. However, there is a concern that implementing policy instruments for climate change adaptation will be challenging for local communities in the mopane woodlands due to the lack of general knowledge about climate change. Therefore, an emphasis on altering their reliance on forest resources for their livelihood by improving their awareness of the impacts of climate change is essential.

Finally, our study discovered that there are many opportunities to strengthen policy instruments for climate change adaptation in the rural communities of Namibia. However, there is a need for awareness creation for local communities and multiple stakeholders in implementing policy instruments for climate change adaptation actions in mopane woodlands. It is also essential to incorporate climate change topics in primary education to equip future generations with the necessary knowledge of climate change adaptation actions.

Further research could explore adaptation activities at the local level that are not visible through national policies and how they can be improved. Finally, our study identifies a need for future research, including physiological characteristics of the *C. mopane* in terms of adaptation and mitigation to climate change, as well as the implementation of policy instruments for climate change adaptation in promoting specific forest ecosystem services in mopane woodlands.

Limitations and Prospects for Future Research

One of the main obstacles in researching policy instruments for climate change adaptation in forest ecosystems in rural communities is the lack of data. As a result, our study employed an online survey involving multiple players and stakeholders. However, challenges such as the limited understanding of climate change among local communities in the study area and their limited access to the internet influenced their involvement in the survey. In other words, only local community members who have access to the internet were able to participate in this study. Although implementing policy instruments is a national approach, we limited our study to the mopane woodlands in northern Namibia, emphasizing the Omusati and Kunene regions due to the higher concentration of *C. mopane* in this area than elsewhere in the country.

Additionally, most of our respondents revealed a limited understanding of implementing policy instruments for climate change adaptation. This situation has influenced their subsequent answers in the survey. Therefore, we recommend future research to evaluate the framework, strategies, effectiveness, and challenges faced in implementing the National Policy on Climate Change for Namibia, which is the catalyst for climate change adaptation and mitigation on the national level in the context of forest ecosystems.

Author Contributions: Conceptualization A.N. and M.H.; methodology, A.N.; software, A.N.; validation, M.H.; formal analysis, A.N.; investigation, A.N. and M.H.; resources, A.N. and M.H.; data curation, A.N.; writing—original draft preparation, A.N.; writing—review and editing, A.N.; visualization, A.N.; supervision, M.H.; project administration, M.H.; funding acquisition, M.H. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the ethical conduct of the Ministry of Environment, Forestry and Tourism, Namibia, and approved by the Directorate of Forestry of the Ministry of Environment, Forestry and Tourism dated 18 August 2022.

Informed Consent Statement: Written informed consent has been obtained from the Ministry of Environment, Forestry, and Tourism of Namibia to publish this paper.

Data Availability Statement: All data relevant to the study are included in the article.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

SURVEY ITEMS

SECTION A: DEMOGRAPHIC INFORMATION

INSTRUCTION: Please put a cross (x) against the appropriate box to specify your choice.

1. Institution represented

Public ☐
Private ☐
Academic/research ☐
Local community ☐

2. Length in service at the institution/length of stay in the area

Less than 1 year ☐
1-5 years ☐
6-10 years ☐
10+ years ☐

3. Educational qualifications

None ☐
Grade 12 ☐
Diploma ☐
Bachelor's degree ☐
Master's degree ☐
Doctorate Degree ☐

4. Position in the institution (for institutions only)

Top management ☐
Middle management ☐
Lower management ☐
Teaching staff/researcher ☐

SECTION B: POLICY INSTRUMENTS FOR CLIMATE CHANGE

1. **Do you have any knowledge or experience in implementing policy instruments for climate change mitigation and adaptation in mopane woodlands in northern Namibia?**

Very experienced ☐
Good knowledge ☐
Limited knowledge ☐
No knowledge at all ☐

2. **How do you rate the implementation of the following policy instruments for climate change mitigation and adaptation measures in mopane woodlands in north-central Namibia?**

Policy instruments	Extremely inactive	Very inactive	Inactive	Active	Very active	Extremely active
Namibia's Climate Change Strategy and Action Plan						
National Policy on Climate Change for Namibia						
National Environmental Education and Education for Sustainable Development Policy						
The Nature Conservation Ordinance No. 4 of 1975						
The Communal Land Reform Act						
Namibia National Forest Policy						
Forestry Strategic Plan						
The Forest Act						

3. **How do you rate the strategies used in the implementation of policy instruments to promote climate change adaptation and mitigation measures in mopane woodlands?**

Policy instruments	Extremely ineffective	Very ineffective	Ineffective	Effective	Very effective	Extremely effective
Minimizing deforestation						
Promoting tree planting						
Promoting agroforestry						
Reducing reliance on firewood as a source of energy						
Promoting alternative building materials						
Awareness creation in climate change and forest ecosystem services						
Research, development, and innovation						

4. How do you rate the effectiveness of the following policy instruments for climate change mitigation and adaptation measures in mopane woodlands?

Policy instruments	Extremely ineffective	Very ineffective	Ineffective	Effective	Very effective	Extremely effective
Namibia's Climate Change Strategy and Action Plan						
National Policy on Climate Change for Namibia						
National Environmental Education and Education for Sustainable Development Policy						
The Nature Conservation Ordinance No. 4 of 1975						
The Communal Land Reform Act						
Namibia National Forest Policy						
Forestry Strategic Plan						
The Forest Act						

5. How do you rate the impacts of the challenges below on the implementation of policy instruments for climate change mitigation and adaptation measures in mopane woodlands in northern Namibia?

Policy instruments	Extremely insignificant	Very insignificant	insignificant	Significant	Very significant	Extremely significant
Harsh and dry climatic conditions						
High unemployment rates and poverty exert pressure on forest ecosystems						
High population growth rates/high demands for land for crop cultivation						
High demands for grazing land						
Low awareness about the impacts of climate change among local communities						
Limited research and poor information dissemination						
Lack of funds for climate change mitigation and adaptation measures						
Limited law enforcement officials due to low government budget						
Other (specify)						

6. What recommendations would you make to improve the implementation of policy instruments for climate change mitigation and adaptation measures in mopane woodlands in northern Namibia?

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.....

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THANK YOU FOR YOUR TIME.

Appendix B

DATA

Table A1. Educational level.

Educational Level	Frequency (*n*)	Percentage (%)	Valid Percentage (%)	Cumulative Percent (%)
Grade 12	14	9.2	10.9	10.9
Certificate	2	1.3	1.6	12.5
Diploma	21	13.8	16.4	28.9
Bachelor's degree	66	43.4	51.6	80.5
Master's degree	19	12.5	14.8	95.3
Doctoral degree	6	3.9	4.7	100
Total	128	84.2	100	

Table A2. Knowledge about climate change policy instruments.

Knowledge about Climate Change Policy Instruments	Frequency	Percentage (%)
Experienced	3	2
Excellent knowledge	11	9
Good knowledge	48	38
Limited knowledge	47	37
No knowledge	19	15
TOTAL	128	100

Table A3. The implementation of policy instruments.

Policy Instruments	Extremely Inactive	Very Inactive	Inactive	Not Sure	Active	Very Active	Extremely Active	Total
Namibia's Climate Change Strategy and Action Plan	4 (3.1%)	11 (8.6%)	29 (22.7%)	50 (39.1%)	27 (21.1%)	6 (4.7%)	1 (0.8%)	128 (100)
National Policy on Climate Change for Namibia	5 (3.9%)	7 (5.5%)	20 (15.6%)	51 (39.8%)	32 (25.0%)	10 (7.8%)	3 (2.3%)	128 (100)
National Environmental Education and Education for Sustainable Development Policy	5 (3.9%)	9 (7.0%)	22 (17.2%)	38 (29.7%)	45 (35.2%)	8 (6.3%)	1 (0.8%)	128 (100)
The Nature Conservation Ordinance No. 4 of 1975	4 (3.1%)	7 (5.5%)	8 (6.3%)	46 (35.9%)	44 (34.4%)	15 (11.7%)	4 (3.1%)	128 (100)
The Communal Land Reform Act	3 (2.3%)	7 (5.5%)	14 (10.9%)	36 (28.1%)	47 (36.7%)	18 (14.1%)	3 (2.3%)	128 (100)
Namibia National Forest Policy	2 (1.6%)	8 (6.3%)	10 (7.8%)	36 (28.1%)	51 (39.8%)	17 (13.3%)	4 (3.1%)	128 (100)
Forestry Strategic Plan	4 (3.1%)	5 (3.9%)	15 (11.7%)	57 (44.5%)	36 (28.1%)	7 (5.5%)	4 (3.1%)	128 (100)
The Forest Act	2 (1.6%)	5 (3.9%)	9 (7.0%)	43 (33.6%)	45 (35.2%)	21 (16.4%)	3 (2.3%)	128 (100)

Table A4. Effectiveness of the policy instruments.

Policy Instruments	Extremely Ineffective	Very Ineffective	Ineffective	Not Sure	Effective	Very Effective	Extremely Effective	Total
Namibia's Climate Change Strategy and Action Plan	4 (3.1%)	5 (3.9%)	23 (18.0%)	51 (39.8%)	37 (28.9%)	5 (3.9%)	3 (2.3%)	128 (100)
National Policy on Climate Change for Namibia	4 (3.1%)	4 (3.1%)	20 (15.6%)	49 (38.3%)	41 (32.0%)	9 (7.0%)	1 (0.8%)	128 (100)
National Environmental Education and Education for Sustainable Development Policy	4 (3.1%)	3 (2.3%)	24 (18.8%)	39 (30.5%)	43 (33.6%)	10 (7.8%)	5 (3.9%)	128 (100)
The Nature Conservation Ordinance No. 4 of 1975	4 (3.1%)	5 (3.9%)	14 (10.9%)	41 (32.0%)	44 (34.4%)	16 (12.5%)	4 (3.1%)	128 (100)
The Communal Land Reform Act	3 (2.3%)	2 (1.6%)	17 (13.3%)	36 (28.1%)	54 (42.2%)	14 (10.9%)	2 (1.6%)	128 (100)
Namibia National Forest Policy	3 (2.3%)	2 (1.6%)	14 (10.9%)	53 (41.4%)	35 (27.3%)	18 (14.1%)	3 (2.3%)	128 (100)
Forestry Strategic Plan	4 (3.1%)	4 (3.1%)	14 (10.9%)	58 (45.3%)	36 (28.1%)	10 (7.8%)	2 (1.6%)	128 (100)
The Forest Act	4 (3.1%)	2 (1.6%)	11 (8.6%)	45 (35.2%)	51 (39.8%)	13 (10.2%)	2 (1.6%)	128 (100)

Table A5. Implementation strategies.

Strategies	Extremely Ineffective	Very Ineffective	Ineffective	Not Sure	Effective	Very Effective	Extremely Effective	Total
Minimizing deforestation	5 (3.9%)	8 (6.3%)	38 (29.7%)	35 (27.3%)	31 (24.2%)	8 (6.3%)	3 (2.3%)	128 (100)
Promoting tree planting	4 (3.1%)	8 (6.3%)	31 (24.2%)	33 (25.8%)	29 (22.7%)	17 (13.3%	6 (4.7%)	128 (100)
Promoting agroforestry	4 (3.1%)	5 (3.9%)	36 (28.1%)	36 (28.1%)	35 (27.3%)	8 (6.3%)	4 (3.1%)	128 (100)
Reducing reliance on firewood as a source of energy	10 (7.8%)	11 (8.6%)	53 (41.4%)	23 (18.0%)	21 (16.4%)	7 (5.5%)	3 (2.3%)	128 (100)
Promoting alternative building materials	8 (6.3%)	3 (2.3%)	30 (23.4%)	32 (25.0%)	36 (28.1%)	16 (12.5%)	3 (2.3%)	128 (100)
Awareness creation in climate change and forest ecosystem services	6 (4.7%)	7 (5.5%)	22 (17.2%)	32 (25.0%)	45 (35.2%)	12 (9.4%)	4 (3.1%)	128 (100)
Research, development, and innovation	5 (3.9%)	2 (1.6%)	36 (28.1%)	35 (27.3%)	39 (30.5%)	8 (6.3%)	3 (2.3%)	128 (100)

Table A6. Challenges.

Challenges	Extremely Insignificant	Very Insignificant	Insignificant	Not Sure	Significant	Very Significant	Extremely Significant	Total
Harsh and dry climatic conditions	4 (3.1%)	5 (3.9%)	10 (7.8%)	36 (28.1%)	37 (28.9%)	28 (21.9%)	8 (6.3%)	128 (100)
High unemployment rates and poverty exert pressure on forest ecosystems	5 (3.9%)	8 (6.3%)	12 (9.4%)	18 (14.1%)	28 (21.9%)	34 (26.6%)	23 (18.0%)	128 (100)
High demands for grazing land	4 (3.1%)	4 (3.1%)	5 (3.9%)	19 (14.8%)	41 (32.0%)	29 (22.7%)	26 (20.3%)	128 (100)
Low awareness about the impacts of climate change among local communities	5 (3.9%)	5 (3.9%)	15 (11.7%)	31 (24.2%)	34 (26.6%)	26 (20.3%)	12 (9.4%)	128 (100)

Table A6. *Cont.*

Challenges	Extremely Insignificant	Very Insignificant	Insignificant	Not Sure	Significant	Very Significant	Extremely Significant	Total
Limited research and poor information dissemination	5 (3.9%)	6 (4.7%)	9 (7.0%)	26 (20.3%)	30 (23.4%)	38 (29.7%)	14 (10.9%)	128 (100)
Lack of funds for climate change mitigation and adaptation measures	9 (7.0%)	6 (4.7%)	4 (3.1%)	22 (17.2%)	30 (23.4%)	40 (31.3%)	17 (13.3%)	128 (100)
Limited law enforcement officials due to low government budget	6 (4.7%)	3 (2.3%)	15 (11.7%)	22 (17.2%)	23 (18.0%)	38 (29.7%)	21 (16.4%)	128 (100)

Table A7. Possible improvements.

Recommendations	Frequency	Percentage (%)
Awareness creation & public education	80	43%
Fund for adaptation & mitigation	26	14%
Rural communities' participatory approach	13	7%
Research & development	13	7%
Active stakeholders' participation	11	6%
Review of policy instruments	8	4%
Alternative building materials	8	4%
Law enforcement	7	4%
Afforestation & reforestation	6	3%
Climate change in basic education	5	3%
Minimize land clearing for agriculture	3	2%
Improve implementation	3	2%
Monitoring & evaluation	2	1%
Total	185	100%

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Forest Ecosystem Services-Based Adaptation Actions Supported by the National Policy on Climate Change for Namibia: Effectiveness, Indicators, and Challenges

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Abstract: Forest ecosystem services are crucial in adaptation, mitigation, and increasing climate change resilience. Although most climate change policies promote adaptation actions in forest ecosystem services, there are limited studies focusing on the forest ecosystem services-based adaptation actions supported by the National Policy on Climate Change for Namibia (NPCC). This paper aims to assess the effectiveness of forestry adaptation actions of the NPCC. An independent *t*-test for non-categorical data was used for the statistical analysis to compare mean scores of the implementation effectiveness of adaptation actions and challenges before and after the NPCC implementation, according to the perceptions of forestry and climate change cross-sectoral experts. A *p*-value less than 0.05 ($p < 0.05$) was designated as the statistical significance. Adaptation actions in forest ecosystem services were significantly effective after the introduction of the NPCC. Biodiversity and carbon sequestration were significantly effective after the introduction of the NPCC. The most significant challenges identified were the lack of awareness, which affected adaptation actions before and after the policy. Afforestation, reforestation, awareness, and forestry research need strengthening to improve the effectiveness of the NPCC. Although our results showed that adaptation actions supported by the NPCC were generally effective after the introduction of the policy, we identified some implementation areas that require strengthening, mainly through research, to help in sound decision-making. We, therefore, recommend future research to analyze the strengths, weaknesses, threats, and opportunities (SWOT) of the NPCC and consequently design/propose a framework for forest ecosystem services-based adaptation actions in the policy to improve adaptation actions.

Keywords: biodiversity; carbon sequestration; soil conservation; socio-economic benefits; Southern Africa; local communities; vulnerability

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1. Introduction

All actions toward climate change adaptation at all levels comply with the Paris Agreement, which aims to reach an international goal of adaptation to climate change [1,2]. This goal seeks to ensure an adequate adaptation response to the global temperature goal, enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change, ultimately contributing to sustainable development [2]. Hence, achieving an adequate adaptation response to the impacts of climate change will require continuous efforts from integrated policy instruments at global, regional, and national levels [3].

On the national level, most countries formulated cross-sectoral policy instruments and strategic national-level actions to promote climate-friendly forestry activities while discouraging climate-adverse ones [4]. For example, China adopted a low-carbon city pilot policy, which was evaluated to effectively reduce carbon emissions while negatively affecting urban land use efficiency [5]. One of the main actions is restoring the vulnerable forests to regain vitality and vigor while safeguarding the local livelihood options [6].

Carbon sequestration, watershed services, soil conservation, biodiversity, and recreational and cultural values [6,7] are part of the primary forest ecosystem services that play a critical role in climate change adaptation and mitigation [8,9]. Climate change affects these forest ecosystem services differently [10]. For example, climate change has a direct and indirect influence on forest biodiversity across the globe [11]. As a result, political support is essential for the systematic integration of ecosystem management into climate change adaptation and policy frameworks and practices [12]. In addition, ecosystem-based climate change adaptation is now recognized by international agreements and policy instruments [13].

The implementation of climate change adaptation policies can be nature-based or technical. However, in the context of European forest ecosystems, nature-based policies, including biodiversity, ecosystem services, and human well-being, were more cost-effective and better at coping with the ethical and inequality issues associated with the distributional impacts of the policy actions [14]. Although ecosystem-based policies might differ in terms of the ecosystem services they focus on, they must be coherent [15].

Namibia is the driest country in sub-Saharan Africa [16]. The country is characterized by high climatic variability in the form of persistent droughts, unpredictable and variable rainfall patterns, variability in temperatures, and scarcity of water [17,18]. The climate in Namibia is typically hot and dry, with an average annual temperature of 18–22 °C [19]. As a result, the country is significantly vulnerable to the impacts of climate change [20,21]. In addition to its highly variable climate, Namibia's acute vulnerability to climate change is also influenced by the high reliance of local livelihoods and important economic sectors on climate-related natural resources such as forest ecosystem services [22–26].

The unique climate conditions of Namibia and its high vulnerability to climate change call for robust policies to guide action on climate change in Namibia at the national level [18]. Hence, the NPCC was adopted in 2011 [27]. The National Climate Change Committee (NCCC) oversees the implementation of the NPCC and comprises representatives of various ministries and other stakeholders, such as the private sector and NGOs [27,28]. The NCCC is chaired by the Ministry of Environment, Forestry, and Tourism (MEFT). The NPCC provides an institutional framework and overarching national strategy for developing, implementing, monitoring, and evaluating climate change mitigation and adaptation activities in Namibia [28]. The NPCC aims to lower Namibia's vulnerability to climate change to contribute to sustainable development in line with Namibia's Vision 2030 [29].

Since climate change is a complex global problem [30], the NPCC was designed to manage climate change responses in a way that recognizes national developmental goals and promotes the integration and coordination of programs of various sector organizations [16]. While climate change issues have been mainstreamed across the country's key sectors, such as agriculture, water resources, tourism, and health, these policies do not include concrete actions to mitigate climate change risks [27]. Hence, Namibia is currently developing its first Nationally Appropriate Mitigation Action (NAMA) and is working on its National Adaptation Plan (NAP) to better guide the country on its way to mitigating and adapting to climate change [27].

Forest ecosystem services play a crucial role in adaptation, mitigation, and increasing resilience to climate change [31]. Forest ecosystem services such as carbon sequestration and biodiversity all contribute to climate change adaptation [13]. Due to its dry conditions, temperature variability, and erratic rainfalls [17,18], Namibia's forests are characterized by savannah woodlands with a combination of trees and shrubs [32]. Despite the status of the forests of Namibia, the question that remains not answered is whether adaptation actions supported by the NPCC were framed in such a way that they promote resilience, adaptation, and mitigation in the context of forest ecosystem services at the national level.

In the context of forest ecosystem services, the focus area of the NPCC encompasses afforestation, reforestation, agroforestry, commercial forestry, community-based forest management, and woodland management [16]. Although continued efforts to increase the country's resilience capabilities and strengthen the country's social and economic

structures against vulnerability take forestry into account as one of the country's most vulnerable sectors [27], there is limited scientific knowledge about specific adaptation actions focusing on Namibia's unique forest ecosystem services within the framework of the NPCC. Secondly, there is no clear scientific evidence of the effectiveness and challenges facing the existing adaptation actions supported by the NPCC in forest ecosystem services. Furthermore, the factors influencing the implementation of the NPCC adaptation actions in forestry have not yet been investigated.

Therefore, it is unclear whether the existing NPCC's measures for climate change adaptation in forest ecosystem services at the national level are adequate. Hence, it is difficult for policymakers to formulate policy actions that address climate change adaptation adequately through forest ecosystem services. Thus, it is crucial to establish a sound understanding in this area because when forest ecosystem managers and policymakers are well-informed, they can benefit from policy actions to support climate change mitigation and adaptation actions [33].

This paper aims to assess the effectiveness of forest ecosystem services-based adaptation actions supported by the NPCC. To achieve the paper's goal, we compare the current adaptation actions with the measures that were implemented before the policy's introduction. Finally, we propose improvements to effectively implement the NPCC and strengthen the adaptive capacity of all types of forest ecosystem services in Namibia.

2. Methods

2.1. Study Area

The study focused on Namibia, a developing country situated in south-western Africa, between latitude 17° S and 29° S and longitude 11° E and 26° E. It shares borders with Angola to the north, South Africa to the south, Botswana to the east, and Zambia to the northeast [19,27]. Namibia is a sparsely populated country with a population of 2.5 million and covers a total surface area of 824,292 km^2 [34].

In addition, its dry conditions significantly influence forest cover [26,35]. It is estimated that forests and woodlands in Namibia cover approximately 20% (about 53 million ha) of the total surface area [36]. Various factors, such as land use, including crop cultivation, affect forest cover in Namibia. In addition, vegetation types are distributed across the country according to climate variability (Figure 1).

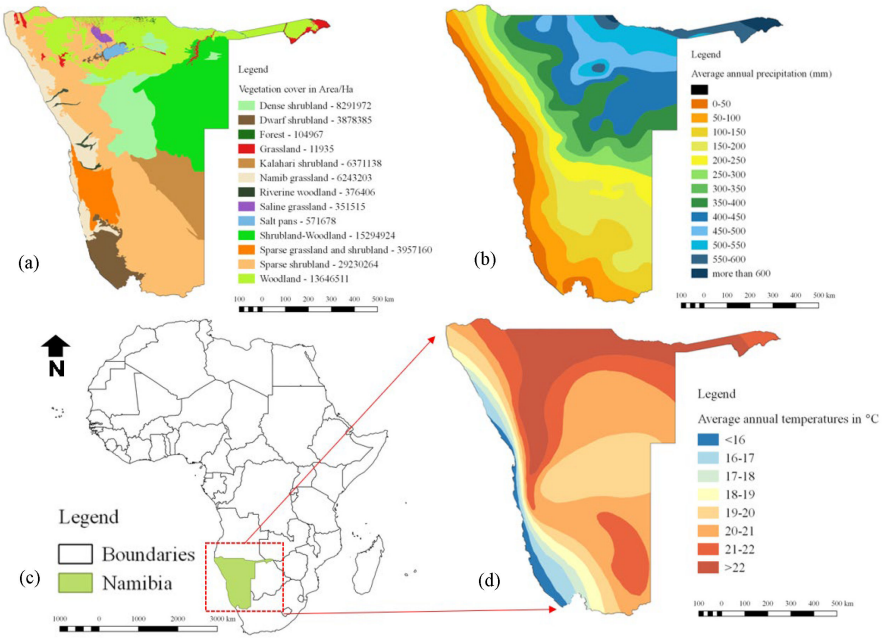

Figure 1. A map of the study area (Namibia) and key descriptions, (**a**) vegetation types, (**b**) precipitation variability, (**c**) the location of Namibia on the map of Africa, and (**d**) temperature variability.

Namibia is between two deserts; the Namib Desert stretches along its west coast, and the Kalahari Desert borders its eastern and southern neighbors, Botswana and South Africa [26]. Due to its geographical location, Namibia's three main vegetation types can be classified as woodlands, savannas (grass cover, trees, and shrubs), and deserts (Namib grassland) [37,38]. Therefore, it is worth noting that climate variability and the nature of vegetation types are the main attributes influencing the level of adaptation actions in forest ecosystems in Namibia.

2.2. Survey

To achieve the aim of the study, we purposively collected data from forestry and climate change experts representing different institutions, including public, private, and government projects, academics, and researchers. We selected specific institutions based on their involvement in climate change adaptation and related activities, mainly research and forest ecosystems management. Since we focused on the practical implementation of the policy, which required a deeper understanding of the policy, we excluded ordinary citizens. Ordinary citizens lack practical understanding of the implementation of policy instruments for climate change adaptation actions [39].

From public institutions, we focused on senior employees, for example, in the Directorate of Forestry (DoF), which is the custodian of forest ecosystem services. We also involved senior employees from the Ministry of Agriculture, Water and Land Reform (MAWLR). Agriculture and forestry have various integrated management approaches that influence forest management practices in Namibia. We also included multiple projects under the Climate Unit of MEFT, such as the Namibia Integrated Landscape Approach for Enhancing Livelihoods and Environmental Governance to Eradicate Poverty (NILALEG), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the National Communications, Biannual update reports, and Greenhouse gas inventory, Capacity-building Initiative for Transparency Stakeholder engagement (CBIT) and Climate Promise and the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL).

For academic institutions, we focused on the lecturers and researchers from the two prominent local universities, namely the departments of environmental sciences at the University of Namibia (UNAM) and the department of agriculture and natural resource sciences at the Namibia University of Science and Technology (NUST).

Since we assessed the effectiveness of adaptation actions before (2001–2010) and after the policy's launch (2011–2021), there were few experts with relevant experience in implementing climate change adaptation approaches in forestry. As mentioned earlier, Namibia is a sparsely populated country with sparsely forested land. As a result, we purposively shared the survey link with 40 cross-sectional experts. However, we could only collect results from 36 cross-sectoral experts, translating into a 90% response rate.

2.3. Data Collection

We administered the questionnaire (Appendix A) to the experts from 27 August 2022 to 30 September 2022, which accounts for 35 days of data collection, including weekends and public holidays. We shared the link for an online semi-structured questionnaire (Survio 2022 version) with target respondents via email, WhatsApp, and LinkedIn. We used these platforms because they are user-friendly, cheap, and commonly used by most professionals daily. We employed an online questionnaire due to its attributes, such that it is less costly, less time-consuming, flexible, and convenient to complete, especially for senior experts occupying busy offices.

Since most of the experts hold higher positions with busy schedules, we made several follow-ups to remind them to participate in the survey. We strategically sent reminder alerts every Monday and every Friday of the week during the survey period. A pre-test survey was conducted with two respondents to ensure the relevancy and accuracy of the questions before the actual data collection.

2.4. Statistical Analysis

We used the independent *t*-test for non-categorical data for the statistical analysis to compare mean scores of the implementation effectiveness, actions, and challenges before and after the NPCC implementation, according to the expert's perceptions (Appendix B). We designated a *p*-value less than 0.05 ($p < 0.05$) as the statistical significance. We performed all the analysis using IBM SPSS version 28 (IBM Corp. Armonk, NY, USA).

The independent samples *t*-test can be represented using the functions below:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

with

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

where

$\overline{x}_1$ = Mean of first sample
$\overline{x}_2$ = Mean of second sample
n_1 = Sample size (i.e., number of observations) of first sample
n_2 = Sample size (i.e., number of observations) of second sample
s_1 = Standard deviation of first sample
s_2 = Standard deviation of second sample
s_p = Pooled standard deviation

As mentioned earlier, our analysis focused on 10 time series before and after the introduction of the NPCC. That is, 10 years (2001–2010) before the policy's launch and 10 years after (2012–2021). We excluded the year 2011 because the policy's effects were most likely not evident in the first year of its implementation. Second, to establish the impact of the temporal implementation status of the policy on the adaptive capacity of forest ecosystem services, we computed an independent *t*-test to compare the overall adaptation levels.

2.5. Qualitative Analysis

For qualitative analysis, we used ATLAS.ti Scientific Software Development GmbH version 22.2.4 (Berlin, Germany) to code and organize qualitative data. Qualitative data were used to explore the experts' perceptions about possible improvements for the implementation actions of the NPCC. Qualitative data were coded according to relevant themes (codes) derived from the proposed revisions for the NPCC.

3. Results

3.1. Effectiveness

Forest ecosystem services manifest primarily in seven services (Table 1). Since climate change affects each type of forest ecosystem in different ways [10], our assessments for the effectiveness of adaptation actions were based on the main forest ecosystems, namely biodiversity, carbon sequestration, soil conservation, socio-economic benefits, recreational and cultural values, watershed services, and high conservation values.

Our results showed that adaptation actions in forest ecosystem services, namely biodiversity (4.36 ± 1.52), carbon sequestration (3.06 ± 1.35), soil conservation (3.39 ± 1.29), and socio-economic benefits (3.44 ± 1.34), were more effective after the NPC. Notably, adaptation actions were significantly higher in biodiversity than in the rest of the forest ecosystem services. In other words, biodiversity's mean effectiveness score after NPCC (4.36 ± 1.52) was significantly higher than before (3.11 ± 0.92) ($p < 0.001$). Similarly, the mean effectiveness score in carbon sequestration was also higher after NPCC (3.06 ± 1.35) than before (2.75 ± 1.34). Although the rest of the forest ecosystem services are not

statistically significantly different, it can be said that adaptation actions after NPCC were more effective than before.

Table 1. Effectiveness scores of the implemented adaptation actions by forest ecosystem services before and after NPCC [1].

Forest Ecosystem Services	Before NPCC (N = 36)	After NPCC (N = 36)	*p*-Value [2]
Biodiversity	3.11 ± 0.92	4.36 ± 1.52	<0.001
Carbon sequestration	2.75 ± 1.34	3.06 ± 1.35	0.338
Soil conservation	3.08 ± 1.32	3.39 ± 1.29	0.324
Socio-economic benefits	3.25 ± 1.20	3.44 ± 1.34	0.519
Recreational and cultural values	3.72 ± 1.09	3.39 ± 1.34	0.249
Watershed services	3.31 ± 0.89	3.17 ± 1.23	0.585
High conservation values	3.56 ± 1.40	3.14 ± 1.25	0.187

[1] Data are presented as mean ± standard deviation (sd); independent *t*-test was applied to compare mean scores before and after NPCC implementation. [2] Significantly different at $p < 0.05$.

3.2. Adaptation Actions Indicators

We established indicators for adaptation actions to assess the effectiveness of forest ecosystems before and after the NPCC (Table 2). Our assessments focused on the main adaptation action indicators supported by the policy.

Table 2. Indicators of actions scores of the implemented policy before and after NPCC [1].

Adaptation Action Indicators	Before NPCC (N = 36)	After NPCC (N = 36)	*p*-Value [2]
Afforestation and reforestation	3.17 ± 1.56	3.33 ± 1.69	0.665
Law enforcement	3.33 ± 1.51	3.61 ± 1.63	0.455
Altering local communities' reliance on forest resources	3.42 ± 1.44	3.56 ± 1.59	0.699
Funding adaptation activities	3.11 ± 1.58	3.53 ± 1.42	0.244
Forestry research	3.17 ± 1.63	3.28 ± 1.60	0.771
Conservation of ecosystem services critically threatened by climate change	30.6 ± 1.41	3.53 ± 1.42	0.162
Stakeholders' collaboration	2.94 ± 1.64	3.53 ± 1.40	0.109

[1] Data are presented as mean ± sd; independent *t*-test was applied to compare mean scores before and after NPCC implementation. [2] Significantly different at $p < 0.05$.

There was no statistically significant difference among the indicators of adaptation actions before and after the NPCC. However, all the adaptation actions showed higher mean effectiveness scores after the NPCC. Law enforcement (3.61 ± 1.63) and altering local communities' reliance on forest resources (3.56 ± 1.59) were the most effective adaptation action indicators after the introduction of the NPCC. Conversely, afforestation and reforestation (3.33 ± 1.69) and forestry research (3.28 ± 1.60) were also effective after the NPCC's launch. However, these two adaptation actions showed the lowest effectiveness scores after the NPCC.

3.3. Challenges

There are several challenges facing implementing the adaptation actions to climate change supported by the NPCC in forest ecosystem services. In this regard, our assessments focused on the main challenges, such as lack of awareness, high demands for agricultural land, limited research, adverse weather conditions, poverty in rural areas, lack of funding options, and poor stakeholders' collaboration (Figure 2).

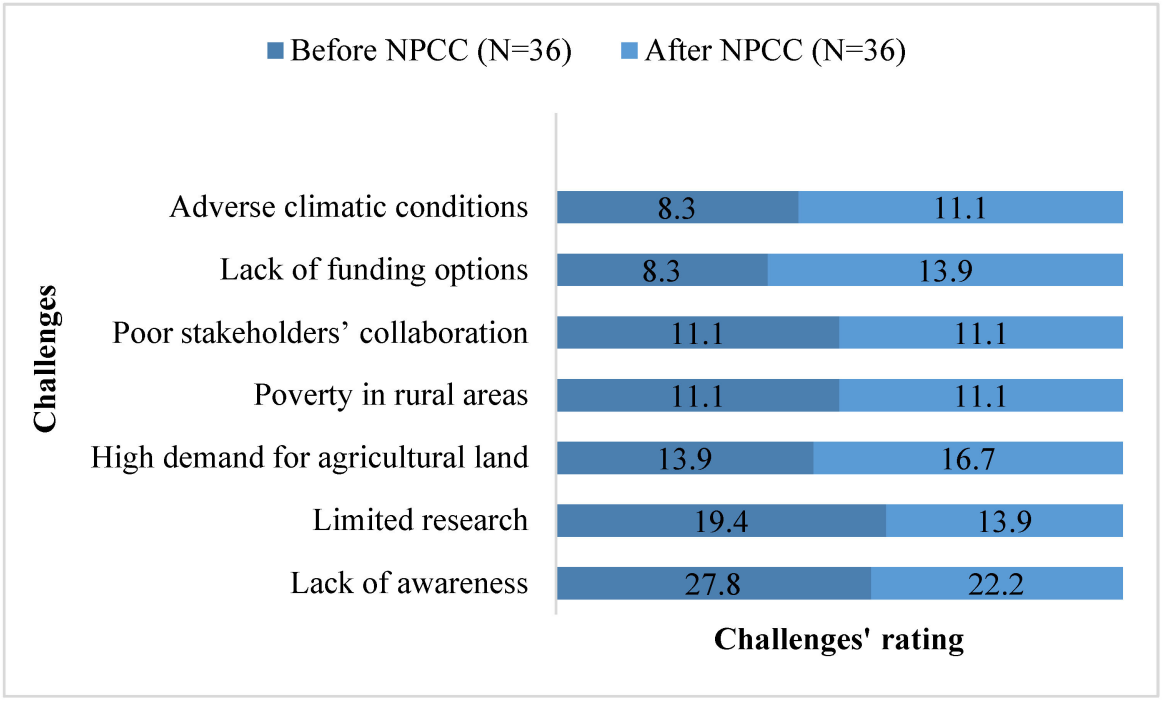

Figure 2. Challenges in the implementation of adaptation actions before and after the NPCC. Challenges' ratings are presented as %.

The most significant challenges were the lack of awareness (27.8% before the NPCC; 22.2% after the NPCC). The lack of awareness in this context refers to the limited information and general understanding of climate change and its impacts in the context of forest ecosystem services. This is one of the obstacles; it affects forest ecosystems and the implementation of adaptation actions [39]. Another severe challenge was limited research (in forestry), rated 19.4% before the NPCC and 13.9% after the NPCC.

The most significant challenges were highly significant before the NPCC. However, challenges such as high demand for agricultural land (16.7%), the lack of funding options (13.9%), and adverse weather conditions (11.1%) were significant after the NPCC.

Overall, it can be said that most challenges facing adaptation actions supported by the NPCC were more severe after the introduction of the NPCC. This situation could be attributed to various factors, including land use changes and management practices. However, research has yet to establish scientific evidence on this aspect.

3.4. Proposed Improvements

According to the experts, there are multiple areas of adaptation actions in forest ecosystem services that need enhancement to improve the effectiveness of the NPCC (Figure 3).

The experts expressed that promoting awareness (33.3%) was the most critical improvement needed to improve the effectiveness of the NPCC. Creating awareness is crucial in promoting adaptation actions because local knowledge is vital to help local communities cope with climate change and variability. Furthermore, awareness creation catalyzes sustainable forest ecosystem management [40].

Additionally, experts further indicated a need for strengthening forestry and climate change research (13.9%). Experts further pointed out that enhancing adaptation measures (11.1%) and availing sufficient funds (11.1%) are other areas that need improvements to increase the effectiveness of the NPCC. The experts also listed promoting the carbon market (2.8%) and renewable energy (2.8%) among the proposed improvements, but with the lowest significance level.

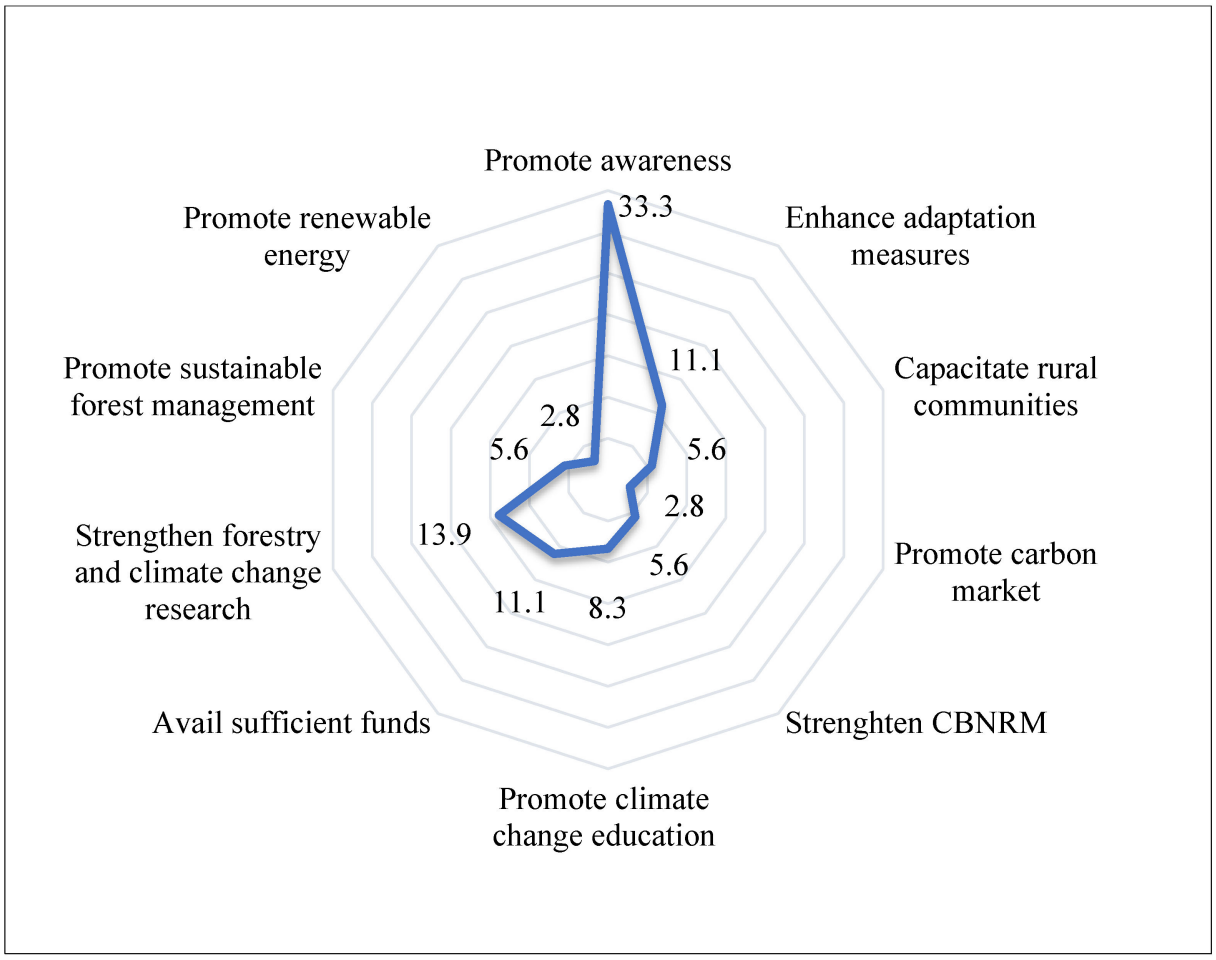

Figure 3. Proposed improvements in the implementation of the NPCC, according to the experts. Proposed improvements for the NPCC are presented as %.

4. Discussion

Forest ecosystems are crucial for adaptation to climate change. Despite forest ecosystems' vast ecological and livelihood importance, they are highly threatened by global changes [41–43]. Therefore, countries have taken different approaches to integrate climate change adaptation into their environmental laws and policies [44,45]. There is a need to incorporate climate change conditions in decision-making and policy formulation to maintain ecosystem capacity across different sectors and social statuses, including rural and urban areas [46]. However, we noted that most forest ecosystem-based policies could be broad in most countries. For example, in India, forest policies have been broadly aimed at conservation, reducing pressure on forests, and providing biomass to the large forest-dependent population for their fuel and fodder needs, apart from generating revenue through the production and sale of timber [47]. Therefore, since climate change significantly impacts forest ecosystems [9,47,48], there is a dire need to revisit forest ecosystem-based policies in the context of climate change adaptation actions, their effectiveness, challenges, and opportunities, and the national level in various countries across the globe.

Furthermore, since climate change is a global phenomenon, it is encouraged that linking local efforts with international initiatives is likely to produce more significant results [49]. One international approach to responding to climate change's effects on forests is forest genetic modification. In this view, since genetic diversity is a crucial component of resilience and adaptability [50], countries are encouraged to include genetic-level responses to climate change in their action plans [51]. However, research gaps remain in this aspect of forest ecosystems and climate change adaptation.

Namibia is among the few countries that emphasize implementing climate change policies at the national level. Although most countries such as Zambia, Mali, and Tanzania implement forest ecosystems in community-based coping strategies [52], national climate change policies exist and mainly emphasize cross-sectoral adaptation actions, including ecosystems' integrity. Although national climate change policy actions in most counties consider the critical role of ecosystems in reducing forest degradation and loss of forest ecosystems [53,54], there seems to be little emphasis on their effectiveness in this regard from the research perspective.

In the case of Namibia, implementing the climate change policy at the national level is crucial, considering that Namibia is the driest country in Sub-Saharan Africa and, hence, one of the most vulnerable countries to the effects of climate change [21]. This situation exposes the country's forest ecosystem services to the severe impacts of climate change. As a result, implementing adaptation actions for climate change is critical [55], especially in forest ecosystem services. However, to ensure effectiveness in adaptation actions, it is essential to implement robust policy instruments.

In this paper, our assessments focused on implementing the NPCC to support adaptation to climate change in forest ecosystem services. Although it is difficult to compare the effectiveness of local policies due to differences in forest ecosystem conditions, the existing literature shows that climate change adaptations at the policy level are insufficiently mainstreamed within broader development approaches in the forest ecosystems context [56].

The goal of the NPCC is to manage climate change responses on the national level [57]. Based on our results, it is evident that the implementation of the NPCC has played a significant role in supporting adaptation actions in forest ecosystem services in Namibia. The effectiveness of the policy was significantly manifested in biodiversity ($p < 0.001$) (Table 1). Although no previous studies provide evidence of the status of biodiversity after the policy was introduced, our results indicate that biodiversity's role as a remedy to climate change has improved through the NPCC. Another function of forest ecosystems is to provide habitats for biodiversity [58]. Forest biodiversity also plays a critical role in carbon sequestration. Our results indicated that carbon sequestration also proved effective after the NPCC. Carbon is stored in five distinct pools in forest ecosystems, namely, aboveground and below-ground live biomass, in deadwood, including snags, litter, and soil [58]. In that way, forest ecosystems' biodiversity plays a critical role in promoting adaptation and resilience to the impacts of climate change. Furthermore, we also identified soil conservation, socio-economic benefits, and recreational and cultural values among the primary forest ecosystem services in which the effectiveness of the policy was significant.

Management policies will more strongly determine the future provision of forest ecosystem services [59]. However, our results noted that the effectiveness of the adaptation actions was not significantly different before and after the policy (NPCC) was introduced in 2011. This situation could be attributed to factors such as the absence of changes in management approaches for forest ecosystem services. In addition to the attitude and behavior of local communities, forest management practices also influence adaptation actions significantly [60]. Furthermore, we noted that another factor that could have influenced the effectiveness of the policy is potentially the fact that it is still in its infancy stage (10 years) of implementation.

Our results are unique in that we focused specifically on the performance of the NPCC in forest ecosystem services at the national level. However, our results suggest that substantial research gaps exist in the context of climate change and forest ecosystem services in Namibia and many other countries around the globe. Most existing studies in different parts of the world focused on the policy guidelines [61] instead of their practical implementation. In South Africa, for example, current research focused on the policy-making process [62] and not necessarily its implementation, particularly in forest ecosystem services.

All adaptation actions supported by the NPCC align with the mission statements of MEFT, which hosts the NCCC [28]. The NCCC oversees the implementation of the NPCC.

Although there was no statistically significant difference among the indicators of adaptation actions before and after the NPCC, our results revealed that all the adaptation actions in our assessments showed higher mean effectiveness scores after the NPCC. Law enforcement and altering local communities' reliance on forest resources (Table 2) were the most effective adaptation action indicators after the introduction of the NPCC. Despite several obstacles that need to be addressed (Figure 2), our overall results proved that the policy effectively supports the existing adaptation actions in various forest ecosystem services.

Even though the policy proved effective in promoting adaptation actions, our results revealed several challenges facing the effectiveness of the policy (Figure 2). The most significant challenges affecting the effectiveness of the policy were the lack of awareness and limited research on forest ecosystem services and climate change. In addition, the high demand for agricultural land and the lack of funding options also affects the policy's implementation. Therefore, our results agree that the design and implementation of climate policies for forest ecosystem-based services should respect the country-specific environmental, economic, and political contexts [63,64].

Additionally, our results noted that implementing climate change policy alone is not enough. Sustainable funds should support it. However, it is worth highlighting that ecosystem-based adaptation actions are costly [65]. The lack of funds for adaptation is an issue in many developing countries, particularly in Africa [66]. For example, South Africa established that improving resources, including funding, was listed among the areas that need strengthening to enhance adaptive capacity [67]. In the same view, regarding adaptation, ecosystems, including forest ecosystems, were listed among the substantially underfunded areas in Africa [68].

The existing global funds seem ineffective in their intended approaches to finance adaptation to climate change. One of the worldwide climate change adaptation funds is the United Nations Framework Convention on Climate Change's (UNFCCC) Green Climate Fund (GCF), which is a financial mechanism designed to fund adaptation actions [69]. The fund has pledged to promote local adaptation funding in underdeveloped nations. However, it has not successfully operationalized this pledge [69]. Hence, it has been established that countries, especially developing ones, including Namibia, require support for implementing and diffusing prioritized technologies, mainly in the energy, agriculture, forestry, and other land use and water sectors [3].

Our results revealed a lack of awareness about climate change and its impacts on forest ecosystem services (Figure 3). It is worth noting that understanding how the climate affects forests, industries, and local communities and how these effects can evolve and incorporating this knowledge into management decisions are all necessary for adaptation actions and climate change policies [70]. Generally, the lack of awareness is an issue among the local rural communities who live in proximity to forest resources in Namibia [39]. This situation challenges the sustainable management of forest resources and consequently contributes to the impacts of climate change on the national level. Therefore, it is crucial to prioritize and avail information and tools to make decisions in solving climate change's effect on forest ecosystems [31]. This goal can be achieved through research about climate change and forestry, which is one of the areas that needs urgent attention in the context of climate change and forestry in Namibia.

Another area that needs improvements is capacity building in rural communities (Figure 3). According to the mission statement of DoF, local communities are mandated to have access to forest resources and utilize them sustainably through the community forest project [24]. However, this approach requires stable funding mechanisms to monitor and ensure local communities' sustainable use of forest resources. The weakness displayed in Community-Based Natural Resources Management (CBNRM) is common in African countries [71]. Therefore, it is vital to avail funds for forest management practices through CBNRM to maximize monitoring during the establishment of participatory forest management associations and maximize its contribution to climate change adaptation.

The results entail that efforts to enhance the effectiveness of adaptation actions of the NPCC to climate change in forest ecosystem services must include steps taken to strengthen climate awareness and understanding amongst forest managers, climate change scientists, local communities, and policymakers. Therefore, approaches such as robust research and continuously engaging all stakeholders in climate discourse, capacity building, and tailor-made climate and forest ecosystems will need to be incorporated. To achieve this, the government and stakeholders should transform the policy into a mainstreaming forest ecosystem-based adaptation policy that applies in everyday practice [72]. Additionally, since climate change is a cross-sectoral phenomenon [73], the government needs to formulate a longer-term cross-sectoral planning mainstreaming approach for more effective climate change adaptation policy implementation. In addition to the knowledge level gap, the study has unearthed the lack of funding options, which might present challenges to the effectiveness of adoption actions in forest ecosystem services. Climate change adaptation actions require sustainable funding mechanisms [74].

Finally, we noted some limitations in our study. For example, we employed an online survey approach in which we purposively chose forestry and climate change experts to assess the effectiveness, adaptation actions, and challenges of the NPCC in forest ecosystem services. As such, the results are limited to implementing the NPCC in the unique forest ecosystem services. These limitations restrict the applicability of these results and replicating them to other policies.

5. Conclusions

This paper assessed the adaptation actions supported by the NPCC in forest ecosystem services of Namibia. The paper focused on the effectiveness and challenges of adaptation actions to climate change. The results suggest that there have been improvements in the adaptation actions after introducing the policy in 2011. After the NPCC, higher effectiveness scores were noted in forest ecosystems, such as biodiversity, carbon sequestration, soil conservation, and socio-economic benefits. Biodiversity and carbon sequestration were significantly effective after the introduction of the policy.

Our results further revealed that the most significant challenges were the lack of awareness, which showed prominence before and after the policy's introduction. Afforestation, reforestation, awareness, and forestry research need strengthening to improve the effectiveness of the policy. In response to the challenges, the experts expressed that promoting awareness was the most critical improvement needed to improve the effectiveness of the NPCC. Although our results showed that adaptation actions supported by the NPCC were generally effective after the policy was introduced, some areas concerning policy implementation still need strengthening through research to help in sound decision-making.

The need for research on forest ecosystem services-based adaptation cannot be understated. Research involves testing, refining, and up-scaling adaptation actions to climate change approaches, policies, and legislation based on the local context. Therefore, we propose that future research should analyze the strengths, weaknesses, threats, and opportunities (SWOT) of the NPCC and consequently design/propose a framework for forest ecosystem services-based adaptation actions in the policy to improve adaptation actions.

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Institutional Review Board Statement: The study was conducted in accordance with the ethical conduct of the National Commission on Research Science and Technology (NCRST), approved on 19 October 2022, and the ethical clearance by the Ministry of Environment, Forestry and Tourism (MEFT) of Namibia, and approved by the Directorate of Forestry (DoF), dated 18 August 2022.

Informed Consent Statement: Written informed consent has been obtained from the Ministry of Environment, Forestry, and Tourism of Namibia to publish this paper.

Data Availability Statement: All data relevant to the study are included in the article.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Survey Questionnaire

National Policy on Climate Change for Namibia: Are there adequate actions for adaption in forest ecosystem services?

SECTION A: DEMOGRAPHIC INFORMATION
INSTRUCTION: Please put a cross (x) against the appropriate box to specify your choice.

1. Institution represented

Public ☐
Private ☐
Developmental partners/projects ☐
Academic/research ☐

2. Experience in the field of forest ecosystem services/environmental science

Less than 1 year ☐
1-5 years ☐
6-10 years ☐
10+ years ☐

3. What is your position in the institution?

Top management ☐
Middle management ☐
Lower management ☐
Junior/general employee ☐
Intern ☐
Others (specify) .....

SECTION B: IMPLEMENTATION OF NPCC IN ADAPTATION IN FORESTRY

1. **How would you rate the following ecosystem services in terms of effective implementation of the instruments that were implemented between 2001 and 2010 before NPCC?**

STRATEGIC ACTIONS	RATING						
	Extremely ineffective	Very ineffective	Ineffective	Not sure	Effective	Very effective	Extremely effective
Biodiversity							
Carbon sequestration							
Soil conservation							
Socio-economic benefits for communities							
Recreational and cultural values							
Watershed services							
High conservation values							

2. **Which instruments played the most significant role in governing actions for climate change adaptation in the context of forest ecosystem services before the NPCC implementation (2001-2010)?**

RATE	YEARS				
	2001-2002	2003-2004	2005-2006	2007-2008	2009-2010
National Forestry Policy					
Forest Act					
National Environmental Education and Education for Sustainable Development Policy					
Communal Land Reform Act					
The Nature Conservation Ordinance No. 4 of 1975					
Other (specify)					

3. **What were the main challenges for policy instruments for climate change adaptation before the implementation of NPCC?**

Lack of awareness about climate change ☐
High demands for land by local communities ☐
Limited research in forestry and climate change ☐
Adverse weather conditions ☐
High rates of illegal logging ☐
Poverty in rural areas ☐
Lack of funding options ☐
Other (specify) ……

4. Which of the following indicators for climate change adaptation were evident before the implementation of NPCC in the context of forest ecosystem services from 2001-2010?

RATE	YEARS				
	2001-2002	2003-2004	2005-2006	2007-2008	2009-2010
Plantations and orchards establishment					
Improved awareness creation					
Improved law enforcement					
Reduced reliance of local communities on forest resources					
Improved funding options for adaptation					
Improved forestry research and innovation					
Improved conservation of ecosystems critically threatened by climate change					
Other (please specify) ……					

5. How do you rate the following strategic actions for climate change adaptation in the context of forest ecosystem services from 2001-2010?

STRATEGIC ACTIONS	RATING						
	Extremely ineffective	Very ineffective	Ineffective	Not sure	Effective	Very effective	Extremely effective
Afforestation and reforestation							
Law enforcement							
Altering local communities' reliance on forest resources							
Funding adaptation activities							
Forestry research							
Conservation of ecosystem services critically threatened by climate change							
Other (specify)……....							

6. How would you rate your knowledge of the NPCC and its implementation strategies in forestry?

- Very good ☐
- Good ☐
- Familiar ☐
- Neutral ☐
- Poor ☐
- Very poor ☐

7. How would you rate the following ecosystem services in terms of effective implementation of the NPCC over the past nine years (2012-2021) of its implementation?

STRATEGIC ACTIONS	RATING						
	Extremely ineffective	Very ineffective	Ineffective	Not sure	Effective	Very effective	Extremely effective
Biodiversity							
Carbon sequestration							
Soil conservation							
Socio-economic benefits for communities							
Recreational and cultural values							
Watershed services							
High conservation values							

8. Which of the following adaptation strategic actions of NPCC does your institution support/focus on the most? (You can choose as many according to the activities of your institution).

Promoting afforestation and reforestation ☐

Supporting law enforcement ☐

Altering local communities' reliance on forest resources ☐

Providing funding for adaptation activities ☐

Supporting existing forestry research ☐

Conservation of forest ecosystems services critically threatened by climate change ☐

Other (specify) ……

9. Which indicators for climate change adaptation have been evident during the implementation of NPCC in the context of forest ecosystem services?

RATE	YEARS				
	2012-2013	2014-2015	2016-2017	2018-2019	2020-2021
Plantations and orchards establishment					
Improved awareness creation					
Improved law enforcement					
Reduced reliance of local communities on forest resources					
Improved funding options for adaptation					
Improved forestry research and innovation					
Improved conservation of ecosystems critically threatened by climate change					
Other (please specify) ……					

10. How do you rate the following strategic actions for NPCC for climate change adaptation in the context of forest ecosystem services?

STRATEGIC ACTIONS	RATING						
	Extremely ineffective	Very ineffective	Ineffective	Not sure	Effective	Very effective	Extremely effective
Afforestation and reforestation							
Law enforcement							
Altering local communities' reliance on forest resources							
Funding adaptation activities							
Forestry research							
Conservation of ecosystem services critically threatened by climate change							
Other (specify)……..							

11. What is the main challenge facing the implementation of NPCC in climate change adaptation in the context of forest ecosystem services? (You can choose as many according to the activities of your institution).

Lack of awareness about climate change ☐
High demands for land by local communities ☐
Limited research in forestry and climate change ☐
Adverse weather conditions ☐
High rates of illegal logging ☐
Poverty in rural areas ☐
Lack of funding options ☐
Other (specify) ……

12. Which of the following would you describe as the most significant in terms of the strengths, weaknesses, opportunities, and threats of NPCC in promoting adaptation in forest ecosystem services?

Strengths	**Opportunities**
Understanding climate change ☐	Improve public awareness ☐
Good forestry management ☐	Various fundings options ☐
Good collaboration among stakeholders ☐	Support from NGOs ☐
Adequate adaptation science and technologies ☐	Urban agriculture ☐
Sound land use planning ☐	Agroforestry practices ☐
Sufficient funds ☐	Other (specify)
Sufficient skills in tree planting ☐	
Established protected areas ☐	
Other (specify)	
Weaknesses	**Threats**
Poor understanding of climate change ☐	Deforestation and land degradation ☐
Poor forestry management ☐	Soil depletion ☐
Poor collaboration among stakeholders ☐	High rates of illegal logging ☐
Inadequate adaptation science and technologies ☐	Adverse weather conditions ☐
Poor land use planning ☐	Increased demands for land use ☐
Insufficient funds ☐	Poverty in rural areas ☐
Poor experience in tree planting ☐	Other (specify)
Lack of established protected areas ☐	
Other (specify)	

13. What recommendations would you make to improve the implementation of NPCC for climate change adaptation measures in the context of forest ecosystem services?

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Appendix B

Results

Table A1. Effectiveness scores of the implemented adaptation actions by forest ecosystem services before and after NPCC.

Forest Ecosystem Services	Before NPCC (N = 36)	After NPCC (N = 36)	*p*-Value
Biodiversity	3.11 ± 0.92	4.36 ± 1.52	<0.001
Carbon sequestration	2.75 ± 1.34	3.06 ± 1.35	0.338
Soil conservation	3.08 ± 1.32	3.39 ± 1.29	0.324
Socio-economic benefits	3.25 ± 1.20	3.44 ± 1.34	0.519
Recreational and cultural values	3.72 ± 1.09	3.39 ± 1.34	0.249
Watershed services	3.31 ± 0.89	3.17 ± 1.23	0.585
High conservation values	3.56 ± 1.40	3.14 ± 1.25	0.187

Data are presented as mean ± standard deviation (sd); independent *t*-test was applied to compare mean scores before and after NPCC implementation. Significantly different at $p < 0.05$.

Table A2. Indicators of actions scores of the implemented policy before and after NPCC.

Adaptation Action Indicators	Before NPCC (N = 36)	After NPCC (N = 36)	*p*-Value
Afforestation and reforestation	3.17 ± 1.56	3.33 ± 1.69	0.665
Law enforcement	3.33 ± 1.51	3.61 ± 1.63	0.455
Altering local communities' reliance on forest resources	3.42 ± 1.44	3.56 ± 1.59	0.699
Funding adaptation activities	3.11 ± 1.58	3.53 ± 1.42	0.244
Forestry research	3.17 ± 1.63	3.28 ± 1.60	0.771
Conservation of ecosystem services critically threatened by climate change	30.6 ± 1.41	3.53 ± 1.42	0.162
Stakeholders' collaboration	2.94 ± 1.64	3.53 ± 1.40	0.109

Data are presented as mean ± sd; independent *t*-test was applied to compare mean scores before and after NPCC implementation. Significantly different at $p < 0.05$.

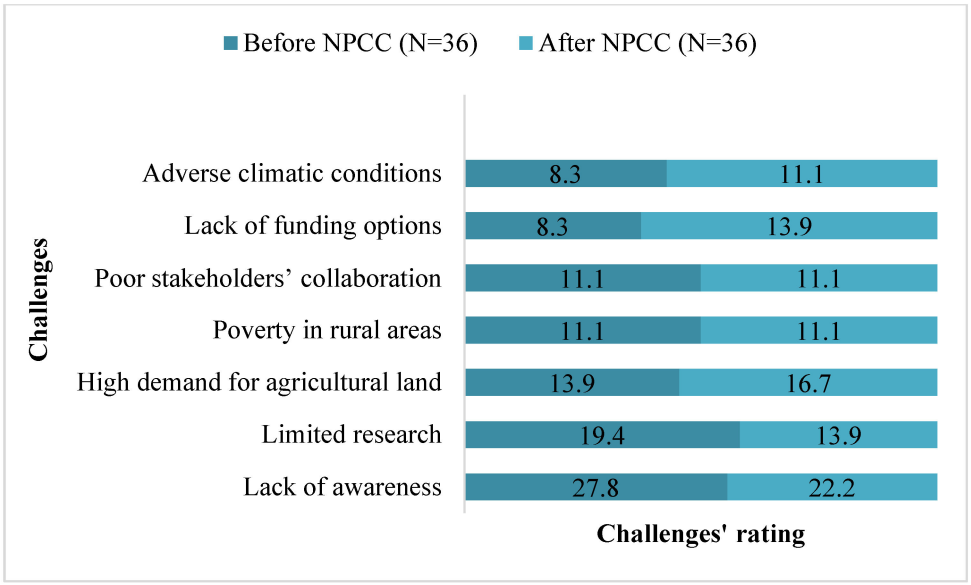

Figure A1. Challenges in the implementation of adaptation actions before and after the NPCC. Challenges' ratings are presented as %.

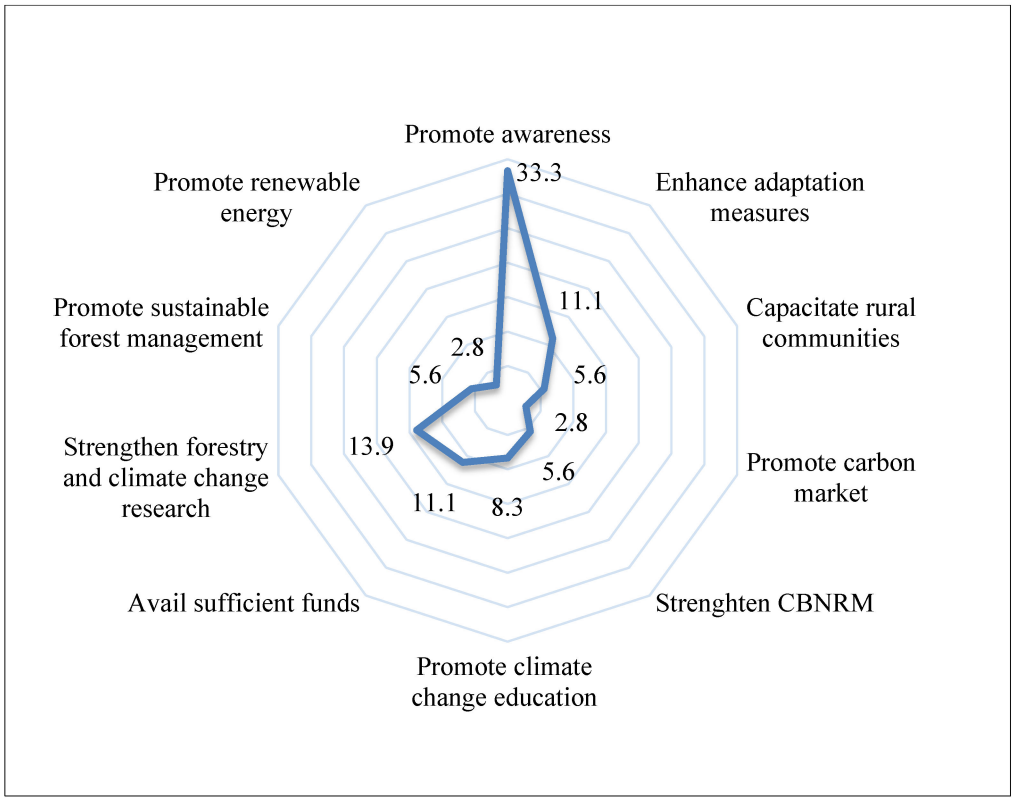

Figure A2. Proposed improvements in the implementation of the NPCC, according to the experts. Proposed improvements for the NPCC are presented as %.

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Manuscript 3

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Socio-Economic Benefits of *Colophospermum mopane* in a Changing Climate in Northern Namibia

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Abstract: Millions of local communities in southern Africa depend on forest ecosystems and the goods and services they provide for their livelihoods. This paper aims to assess the socio-economic benefits of forest goods and services in a changing climate by focusing on the forest products of *Colophospermum mopane* (*C. mopane*) in the Kunene and Omusati regions in northern Namibia. We used *C. mopane* product data from 2011 to 2021. Our analyses showed that local communities harvested five main products from *C. mopane*, namely firewood, poles, droppers, rafters, and roots. Firewood and poles were the primary *C. mopane* products harvested by local communities, mainly for subsistence use. Our results suggest that *C. mopane* potentially continues to the provision of goods and services for the livelihood of local communities, despite the changing climate in northern Namibia. We propose future studies in predictive analysis focus on extreme weather events, such as forest fires, droughts, floods, and other climate-related hazards that affect goods and services provided by forest ecosystems in the northern regions and the entire country.

Keywords: climate change; *Colophospermum mopane*; commercial use; forest products; Kunene region; Omusati region; rural communities; subsistence use; northern Namibia

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1. Introduction

Millions of local communities in southern Africa depend on forest ecosystems and the goods and services they provide for their livelihoods [1,2], including ecosystem services provided by *C. mopane* (Kirk ex Benth) species. In addition to services such as carbon sequestration and the protection of watersheds and biodiversity [3], forest ecosystems provide goods and services to local communities in various forms in the region, ranging from timber and non-timber forest products (NTFPs) [4]. Local communities utilize forest products, such as fuel wood, construction materials, medicine, and food, for marketing and household consumption [5]. However, various previous studies have acknowledged that forest ecosystems in southern Africa are highly vulnerable to climate change [1,2,6]. Some of the identified climate risks to forest ecosystems in the region include, for example, altering the growth rates of woodland flora and impacting species composition and productivity [3,7].

The southern part of Africa is one of the most vulnerable regions to climate change [8]. This situation is due to the region's high exposure to climate change, poor socio-economic conditions, increased reliance on natural resources, and inability to implement adaptive measures effectively [8–10]. For example, in the Sub-Saharan African region, unpredictable rainfall and recurrent droughts significantly impact agricultural production [11], aggravating consequences, including high risks to food security [12].

Climate change projections for southern Africa further predict increased droughts, the frequency, and intensity of wildfires, land degradation, low agricultural and vegetation productivity, extreme temperatures, and increased food insecurity [13]. Furthermore, climate change is also associated with increasing desertification [14]. Additionally, according

to [15], extreme temperatures, high evapotranspiration, and high human activity intensity are some of the main drivers of desertification in some parts of Africa, particularly southern Africa.

Namibia is considered the driest country in southern Africa [16–20]. As a result, Namibia is a southern African country that is significantly impacted by climate change due to its arid conditions [21–23]. Climate change has been a significant challenge, threatening progress toward the country's national and millennium development goals [24]. The recent prolonged drought experienced in the country has severely impacted the functions of both human communities and their livelihoods, as well as ecological ecosystems, particularly in providing essential ecosystem services [21,24].

Namibia's temperature trends have risen by 0.58 °C to 1.2 °C on average over the past 50 years, with more significant increases in the country's northern parts [25]. Rainfall trends are less evident than temperature trends over the past 50 years, and there are substantial variations in the direction and magnitude of the changes observed across the region [25,26]. Precipitation trends are challenging to discern given the country's typically erratic rainfall; extreme rainfall contributes a significant proportion of the annual rainfall in some regions [25,27]. However, there is no adequate research concerning long-term climate variability across the northern Namibia regions to date [15].

There is substantial literature about the impacts of climate change on various forest and woodland species in southern Africa [28,29], including studies addressing multiple aspects of *C. mopane* [30–34]. However, studies focusing on the socio-economic benefits of mopane woodlands in a changing climate in southern Africa, particularly in northern Namibia, are still limited [35–38]. Therefore, this paper aims to assess the socio-economic benefits of *C. mopane* in a changing climate by focusing on the products harvested for use at the local community level.

2. Materials and Methods

2.1. Study Area

The geographical location of Namibia is in the south-west of Africa. South Africa borders it to the east and south-east, Zambia to the north-east, Angola to the north, and Botswana to the east [22]. It is a semi-dry country with deficient rainfall compared to other countries in the southern part of Africa [21]. Due to its unique climate conditions, Namibia is considered one of the most vulnerable countries to climate change impacts [13]. Namibia has a population of 2.5 million and covers a total surface area of 824,292 km^2 [24].

We focused on two of the fourteen political regions of Namibia (the Omusati and Kunene regions) [39] (Figure 1). The two target regions fall in the northern geographical zones of Namibia [40]. Together, they cover 17% of the total area and constitute 13% of the population of Namibia. The target regions also form part of the *Baikiaea-mopane* woodlands of southern Africa [41] and represent areas with the highest distribution of *C. mopane* species in Namibia, with the Omusati region having the highest distribution of the species between the two regions [42].

The northern part of Namibia is predominantly rural and is one of the hotspots for climate-change-related impacts [24,43]. Rural communities in the target regions heavily rely on subsistence agricultural practices and other forest-related ecosystem services, particularly from the *Baikiaea-mopane* woodlands, for their livelihoods [44,45]. Agricultural practices alone contribute between 22% and 32% of the local livelihoods of the Omusati and Kunene regions, respectively [46–48]. Between 2001 and 2018, the two regions experienced a combined tree cover loss of 302 hectares [49].

The area is semi-arid and characterized by high temperatures, ranging from 5 °C to 37 °C, whereas the annual average rainfall is about 350-500 mm between November and April [50]. The yearly rainfall of the Omusati region ranges from 400 mm to 500 mm per annum [48]. Average daily temperatures vary from 6 °C to 35 °C depending on the season. For example, summers are sweltering, with a maximum temperature of between 30 °C and 35 °C during the hottest months [46]. The Kunene region occupies the north-west corner of

Namibia and shares borders with the Omusati region in the eastern part [51]. Therefore, the two regions have similar climatic conditions. However, slight differences in weather and climatic conditions are noticeable. Irregular annual rainfall increases from the west to the east of the region from less than 50 mm to 415 mm [51,52]. Average daily temperatures range from 5 °C to 35 °C depending on the season [47]. Summer day temperatures are often sweltering, reaching up to 35 °C with minimum temperatures of 14 °C on average. During the winter, temperatures can range from 5 °C to 26 °C [47].

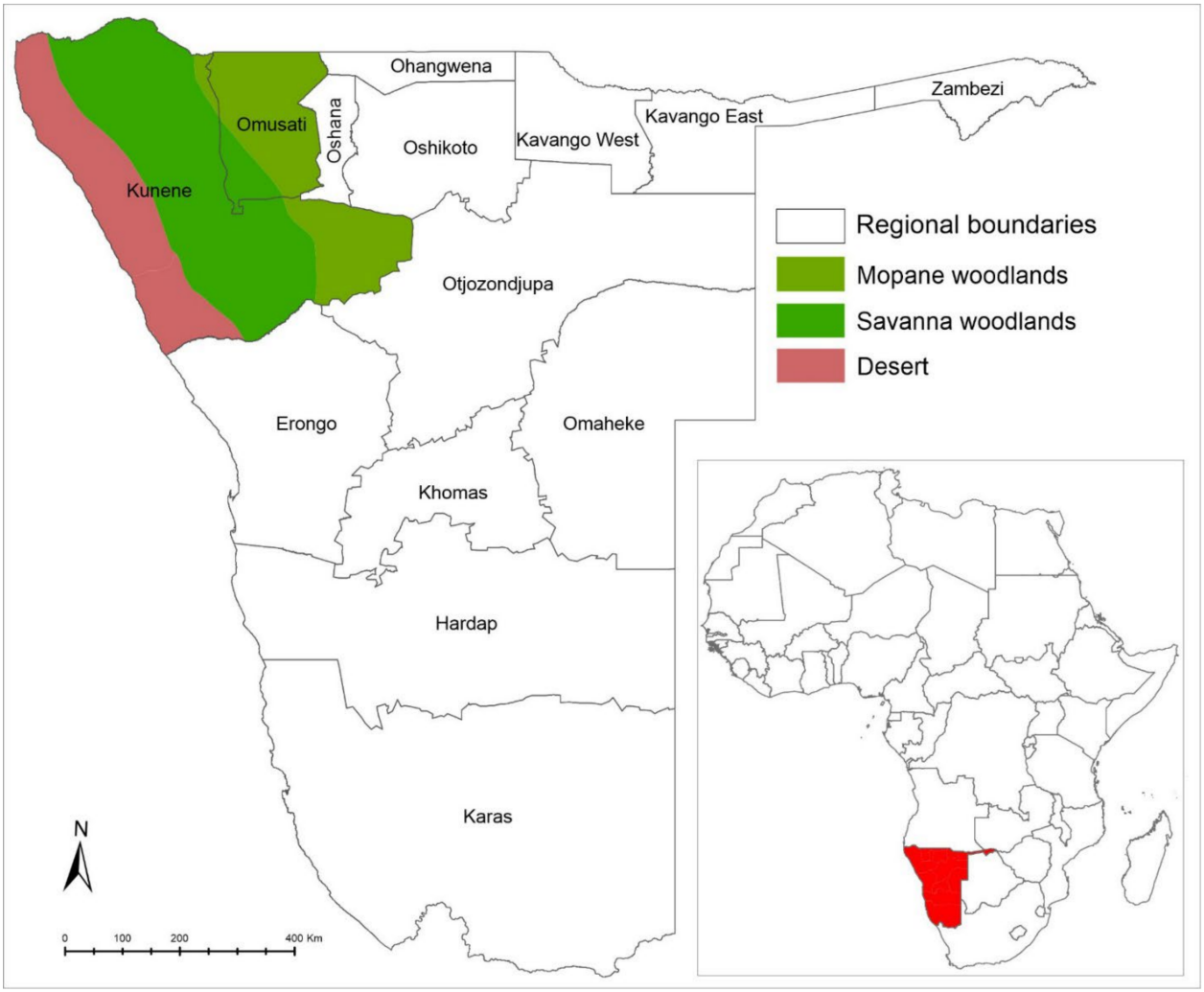


Figure 1. The location of the study area and key descriptions of the area. The red area is the location of Namibia on the map of Africa.

2.2. Focal Species

C. mopane belongs to the Fabaceae family [32]. The tree species can grow into big trees, ranging from 4 m to 18 m in height [32,40]. It is often present in alluvial, alkaline, and poorly drained soils, which it tolerates better than other species [32]. The bark has a rough texture that ranges from dark grey to blackish [34]. The heartwood is dark reddish to almost black, durable, rugged, and heavy [40]. The leaves are drooping and made up of two leaflets that look like butterfly wings. During the winter, the leaves are shed, and most trees are bare by the end of the season. *C. mopane* often forms pure stands of two distinct types [40]. On favorable sites, the stands are made up of tall trees referred to as 'cathedral mopane' but when the soil conditions are less favorable, the vegetation is referred to as 'mopane shrub' [53].

C. mopane vegetation is found in about eight countries in southern Africa, where many different ethnic groups live [33]. The distribution of *C. mopane* is best associated with low to moderate rainfall, high temperatures, low altitudes, and various soil types [43]. Hence, the *C. mopane* savanna covers a large area, extending south-western Angola and into Namibia, as far south as Brandberg mountain, the highest peak in Namibia [54] (Figure 2).

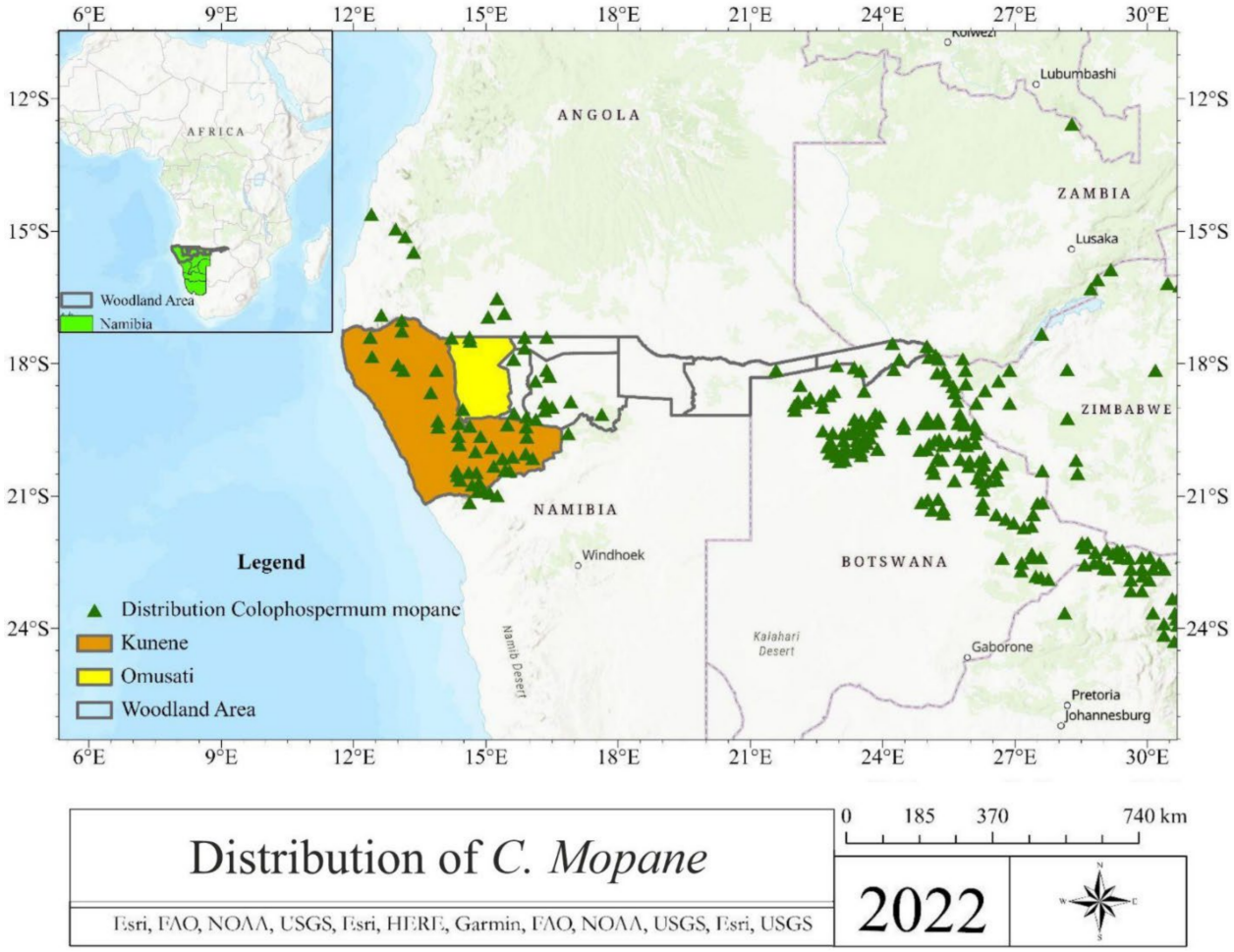


Figure 2. The distribution of *C. mopane*.

C. mopane prefers fine-grained sand and clay-loam sites formed from basalt, alluvial material, and lime [41]. The species is more competitive than any other species, mainly when the sites are periodically waterlogged and on solonetzic sites. *C. mopane* is predominantly found in low to moderate rainfall, high temperatures, low altitudes, and various soil types [32]. As a result, the northern part of Namibia has the highest concentration of *C. mopane*.

C. mopane is considered a natural resource and a source of income in the daily lives of local people [32,33]. It is the primary source of poles in dry regions because of its durability and availability, and is a source of fuelwood, droppers, rafters, and bark rope for subsistence use by local farmers in the most northern parts of Namibia [40]. The tree species is used for similar purposes in other parts of southern Africa [55]. Due to its dominance in the area [42,56], high economic values, and consequently high demands for multiple uses at the local community level, *C. mopane* was chosen as the focal species for this study.

2.3. C. mopane Products Data

One of the main challenges in forest ecosystems and forest resource utilization by local communities' research is a lack of data. As a result, we could only obtain data for *C. mopane*

products from 2011 to 2021. We focused on the five main products that local communities harvest from *C. mopane* in the area [42]. These products included firewood, poles, rafters, droppers, and roots. Local communities use such products for subsistence use (own use) and commercial purposes [42,45].

We gathered data for *C. mopane* products from harvesting permit record books through the Directorate of Forestry (DoF) of the Ministry of Environment, Forestry, and Tourism (MEFT). We used harvest permit books from all five DoF offices (Okahao, Onesi, Outapi Opuwo, and Tsandi) in the Omusati and Kunene regions. Data collected included the types of products (firewood, poles, droppers, rafters, and roots), uses, quantities, permit costs, and harvesting years. The five DoF offices formed the hotspots of our study. We collected data for 239 villages across the study area from these hotspots. Data included all harvesting permits of *C. mopane* from private and community forests from 2011–2021.

According to the pricing structure of the DoF, local communities pay between NAD 10–60 (Namibian dollars, equivalent to USD 0.67) depending on the type of permit (harvesting, transportation, and marketing) and use (commercial and own use/subsistence). The permit's validity differs with permits ranging from seven days to three months.

Furthermore, it is worth highlighting that due to the limited resources, the Directorate does not encourage the commercialization of forest products at the local level [57]. However, local communities sell forest products for commercial use in the following forms: poles, droppers, and rafters at NAD 10 per piece; and firewood and roots at NAD 12 per bundle [57].

2.4. Data Analyses

Estimations of the local weights of different wood products harvested by the local communities were developed by the authors of [57]. On average, a bundle of firewood/root is 0.013 tons, whereas poles are 0.0094 tons, droppers are 0.001 tons, and rafters are 0.001 tons per piece. To estimate the income received by the collector, we used the following formula:

(Total amount of collected wood products (in m^3) $\times$ market price/m^3). As the permit fee amount was negligible, we did not include it in the formula.

The continuous data were first checked for normality using the Kolmogorov–Smirnov normality test. The non-categorical and not-normally distributed data, such as harvest per product changes and potential benefit received by the respondents over time, were analyzed using the Kruskal–Wallis test, followed by the Bonferroni test for pairwise comparisons using 2011 as the reference year. We analyzed data using IBM SPSS version 26 (IBM Corp., Armonk, NY, USA). We entered, coded, and classified the data according to the two main uses, forest products and years of production. A p-value of less than 0.05 was deemed statistically significant in all analyses in this paper. According to the permit system of the DoF, forest products are recorded in different units. For example, there are pieces for poles, droppers, rafters, and tons for firewood and roots. Therefore, we standardized the units to tons (Table A1, Appendix A).

2.5. Climate Trend Analyses

We further performed climate trend analyses focusing on temperature and precipitation over the study period (2011–2021). The analyses aimed to provide a picture of how climate change affects forest ecosystems in various ways [58,59] and, consequently, harvesting patterns. However, the relationship between climate change and forest production is complex. It requires long-term data for all variables. That is why there is little previous research on this aspect in Namibia. Therefore, our analyses only give an overview of the changes in climate parameters (temperature and precipitation) to provide a baseline for future long-term analyses. We obtained temperature and precipitation data from the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL).

3. Results

3.1. Harvests per Use Types

The products were classified according to the two main use types, namely subsistence and commercial (Figure 3a,b).

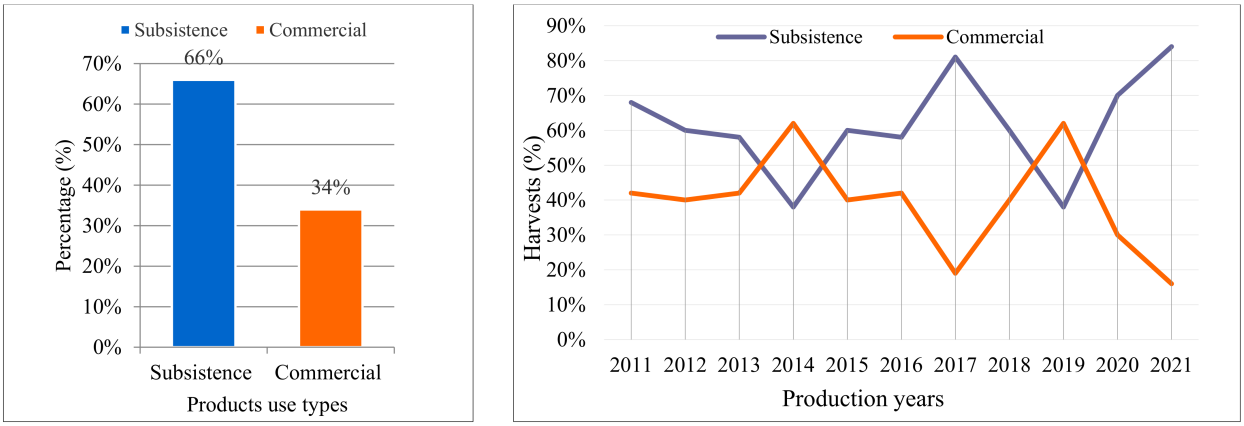


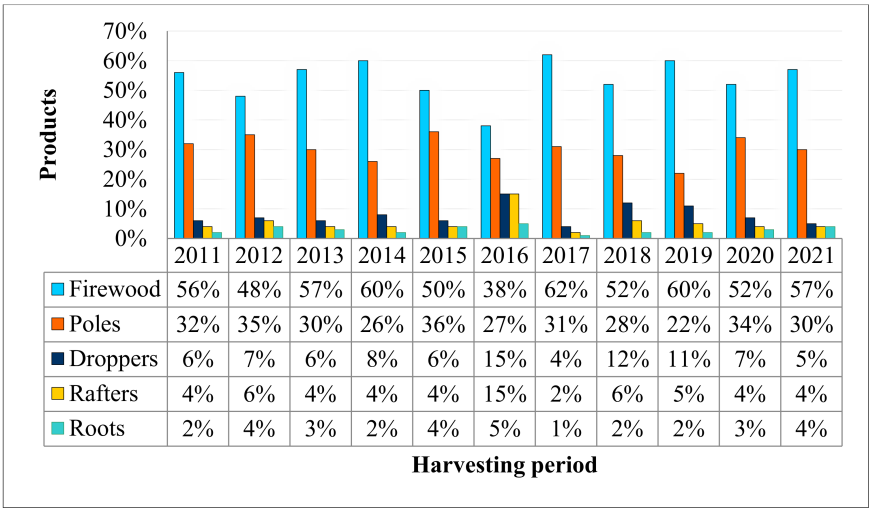
Figure 3. Product use types for *C. mopane* from 2011 to 2021; (**a**) percentage of two main types of use, and (**b**): trends in the harvests of products by use type from 2011–2021.

Our results further revealed that local communities mainly harvest *C. mopane* products for subsistence use (66%) (Figure 3a). However, there were also harvests for commercial products, which accounted for 34%.

Harvests of *C. mopane* products have fluctuated over the years (Figure 3b). Harvests for subsistence use were highest in the years 2021 (84%) and 2017 (81%). The lowest harvests for subsistence use were recorded with equal scores of 38% in the years 2014 and 2019. On the other hand, harvests for commercial use showed the highest same records of 62% in 2014 and 2019. Finally, we identified the lowest harvest records for commercial use in 2021 (15%).

3.2. Harvests per Products

There have been continuous harvests for multiple *C. mopane* products harvested annually between 2011 and 2021 in the Kunene and Omusati regions (Figure 4).



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Firewood	56%	48%	57%	60%	50%	38%	62%	52%	60%	52%	57%
Poles	32%	35%	30%	26%	36%	27%	31%	28%	22%	34%	30%
Droppers	6%	7%	6%	8%	6%	15%	4%	12%	11%	7%	5%
Rafters	4%	6%	4%	4%	4%	15%	2%	6%	5%	4%	4%
Roots	2%	4%	3%	2%	4%	5%	1%	2%	2%	3%	4%

Figure 4. *C. mopane* products harvested per year.

The results showed that throughout the years (2011–2021), the highest harvests recorded were for firewood and poles. For example, in 2011, firewood harvests were at 56%, followed by poles (32%), and the lowest was roots (2%). Similar harvests were recorded in subsequent years. However, a slight decline was recorded in 2016 in the harvests of firewood (38%) and poles (26%). Conversely, a slight rise was recorded in the harvests for droppers (15%) and rafters (15%) in 2017. However, there was an increase in the harvests of the main products after 2016. For example, firewood comprised the highest record of 62%, while poles were at 31% in 2017.

Table A1 (Appendix A) shows changes in each product use from 2011 to 2021 and the comparison to the baseline year (2011). There was a significant increase in the production of firewood from 2011 to 2021 ($p < 0.001$), but the other years were similar to the reference year. Meanwhile, the production of droppers significantly increased in 2012 compared to 2011 ($p < 0.001$), while the other years were considered not statistically different.

3.3. Total Harvests

The proportion of the main product harvests showed that firewood and poles were the highest (Figure 5).

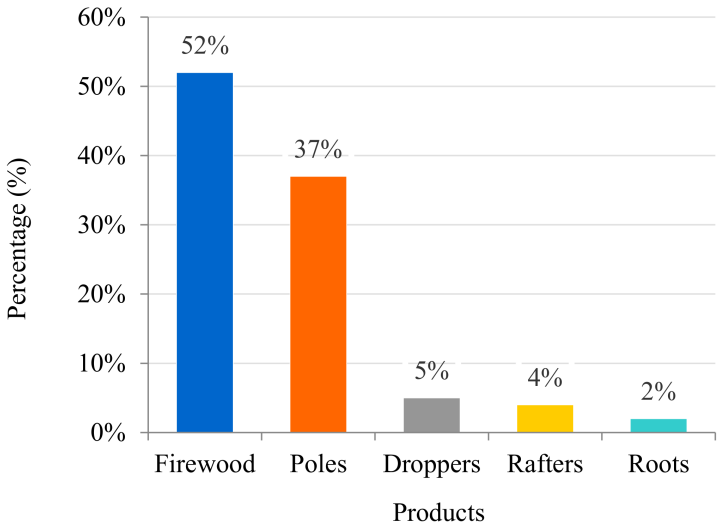


Figure 5. Total harvests of the primary forest products from *C. mopane*.

Our results showed that all five products were harvested throughout the study period, but in different quantities. Our total harvests analyses showed that firewood was significantly the highest forest product harvested from *C. mopane* (52%) during the entire study period. Secondly, poles (37%) were also considerably harvested over the study period. The least harvested products during the study period were droppers (5%), rafters (4%), and roots (2%).

3.4. Total Temperature and Precipitation Changes

Although changes in climate are best investigated over a long time, our analyses give an overview of how likely it is that climate change will affect forest production and the livelihood of local communities in *C. mopane* woodlands (Figure 6).

It is generally understood that climate change has various negative impacts on forest ecosystems, including forest fires and tree mortality caused by warming and frequencies of drought and flood occurrence [37,60,61]. We identified a negative correlation between changes in temperatures and precipitation, which can be perceived as a threat to the future of *C. mopane* ecosystems and production outputs.

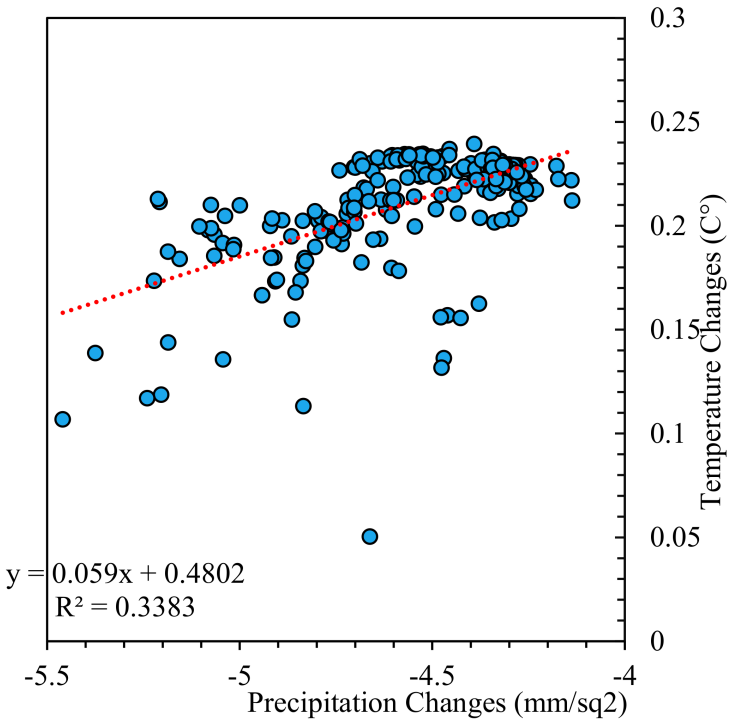


Figure 6. Changes in the amount of precipitation and temperature over the study period.

There was a maximum decrease in precipitation in the areas with a minimum increase in temperature across the study area. In general, the trends show that the temperature increased during the study area, whereas the precipitation decreased. A decrease in precipitation results in low forest productivity. For example, trees' growth will be stunted and pest and disease outbreak will worsen.

4. Discussion

Forest ecosystems play an essential role in the livelihoods of rural communities in southern Africa and other developing parts of the world, where forests are the vital elements of livelihood [62]. Nearly 2.9 billion people in low and middle-income countries cook and heat their homes by burning solid fuels, such as fuelwood [63].

C. mopane displays adaptive mechanisms to the dry conditions of Namibia. One of the adaptive features of the species is deep root systems [7,32]. As a result, this species can regenerate and grow despite the changing climatic conditions [64]. Hence, our results revealed that *C. mopane* woodlands provide and would potentially continue to provide goods and services for the livelihood of local communities, especially in the northern regions of Namibia (Figure 4). The main forest products identified were firewood for cooking, heating, and lighting and poles for construction.

Our results indicate that firewood is the northern area's most significant *C. mopane* product (Figure 5). Statistically, our results show that there was a significant increase in the production of firewood over the entire study period ($p < 0.001$). On the contrary, the production of other products has been fluctuating. For example, droppers significantly increased in 2012 compared to 2011 ($p < 0.001$) (Table A1, Appendix A).

The high firewood consumption is because the area is primarily rural, where most residents depend on firewood for lighting and heating [45,56,65]. For example, most residents in the northern regions of Namibia use firewood primarily for cooking [66]. Our results coincide with the literature which reveals that many African countries have high demands for fuelwood consumption. For example, Ethiopia (93%), Nigeria (80%), and the Democratic Republic of the Congo (74%) are the leading countries in the use of firewood

at the local level [67]. In South Africa, recent research shows that fuelwood is still used to some extent by 96% of rural households [68,69].

Our results further reveal that local communities mostly use *C. mopane* products for subsistence (Figure 3). These indications are in alignment with the mandate of DoF regulations. Due to climatic conditions, coupled with limited forest resources, the management principles of forest ecosystems of Namibia do not encourage the commercialization of forest resources at the community level [45,70]. Through these forestry management principles, forest managers, in collaboration with the relevant stakeholders, exercise a sustainable management approach to curb the possible depletion of resources [45]. Such management principles also consider deforestation and forest degradation alarming, aggravating climate change [71]. At the same time, it is worth highlighting that management approaches that exclude local communities from forest resources invite illegal activities from local communities close to forest ecosystems [72,73]. Therefore, it is essential to promote the sustainable utilization of forest resources.

Additionally, it is crucial to emphasize that the continuous utilization of forest products in a changing climate depend on the effectiveness of collective adaptation and sustainable forest management approaches [30]. Effective law enforcement is one strategy to harmonize adaptation and sustainably manage forest ecosystems to avoid illegal operations, such as unlawful harvesting. Afforestation and reforestation are other approaches that need strengthening to sustain forest ecosystems [70]. Such forest management approaches are essential in *C. mopane* woodlands, given species' the ability to survive the area's harsh climatic conditions. In addition, silvicultural activities against forest disturbances, such as forest fires, pests, and diseases, also need strengthening [30,37]. However, there is limited scientific research in the context of climate change, forest ecosystems, and projected disturbances in Namibia.

Our climate change analyses showed that there was a maximum decrease in precipitation in the areas with a minimum increase in temperature across the study area (Figure 6). The temperature increased over the study area, whereas the precipitation decreased. As generally perceived, a decrease in precipitation has a negative impact on forest productivity which manifests in various ways. For example, trees' growth will be stunted and pest and disease outbreak will worsen. Increasing temperatures will also alter the functions of the ecological systems of the forest [61]. However, more research is urgently needed to investigate this phenomenon from this angle in forest ecosystems in northern Namibia.

Food security is another crucial aspect of discussions on forest ecosystem services in a changing climate [74]. For example, during low rainfall, local communities do not produce good yields from other activities that support their livelihoods. In the case of the northern regions of Namibia, most rural communities depend on livestock and crop farming [43,75,76]. However, due to periodic erratic rainfalls and severe droughts, local communities diversify their livelihoods to off-farm activities [43], including using forest resources for income generation to support their livelihoods [42]. As a result, local communities use of forest resources will worsen during severe droughts.

Finally, we identified that this type of study requires long-term climate data, particularly precipitation and temperature trends concerning growth and mortality rates, to determine the status of the forest ecosystems. Unfortunately, such data are lacking on Namibia's forest ecosystems and climate change. We also noticed that the commercialization of forest products needs intensive investigation and monitoring to evaluate the value of products at the local community level.

5. Conclusions

Our analyses showed that local communities harvested five main products from *C. mopane*, namely firewood, poles, droppers, rafters, and roots. Firewood was the primary forest product, followed by poles and droppers. Total harvests appeared to fluctuate over the years. Therefore, our results suggest that forest ecosystems will continue to potentially benefit the livelihoods of local communities in northern Namibia despite the changing

climate. However, there is a need for predictive analyses to estimate the rate at which forest ecosystems will potentially continue to support local livelihoods in correlation with the changes in climate parameters, such as precipitation and temperature.

An increase in the temperature, and a decrease as identified over the study period, will potentially result in the circumstances, such as severe droughts, local communities are most likely to exert considerable pressure on forest ecosystems for production outputs. This could be one of the many ways climate change contributes to the degradation of forest ecosystems from the perspective of production outputs. Unfortunately, Namibia lacks a robust national system that provides data for forest products at the rural community level. There is also a lack of spatially extensive climate data. Therefore, there is limited access to digitized data at the country level. Therefore, a national system is needed to provide forest ecosystem service information to the public through DoF offices countrywide.

In addition, to help the country produce effective adaption and mitigation measures against climate change, it will be ideal if the MEFT and relevant stakeholders establish a climate database system that records forest products, weather, and climate data. We further propose that future studies focus on predictive analyses of the impacts of climate change on the status of forest ecosystem services in Namibia. More specifically, future research needs to assess extreme weather events, such as forest fires, droughts, floods, and other climate-related hazards, that affect goods and services provided by forest ecosystems in the northern regions and the entire country. Furthermore, this study has the potential to serve as a forest ecosystem management tool for the forestry sector in Namibia. In the same view, in collaboration with local communities, forestry managers can draw insights from this study to formulate sustainable forest ecosystem management strategies to ensure that *C. mopane* ecosystems continue to provide socio-economic benefits for local communities in a changing climate. Finally, the utilization and commercialization of forest products at the local community level should be closely monitored through a robust database system to ensure sustainability and adaptation to a changing climate.

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Institutional Review Board Statement: The study was conducted in accordance with the ethical conduct of the National Commission on Research Science and Technology (NCRST), issued on 13 December 2022, and the ethical clearance by the Ministry of Environment, Forestry and Tourism (MEFT) of Namibia, and approved by the Directorate of Forestry (DoF), dated 18 August 2022.

Informed Consent Statement: Written informed consent has been obtained from the Ministry of Environment, Forestry, and Tourism of Namibia and the National Commission on Research Science and Technology (NCRST) to publish this paper.

Data Availability Statement: All data relevant to the study are included in the article.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A1. Changes in wood product volume collection compared to the referral year (2021) [1].

Wood Products	Referral Year	Observed Year									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Poles (N = 1222)											
Volume, m^3	40,000 (1;440,000)	80,000 ** (3;200,000)	80,000 ** (10;500,000)	55 ** (6;240,000)	100 ** (1;1,000,000)	30 ** (1;200,000)	120 ** (1;600,000)	100,000 ** (30;150,000)	55,000 (8;1200,000)	500,000 * (1000;45,000,000)	33,000 (1000;200,000)
Income, ×1000 NAD	20,000 (1;220,000)	40,000* (2;100,000)	40,000 ** (5;250,000)	27,500 ** (3;120,000)	50,000 ** (5;500,000)	15,000 ** (1;100,000)	30,000 ** (1;300,000)	50,000 ** (15;75000)	27,500 (4;575000)	25,000 * (500;22000,000)	16,500 (500;100,000)
Firewood (N = 1723)											
Volume, m^3	1000 (1;7000)	100 ** (1;2000)	100 ** (1;2000)	60 ** (4;44563)	60 ** (1;2000)	4 ** (1;150,000)	100 ** (1;10,000)	100 ** (6;80,000)	1000 * (8;10,000)	1000 * (20;145000)	1000 ** (5;86000)
Income, ×1000 NAD	500 (0.4;3500)	50 ** (5;1000)	50 ** (5;3500)	30 ** (2;22,282)	30 ** (1;1000)	2 ** (1;75000	50 ** (5;5000)	500 ** (3;40,000)	500 * (4;5000)	500 * (10;72,500)	500 ** (3;43,000)
Droppers (N = 190)											
Volume, m^3	40 (3;240,000)	14,000 (60,000;200,000)	120,000 ** (30;340,000)	50 (10;150)	81 (1;600,000)	300,000 ** (1;334,000)	120 (50;100,000)	100 (30;200)	100,000 * (80,000;250,000)	100,000 ** (90,000;200,000)	175,000 ** (2000;500,000)
Income, ×1000 NAD	3 (0.2;16,216)	9460 (4054;13,5135)	8108 ** (1;22,973)	3 (1;10)	6 (0.1;40,541)	20270 ** (0.1;22,566)	8 (3;6757)	7 (2;15.5)	6757 * (5405;16,892)	6757 ** (1351;60,811)	11824 ** (135;33,784)
Rafters and Roots											
Volume, m^3	100500 (1000;200,000)	80,000 (24,000;380,000)	100,000 (1000;400,000)	80,010 (20;160,000)	80,000 (25000;110,000)	80,000 (6;150,000)	99,000 (2;1900,000)	75,000 (2000;200,000)	90,000 (40,000;840,000)	70,000 (1000;200,000)	40,000 (1000;250,000)
Income, ×1000 NAD	6965 (417;13,514)	5405 (1622;25,676)	6757 (417;27,027)	5410 (1689;7432)	5405 (3;10,135)	6689 (1;128,378)	5068 (676;13,514)	6081 (2703;56,757)	5070 (677;13,513)	4230 (417;135,135)	2703 (68;16,892)

[1] Volume and income were presented as median (min, max), Group comparisons were analyzed using the Kruskal–Wallis test, continued by the Bonferroni test for pairwise comparison with the referral year (2021). Income was calculated as volume/piece (in m^3) × market price of wood product (NAD)/piece (in m^3). * = significant level at $p < 0.05$ with the referral year (2021); ** = significant level at $p < 0.001$ with the referral year (2021).

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CHAPTER FOUR

DISCUSSION OF THE FINDINGS

This chapter discusses the study findings divided into two sections, namely forest products and policy instruments. The discussions compare the results with the relevant literature. While the research focused on Namibia, some of the findings may be relevant to other regions with similar conditions.

4.1 Socio-economic Benefits Provided by Forest Ecosystems in Northern Namibia

The main hypothesis of this study assumed that forest ecosystems still provide socio-economic benefits to sustain local community livelihoods in a changing climate during the study period in northern Namibia. This hypothesis was based on the evidence from research worldwide that confirms that forest ecosystems sustain the livelihoods of local rural communities that depend on forest resources (del Río et al., 2021; Ding and Nunes, 2014; Nikodemus and Hájek, 2015). The results of the current study proved that the assumption (hypothesis) about the continuous utilization of forest products at the rural communities' level in a changing climate is evident in northern Namibia.

Additionally, the current findings coincide with literature highlighting that forest resources continue to play a vital role in rural communities in developing countries by providing services, products, and incomes (Wale et al., 2022b). As a result, the socio-economic benefits of forests have attracted research in recent years due to the changing climate (Dalu et al., 2021; Shackleton and Shackleton, 2004; Wale et al., 2022a). As highlighted earlier, this study investigated the socio-economic benefits of forest ecosystems by focusing on the products of *C. mopane* in a changing climate in rural communities in northern Namibia.

The southern African region has an average forest cover of 32%, with most tropical forests (De Cauwer et al., 2018). Approximately 70% of the sub-Saharan population lives in rural areas, of which more than 90% of households depend on natural forest products to sustain their livelihoods (Dalu et al., 2021). Therefore, it is a fact that forest resources provide numerous benefits to rural communities and society at large in many ways in the region (Shackleton et al., 2022).

The dependence of local rural communities on forests is not a recent discovery. Literature affirms that most local rural people in developing countries have been immensely dependent on forests for centuries (Garekae et al., 2020). The dependency on forests of rural communities is

generally associated with poverty. Profoundly, poverty is about the relationship between resources and needs (Leichenko and Silva, 2014). However, the dependency of local rural communities on forests is worrisome because the southern African region is also highly vulnerable to the effects of climate change (Tucker et al., 2015).

Despite its arid conditions, Namibia is among the southern African countries, with most of the local rural communities dependent on forests for their livelihoods (Nikodemus and Hájek, 2015; Vrabcová et al., 2019). It is generally considered the driest country in Sub-Saharan Africa (Ministry of Environment and Tourism, 2010; Shikangalah, 2020; World Bank Group, 2021). Its forests only comprise 2% of the total forests in the Southern African Development Community (SADC) (Kayambazinthu and Oeba, 2019). As a result, its forest ecosystems are exposed to the impacts of climate change. In recent years, the country has witnessed various manifestations of climate change such as prolonged drought seasons, recurring floods, forest, and forest fires (Iijima et al., 2018).

Although the impacts of climate change are severe in rural communities where the dependence on forest resources is high (Inman et al., 2020), it is interesting that the results of this study proved that forest ecosystems are still vital in sustaining livelihoods for local communities. In addition, literature affirms that about 70% of the Namibian population depends directly on natural resources for their livelihoods (GIZ, 2011). Natural resources support livelihoods through farming, grazing land, medicinal plants, animal products, fuel, and shelter. Forests support local rural communities' livelihoods for various reasons. For example, local rural communities live close to forest ecosystems where forest resources are a primary source of food, energy, medicine, and wood for construction (Korir, 2019; Vrabcová et al., 2019).

Additionally, the results showed that local rural communities depend on forests for subsistence and commercial uses. However, in the case of the local rural communities in northern Namibia, the results showed that they mainly use forest products from *C. mopane* for subsistence use. In other words, rural communities mostly use forest products to sustain their households and families. However, local rural communities also generally generate some income from forest products, but on a small-scale basis (Nikodemus and Hájek, 2015; Vrabcová et al., 2019).

It is worth highlighting that the key factor contributing to the low commercialization of the forest products and wood industry is the poor status of the forest cover in Namibia (Nikodemus and Hájek, 2015). Forest and woodlands have a combined cover of approximately 20%, with

forests alone covering less than 10% of the country's total land area of about 823,680 km^2 (Mendelsohn and El Obeid, 2005). However, the status of forests and woodlands cover could have slightly declined due to the expansion of various land uses, including agriculture.

Although it is not documented from the research perspective, the wood industry is growing at a snail's pace. Therefore, the forestry sector does not contribute significantly to the national economy. Its contribution to the Gross Domestic Product (GDP) is estimated at approximately 3% (Barnes et al., 2010). However, recent statistics estimate that combined with agriculture, forestry's sector contribution collectively increased from 3.4% in 2016 to 4.6% in 2018 (Laubscher et al., 2019).

The study identified five main products: firewood, poles, droppers, rafters, and roots. The degree of the communities' reliance on forest products varies from product to product (Ali et al., 2020). In this study, firewood was the most significant forest product in northern Namibia's local communities. The high demand for firewood is attributed to the area being primarily rural, where most residents depend on firewood for lighting and heating (Munyayi, 2015; Vrabcová et al., 2019). This is because local rural communities, which make up about half of Namibia's population, lack electricity (Netshipise and Semenya, 2022).

The dominance of firewood in rural communities in northern Namibia is a renowned phenomenon (Hainduwa et al., 2016). The use of firewood is common in rural areas in developing countries. Existing research ascertains that roughly 2.3 billion people in developing countries will remain dependent on firewood for these purposes within the next decades (Scheid et al., 2018). In Sub-Saharan Africa, firewood is identified as a major source of cooking and heating energy for most rural households (Kayambazinthu and Oeba, 2019). The consumption of firewood consumption is associated with poverty in rural areas (Netshipise and Semenya, 2022). As a result, firewood is considered a viable energy option for many households in developing countries (Muazu et al., 2020). Conversely, the use of firewood has some negative ecological consequences. For example, firewood consumption contributes to CO_2 emissions (Paládi et al., 2014; Ram and Bahadur, 2020), the main greenhouse gas.

The results further identified that local rural communities use forest products mainly in the form of NTFPs. The most used products, such as fuelwood, poles, rafters, droppers, and mopane roots, are all NTPFs. It is worth pointing out that this is a common practice in most Sub-Saharan countries. Other research identified forests that are also classified as NTFPs, such as wooden utensils, edible fruits, grass hand-brushes, and twig hand-brushes, used by 85% or more of

households (Shackleton and Shackleton, 2004). NTFPs are often presented as a significant contributor to livelihoods, as sources of food and cash for rural communities in developing countries (Iponga et al., 2018).

It was further assumed that temperature and precipitation changes could affect the socio-economic benefits of forest ecosystems in northern Namibia. The use of forest products from *C. mopane* is, however, threatened by the changing climate conditions in the area. The study identified increased temperatures and decreased precipitation in the mopane woodlands during 2011-2021. In this specific aspect, the study determined that total changes in annual mean temperature affected the annual mean precipitation over the study period.

Unfortunately, the concept of the impact of climate change on forest ecosystems is complicated and expensive to quantify (Boisvenue and Running, 2006). For example, several critical ecological effects must be considered to assess the potential impacts of climate change on forest ecosystems (Sohngen and Sedjo, 2005). However, the available literature establishes that the frequency and intensity of extreme weather events, such as droughts and floods, have increased in some regions, including most parts of Africa (IPCC, 2019). It is also predicted that the negative impacts of total temperature changes will affect forest ecosystems' productivity in the long run (Boisvenue and Running, 2006; Morin et al., 2018; Weslien et al., 2009).

In the case of Namibia, it is predicted that its climate will become warmer and drier for the rest of this century due to climate change (Munyayi, 2015). Consequently, floods, forest fires, droughts, windstorms, pests, and diseases will occur because of the changing climate. Thus, tree mortality and growth rates will be affected, affecting forest productivity and the livelihoods of local rural communities (Blanco et al., 2021; Gauli et al., 2022).

The results coincide with the existing literature that proves that forests are essential for the livelihoods of the local rural communities in the developing world. Literature affirms that more than half of Africa’s population depends directly and indirectly on forests for their livelihoods (Somorin, 2010). Forest products, for example, firewood, roots, droppers, poles, wild berries, and mopane worms, are a significant component of the rural communities' livelihoods, especially for coping with climate variability and extreme weather events that affect agricultural productivity in some ways (Paumgarten and Shackleton, 2011).

Regarding the relationship between climate variability and the dependence of the local rural communities on forest resources, this study showed a significant increase in firewood production over the entire study period. These findings align with the identified climate patterns

(total temperature and precipitation changes). The changes in annual mean temperatures affect precipitation, resulting in erratic rainfall patterns, mainly severe floods and recurring droughts.

As pointed out (Paumgarten and Shackleton, 2011), local rural communities tend to resort to forest products as a survival mechanism due to the effects of climate change. The northern regions of Namibia are prone to severe floods and droughts. For example, in 2019, there was a severe drought (Liu and Zhou, 2021; Shikangalah, 2020). As a result, local rural communities did not cultivate crop fields, and their livestock barely survived. However, despite the pressure resulting from the impacts of climate change, it is critically vital to safeguard the utilization of forest resources because they are essential for both livelihoods and ecological purposes.

Therefore, it is worth highlighting that to sustain the utilization of forest products in a changing climate, a collection of effective adaptation and sustainable forest management approaches combined with effective legislation and policy instruments (Kapuka and Hlásny, 2021). Effective law enforcement is one strategy to harmonize adaptation and sustainably manage forest ecosystems to avoid illegal operations, such as unlawful harvesting.

4.2 Policy Instruments for Climate Change Adaptation in Forestry

Forest resources play a critical role in the livelihoods of local communities in developing countries. However, it should be acknowledged that climate change is the biggest threat faced by humanity and natural environments. Hence, mitigation and adaptation strategies dealing with climate change have been developed locally and nationally (Barry and Hoyne, 2021).

Therefore, the study's second hypothesis focused on implementing legislation and policy instruments for climate change adaptation actions in forest ecosystems. It was assumed that the implementation of various local legislation and policy instruments for climate change is effective in promoting socio-economic benefits and adaptation actions in mopane woodlands.

The constitution of Namibia provides a coherent cross-sectoral approach in order to achieve climate change adaptation goals on the national level (England et al., 2018). It is worth noting that there are various environmental and climate change legislation and policy instruments in the constitution of Namibia (Ruppel and Ruppel-Schlichting, 2022).

However, the study focused on eight of the main cross-sectoral legislation and policy instruments that are directly integrated into the protection and conservation of forest ecosystems in Namibia. The policy instruments included in the study are NPCC, Namibia’s Climate Change Strategy and Action Plan, National Environmental Education and Education for Sustainable

Development Policy, Nature Conservation Ordinance No. 4 of 1975, the Communal Land Reform Act, Namibia National Forest Policy, Forestry Strategic Plan, and the Forest Act.

The results showed that most of the legislation and policy instruments proved effective in promoting climate change adaptation actions in forest ecosystems. The most effective legislation and policy instruments were the Communal Land Reform Act, the Forest Act, Namibia National Forest Policy, and Forestry Strategic Plan. The least effective policy instruments included the National Environmental Education and Education for Sustainable Development Policy, Namibia's Climate Change Strategy and Action Plan, and the NPCC.

Although different legislation and policy instruments represent their respective sectors, they operate in coherency toward climate change adaptation. Since forests are an essential environmental feature, all policy instruments promote adaptation in forestry in one way or another. For example, the Communal Land Reform Act of the Ministry of Agriculture, Water, and Land Reform (MWARL) is crucial for determining land use in rural areas. Forestry and agricultural activities in rural communities of Namibia must comply with the Communal Land Reform Act. The Communal Land Reform Act determines rural forestry ownership (private, communal, and state). Therefore, it plays a significant role in climate change adaptation in the mopane woodlands. Local communities predominantly practice agriculture for subsistence purposes, which has led to desertification in the area. These and possibly more factors have influenced the effectiveness of forestry legislative activities in the mopane woodlands.

In addition to various collective policy instruments, the study investigated adaptation actions supported by the NPCC in forest ecosystems. The NPCC is the central force for climate change actions at the national level that provides an institutional framework and overarching national strategy for developing, implementing, monitoring, and evaluating climate change mitigation and adaptation activities in Namibia (Ministry of Environment, Forestry, and Tourism, 2021). Although it might be perceived as a new policy since it was enacted in 2011 (Ministry of Environment and Tourism, 2010), this current study showed that it improved adaptation actions notably.

The results showed that adaptation actions in forest ecosystem services such as biodiversity, carbon sequestration, soil conservation, and socio-economic benefits have been effective after the introduction of the NPCC. Biodiversity showed the most significant effect of all the ecosystem services after introducing the NPCC. Although the literature indicates that biodiversity is often neglected in policy formulation (Thompson et al., 2011), Namibia's natural

resources and biodiversity offer high potential for the country's socio-economic development (GIZ, 2011).

Prioritizing biodiversity productivity is crucial. Global analysis of biodiversity provides strong evidence that the productivity of forests would decrease at an alarming rate with biodiversity loss (Liang et al., 2016). Besides biodiversity, the results showed that carbon sequestration was also more significant after the NPCC. Based on this evidence, it is safe to conclude that the NPCC has effectively promoted adaptation actions in forest ecosystems. Afforestation, reforestation, awareness, and forestry research need strengthening to improve the effectiveness of the NPCC. Additionally, the study identified several approaches that require strengthening to maximize the potential of the NPCC. These approaches included afforestation, reforestation, awareness, and forestry research.

Implementing legislation and policy instruments for climate change adaptation in forest ecosystems of northern Namibia faces various challenges, ranging from natural conditions to legislation and human activities. One of the critical challenges is the natural conditions of Namibia's forest ecosystems. As pointed out earlier, natural conditions, arid and erratic conditions, particularly in the mopane woodlands (Mupambwa et al., 2019; Teshirogi et al., 2017), influence vegetation cover and, consequently, forest ecosystems in the area.

In this current study, a limited general understanding of climate change, its impacts, Namibia's dry conditions, and the lack of funds for adaptation measures were identified as significant challenges hampering the implementation of policy instruments for climate change adaptation in mopane woodlands. The most significant challenge was the lack of awareness, which affected various legislation and policy instruments in forest ecosystems. In the case of the NPCC, the same challenges were evident before and after introducing the policy.

Effective implementation of legislation and policy instruments requires collective efforts by cross-sectoral institutions (England et al., 2018). However, the study detected that implementing institutions and stakeholders seem reluctant to implement policy instruments, especially in less forested areas, such as mopane woodlands. Successful implementation of legislation and policy instruments will require involving local communities, which starts with awareness creation (Korir, 2019; Sibiya et al., 2022). However, the study revealed that awareness creation is one of the critical areas that need strengthening in the implementation of legislation and policy instruments for climate change adaptation actions in forest ecosystems in northern Namibia.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The first part of this chapter concludes the entire research by summarizing and concluding the study findings. Secondly, several questions and issues arose and remain unresolved from the research objectives, knowledge generated, and the limitations of the approaches applied in this thesis. Therefore, the chapter also presents recommendations for the practical application of the findings and future research.

5.1 Conclusions

The contribution of forests to the livelihoods of rural communities in developing countries has a long history (Somorin, 2010). Southern Africa is one of the regions where most of the local rural communities use several different NTFPs to meet their everyday needs (Shackleton and Shackleton, 2004). However, there is no doubt that provisional forest ecosystem services face threats from climate change worldwide (Ochuodho and Lantz, 2014).

The first hypothesis was on the assumption that forest ecosystems continue to provide socio-economic benefits to sustain local community livelihoods in northern Namibia despite a changing climate. Interestingly, this current study proves that mopane woodlands continue to support livelihoods for the rural communities in mopane woodlands in northern Namibia while contributing to biodiversity conservation with the help of various policy instruments. The results showed that local communities mainly harvested different NTFPs from *C. mopane* during the study period. The five main products from mopane woodlands included firewood and poles were the leading products, mainly for subsistence use. Like in other developing countries, firewood was identified as mopane woodlands' most used forest product.

The second hypothesis provided evidence that temperature and precipitation changes could potentially affect the socio-economic benefits of forest ecosystems in northern Namibia. The study identified annual mean changes in temperature and precipitation over the study period. However, the results indicated that although climate change affects forest ecosystems worldwide (Keenan, 2015), local rural communities can still sustain their livelihoods with forest resources. In the case of mopane woodlands, socio-economic benefits from mopane woodlands are possible for the next couple of decades despite the changing climate conditions.

Thirdly, the study hypothesized that local legislation and policy instruments could promote adaptation actions and socio-economic benefits in forest ecosystems. More specifically, the

study assumed that effective policy instruments could promote socio-economic benefits and adaptation actions in mopane woodlands in a changing climate. The study proved that most of the existing local cross-sectoral legislation and policy instruments were effective.

Forests are essential for biodiversity and socio-economic benefits. However, it is also important to pay attention to the issue of overharvesting. Overharvesting of forest products has been observed at the national level (Mbai et al., 2021). Due to the high demands of forest resources by local rural communities for multiple uses, it is crucial to ensure the effective implementation of policy instruments for climate change adaptation actions.

The study also noted that legislation and policy implementation in forest ecosystem services in a changing climate did not receive enough attention in research in southern Africa to this date. However, it is essential to note that this can be achieved through legislation, policy instruments, and sustainable forest management approaches to maintain socio-economic benefits from forests. Policy instruments are crucial in building resilience and adaptation to the impacts of climate change in these vulnerable communities. However, this subject did not receive sufficient attention from research in various regions, including southern Africa in the mopane woodlands in northern Namibia.

Although there are various policy instruments for adaptation to climate change, policymakers, implementation institutions, and stakeholders do not appear to feel the urgency for prioritizing policy instruments in the less forested mopane woodlands. However, it is essential to point out that this attitude is the critical driver of the lack of awareness of climate change and its adaptation legislation and policy instruments in rural areas. Due to the lack of understanding, adaptation actions for climate change in forest ecosystems might be challenging to maximize. At the same time, awareness of the values of forest ecosystems is of great importance for the quality of human life. This awareness should translate into social behavior using natural resources (Kornatowska and Sienkiewicz, 2018).

Overall, the current study achieved its aim in that the results proved that forest ecosystems remain viable in sustaining the livelihoods of the local rural communities in northern Namibia. In other words, the results imply that socio-economic benefits remain one of the primary provisional forest ecosystem services in a changing climate in northern Namibia. Secondly, various policy instruments for climate change adaptation actions, including the NPCC, play a significant role in protecting and conserving forest ecosystems in rural communities. However,

limited research, lack of funds, and lack of awareness are the main challenges hindering the implementation of policy instruments in forest ecosystems.

Finally, as a source of many goods and services, the forest should be valued from the perspective of its existence as natural capital and in terms of its contribution to socio-economic life (Kornatowska and Sienkiewicz, 2018). Therefore, the findings from this current research contribute to understanding the socio-economic benefits of mopane woodlands in a changing climate and the effectiveness of adaptation options through legislation and policy instruments. Hence, the study can be used to recommend enhancing sustainable management and utilization of forest-related products under the required climate change interventions.

5.2 Recommendations for Practical Applications of the Findings

Various legislation and policy instruments proved effective in climate change adaptation actions in forest ecosystems, specifically mopane woodlands. However, the study identified several areas that need improvements in forest management strategies, research, legislation and policy instruments, and the socio-economic benefits of forest ecosystems in a changing climate. Therefore, the study suggests the following improvements for practical applications.

Due to the increasingly changing climate, which exerts pressure on the dependence of local rural communities on forests, it is critically vital to monitor the utilization of forest resources sustainably due to their importance for both livelihoods and ecological purposes. Forest managers, climate change experts, local rural authorities, and relevant stakeholders must establish a forest products and climate database system to address this issue. Such a system can record data on the utilization of forest products, weather extremes, and climate data.

Furthermore, the current study noted that Namibia faces several complex environmental challenges, including land degradation, water scarcity and pollution, deforestation, biodiversity loss, and climate change (Ruppel and Ruppel-Schlichting, 2022). The continuous use of forest products identified in this study has positive and negative consequences. Hence, in collaboration with local communities, forest managers can draw insights from this study to re-design sustainable forest ecosystem management strategies.

Furthermore, the findings of this study can be helpful to ensure that forest ecosystems continue to provide socio-economic benefits for local communities in a changing climate without compromising biodiversity conservation. One recommended strategy is to develop a monitoring system to guide the utilization and commercialization of forest products at the local community level. Therefore, in collaboration with local communities, forest managers, climate

change experts, and relevant authorities should establish a robust database and reporting system to ensure the sustainable use of forest products in line with adaptation actions for climate change.

Regarding the implementation of legislation and policy instruments, policymakers and relevant stakeholders should emphasize multiple options for altering rural communities' reliance on forest resources for their livelihoods by improving their awareness of the impacts of climate change. Finally, there is also a need for awareness creation for local communities and multiple stakeholders in implementing policy instruments for climate change adaptation actions in mopane woodlands. It is also essential to incorporate climate change topics in primary education to equip future generations with the necessary knowledge of climate change adaptation actions.

5.3 Recommendation for Future Research

The increasing importance of provisional services of forest ecosystems for local communities in a changing climate is increasing the attention of the academic world and policymakers (Bottaro et al., 2022). Although many studies have investigated this subject from the perspective of rural livelihoods and forests, there is little knowledge about the socio-economic benefits of mopane woodlands, especially considering the increasingly changing climate. Understanding this subject is crucial because there are often various dynamics in specific regions or communities (Dalu et al., 2021). Secondly, understanding this subject is also vital for formulating necessary responses to the increasingly changing climate.

However, since this is one of the pioneer studies about this subject, this study discovered that socio-economic benefits in forest ecosystems in a changing climate did not receive sufficient attention from research in various regions, including southern Africa, especially in the mopane woodlands in northern Namibia. Therefore, this study recommends the following research ideas:

Forest products are a significant component of rural communities' livelihoods, especially for coping with climate variability and extreme weather events that affect agricultural productivity in some ways (Paumgarten and Shackleton, 2011). Hence, the study proposes future studies to perform predictive analysis for extreme weather events, including forest fires, droughts, floods, and other climate-related hazards that affect goods and services provided by forest ecosystems in the northern regions and the entire country.

Furthermore, the study identified a research gap in implementing various legislation and policy instruments in forest ecosystems. To this date, legislation and policy instruments for climate change adaptation actions in forest ecosystems did not receive sufficient attention from a research point of view in Namibia. Therefore, the study suggests a need for research to evaluate climate change legislation and policy instruments' framework and their implementation strategies in the context of forest ecosystems, especially in rural communities in Namibia.

Finally, the study also identified a specific research gap regarding the implementation of the NPCC, which is the central force for climate change adaptation actions at the national level. To implement the NPCC successfully, it is essential that we fully understand the challenges and opportunities comprehensively. Therefore, this study proposes future research to perform a SWOT analysis of the NPCC and consequently design/propose its implementation framework in forest ecosystem services-based adaptation actions in rural communities.

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APPENDICES

Appendix A: Harvesting Permit Sample

PERMIT NUMBER 51832

MINISTRY OF AGRICULTURE, WATER AND FORESTRY
DIRECTORATE OF FORESTRY, PRIVATE BAG 13184, WINDHOEK

FOREST PERMIT

TYPE OF PERMIT:	Harvesting		Transport		Marketing	Export	
	Commercial	Own use	Commercial	Own use		Commercial	Own use

Permission is hereby granted in terms of the Forest Act, 2001 (Act 12 of 2001) as amended Act no 13 of 2005 to

Permit Holder Name:	Abraham Kanime
Namibian Id/ Passport:	60021900769
Address:	Onyaanya - Onesindjera
Contact Telephone No:	0811244479
Name, Size, No. of Farm:	Communal land area
District:	Okahao
Region:	Omusati

To Harvest/Transport/Market/Export (encircle applicable) Forest Produce specified below, subject to the conditions on the reverse side

SPECIES	PRODUCT	QUANTITY (m³, kg or ton)
C. mopane	Rafters	300 Rafters

Loading Point Address	Onandjanga - Onandjera
Destination Address	Onyaanya - Onesindjera
Transport Agent/Vehicle Registration No	N 17227 O W

THIS PERMIT IS VALID: FROM 20-09-18 UNTIL 28-09-18

OFFICIAL STAMP

No permit is valid without an official stamp

Ministry of Agriculture Water and Forestry Directorate of Forestry 18-09-2018 P/Bag 508, Outapi Sub-Station Okahao Republic of Namibia

AMOUNT PAID: 10-00
RECEIPT NUMBER: RSS43789
Name of Issuing officer: Lindsay Nghiltuwanga
Signature of Issuing officer: [illegible]
Place and Date: Okahao 18-09-18

Signature of Permit Holder: ....

ALL OFFICIAL CORRESPONDENCE MUST BE ADDRESSED TO THE PERMANT SECRETARY

Appendix B: Research Permit (NCRST)

FORM RST/4

NATIONAL COMMISSION ON RESEARCH, SCIENCE AND TECHNOLOGY

RESEARCH, SCIENCE AND TECHNOLOGY ACT, 2004

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

(Section 21 and Regulation 22)

Permit Number
RPIV013122022

Name of Non-Namibian-based Research Institute/Person: Andreas Nikodemus	**Physical Address:** Czech University of Life Science, Prague, Kaamycka, Suchdol, Prague, Czech Republic		
Issue Date: 13 December 2022	**Commence Date:** 13 December 2022		
Termination Date: 31 December 2023	**Sample Taking Authorised:**	YES ☐	NO ☑

Type of Research Authorised

The Impact of Climate Change on Forest Resources, Forest Fire, Water Quality, and Forest Ecosystem Services.

Non-Commercial research and the use of the resources be limited to what is specified in the research proposal.

Type and Size of Sample Taking Authorised
N/A

Locations Authorised for Research and/or Sample Taking
Kunene, Omusati Region and the Ministry Environment, Forestry and Tourism

Intended Use of Samples
N/A

Responsible Person: Andreas Nikodemus	**Contact No:** +264813747382/+240733170142

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

Official Stamp of the National Commission on Research, Science & Technology

National Commission on Research Science & Technology
13 DEC 2022
P/Bag 13253
Windhoek, Namibia

Appendix C: Research Authorization Letter (DoF)

MINISTRY OF ENVIRONMENT, FORESTRY AND TOURISM

From: Johnson Ndokosho
johnson.ndokosho@meft.gov.na

P/Bag 13306, Whk
18 August 2022

APPROVAL FOR ETHICAL CLEARANCE FOR RESEARCH FOR ANDREAS NIKODEMUS

The Directorate of Forestry (DoF) of the Ministry of Environment, Forestry, and Tourism (MEFT) avails its compliments to your esteemed organization and would like to avail the following to your kind attention:

Andreas Nikodemus, employed by the MEFT and a 3rd year PhD student at the Czech University of Life Sciences Prague has chosen to undertake research that focuses on the topic:

"An analysis of the impact of climate change on forest ecosystem services: A special focus on the socio-economic benefits of *Colophospermum mopane* in north-central Namibia."

His study focuses on the following areas:

1. The impacts of climate change on forest ecosystem services;
2. Economic instruments for climate change adaptation in the context of forest ecosystem services;
3. Policy instruments for climate change adaptation in the context of forest ecosystem services;
4. The impacts of climate change on the water crisis in the context of forest ecosystem services and
5. The impacts of climate change on climate change and forest fires in the context of forest ecosystem services.

On behalf of DoF, I humbly request your offices to assist the bearer of this letter in enhancing his academic endeavours. I wish to assure you that the information/data provided from your offices will only be for academic purposes and for the improvements in the management of forest resources and in strict confidence as he will use statistical averages.

Thank you in advance for your cooperation.

Yours Faithfully,

Johnson Ndokosho
The Director of the Directorate of Forestry
Ministry of Environment, Forestry, and Tourism
Windhoek

Ministry of Environment, Forestry and Tourism
Office of the Director
18 AUG 2022
Forestry Head Office
Private Bag 13306, Windhoek
Republic of Namibia

Appendix D: Scientific Conferences and Workshops

Conference name	Presentation topic	Place/Host	Date
The 22nd Annual Conference Environmental Economics, Policy, and International Environmental Relations	Analysing the impacts of climate change on forest ecosystem services: Effects on socio-economic benefits in the North-Western Part of Namibia (Literary research and methodology) *Authors: Andreas Nikodemus and Miroslav Hájek*	University of Economics, Prague	19-20 November 2020
The 23rd Annual Conference Environmental Economics, Policy and International Environmental Relations	Analysing the impacts of climate change on forest ecosystem services: Effects on socio-economic benefits in the North-Central Part of Namibia (Revised Literary research and methodology) *Authors: Andreas Nikodemus and Miroslav Hájek*	University of Economics, Prague	25-26 November 2021
Meeting of economics departments 2022	Funding mechanisms for climate change adaptation actions in the context of forest ecosystem services in Southern Africa (Article in draft) *Authors: Andreas Nikodemus, Diana Carolina Huertas Bernal, and Miroslav Hájek*	Economic Departments and Institutes of Forestry and Timber Faculties, Kostelec, Czech Republic	21-22 September 2022.
ELLS Scientific Student Conference 2022	Oral presentation/discussion – presented about my doctoral studies experience, Campfire session. *Presenter/speaker: Andreas Nikodemus*	Czech University of Life Sciences, Prague	23-24 September 2022
The XVIII Yearbook of the International Conference: Accounting and Reporting for Sustainable Development	Analysing the sustainability of production processes and design of sustainable development indicators for activities supported within the framework of the forest bioeconomy of the European Union and Southern Africa (Article in draft) *Authors: Andreas Nikodemus, Diana Carolina Huertas Bernal, and Miroslav Hájek*	Brno, Czech Republic, BV Administrative Building	6 and 7 October 2022
24th International Conference on Environmental Economics, Policy, and International Environmental Relations	Implementing local climate change adaptation actions: The role of various policy instruments in mopane (*Colophospermum mopane*) woodlands, northern Namibia (Published article) *Authors: Andreas Nikodemus and Miroslav Hájek*	Prague University of Economics and Business and Charles University	24-25 November 2022

Appendix E: Foreign Internship Confirmation Letters

NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY
Faculty of Natural Resources and Spatial Sciences
Department of Agriculture and Natural Resources Sciences

13 Jackson Kaujeua Street
Private Bag 13388
Windhoek
NAMIBIA

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F: +264 61 207 9141
E: nra@nust.na
W: www.nust.na

21-10-2021

SUBJECT: LETTER OF CONFIRMATION OF COMPLETION OF INTERNSHIP FOR MR ANDREAS NIKODEMUS

This letter serves to testify that the bearer of this document, Mr Nikodemus Andreas has been placed as an intern at the Department of Natural Resources Management of the Faculty of Agriculture and Natural Resources Management at the Namibia University of Science and Technology for four weeks (13 September – 08 October 2021).

During his term of placement at the Institution, Mr Nikodemus' line of responsibilities included assisting with lectures, fieldwork preparation, field data collection, compiling of fieldwork reports, and supervision of Bachelor of Honors students in the course Forest Management.

Mr Nikodemus is organized, reliable and hardworking. He can work independently and can follow through to ensure that the job gets done. He is flexible and willing to work on any project that is assigned to him. He was quick to volunteer to assist in other areas of the institution's operations.

If you have any enquiries concerning Mr Nikodemus' placement at our Institution, do not hesitate to contact me.

Faithfully yours,

Jonathan M. Kamwi, PhD
Head of Department
+26481 207 2568
E-mail: jkamwi@nust.na

NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY
P/Bag 13388 Windhoek NAMIBIA
2021 -10- 21
FACULTY OF NATURAL RESOURCES AND SPATIAL SCIENCES
Department: Agriculture and Natural Resources Sciences

Appendix F: Future Research Plan

Title	Target journal	Status
1. Unveiling the Impact of Climate Variability on Forest Fire Occurrence in Namibia: A Modeling Study	Fire Ecology - Springer	Under review
2. Funding mechanisms for climate change adaptation actions in forest ecosystem services of southern Africa	Ecosystem Services	In progress
3. Assessing water level and quality for forest restoration in response to climate change in mopane (*Colophospermum mopane*) woodlands in northern Namibia	Environmental Research	In progress
4. Adaptation actions of the National Climate Change Policy in forestry in Namibia: Challenges and opportunities	Climate Policy	In draft
5. Climate change, weather extremes and their impact on socio-economic benefits in the context of forestry in northern Namibia	Regional Environmental change	Data collection (survey)
6. The influence of climate change on forest fire occurrences in northern Namibia: Impact on socio-economic impacts	Frontiers in Forests	Data collection (survey)
7. Local rural communities' participatory approach in climate change adaptation actions in the context of forest ecosystems in northern Namibia	Ecosystem Services	Data collection (survey)
8. Analysing the market values of *C. mopane* products at the local rural community level in changing climate in northern Namibia	Frontiers in Forests	Data collection (survey)
9. Assessing the attitude of local communities toward climate change adaptation actions in rural communities of Namibia	Environmental Research	2024/2025